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Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance - Broadcast (ADS-B)

DRAFT Final Review and Comment

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Foreword

This report was prepared by Special Committee 186 (SC-186) and approved by the RTCA Program Management Committee (PMC) on MM DD, 2009.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunications Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration technical Standard Orders.

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1 PURPOSE AND SCOPE

1.1 Introduction

This document contains Minimum Operational Performance Standards for airborne equipment to support Automatic Dependent Surveillance - Broadcast (ADS-B) utilizing the Universal Access Transceiver (UAT). ADS-B is a system by which aircraft and certain equipped surface vehicles can share position, velocity, and other information with one another (and also with ground-based facilities/fixed locations such as air traffic services) via radio broadcast techniques. UAT is a multi-purpose aeronautical data link intended to support not only ADS-B, but also Flight Information Service - Broadcast (FIS-B), Traffic Information Service - Broadcast (TIS-B), and, if required in the future, supplementary ranging and positioning capabilities. While UAT has been expressly designed as a multi-purpose data link for surveillance-related applications, the focus of this document is on its support of ADS-B and basic ground uplink capabilities.

The standards contained in this document specify desired system characteristics that should prove useful to designers, manufacturers, installers and users of UAT equipment. Compliance with these standards is recommended as one means of ensuring that the equipment will satisfactorily perform its intended functions under conditions normally encountered in routine aeronautical operations. Some or all of these standards could be referenced by appropriate government agencies for certification and operational approval. Such regulatory application of any part of this document is solely the responsibility of appropriate government agencies. This version of these MOPS (RTCA DO-282B) reflects additional operational experience with UAT, lessons learned in certification of UAT equipment, and further inputs from the International aviation community during the development of International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) for UAT.

Note: *The use of **"shall"** in the body of this document indicates a requirement. The use of "**should**" indicates a characteristic that is highly recommended, but is not required.*

Since the basic equipment implementation includes computer processing, RTCA DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*, should be considered. Application of the software requirements of RTCA DO-178B should take into account the level of criticality of supported functions, consequences of equipment failure, and the presence and effectiveness of back-up and fault-monitoring features.

Section 1 of this document provides information and assumptions needed to understand the rationale for the equipment characteristics and requirements in this document. A high-level technical description of ADS-B and the UAT data link is provided, including the ability of UAT to support FIS-B, TIS-B, and independent ranging. The section also describes operational goals for ADS-B as envisioned by members of RTCA Special Committee SC-186 and the RTCA Free Flight Select Committee. This section, along with RTCA DO-242A, *Minimum Aviation System Performance Standards (MASPS) for ADS-B*, forms the basis for the standards stated in Sections 2 through 4.

Section 2 contains the minimum operational performance standards for the equipment. These standards define required performance under standard operating conditions, as well as under stressed physical environmental conditions. Also included are recommended bench test procedures to demonstrate equipment compliance with the stated minimum requirements. While the emphasis in this document is on UAT's support of ADS-B, performance standards to support FIS-B and other ground uplink applications are also discussed. RTCA DO-267, *Minimum Aviation System Performance Standards for Flight Information Service - Broadcast* provides a more complete treatment of FIS-B system performance standards.

Section 3 describes the performance required of installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4 describes the operational performance characteristics of the installed equipment, features, and controls.

Appendix A provides a Glossary and List of Acronyms.

Appendix B is the MASPS Compliance Matrix, that provides a cross-reference matrix to related requirements in this document with those in RTCA DO-242A, the ADS-B MASPS. Compliance with RTCA DO-267, the FIS-B MASPS, is also discussed.

Appendix C contains an Example ADS-B Message Coding for the UAT System.

Appendix D describes assumptions made in this document on future UAT Ground Infrastructure. These assumptions have been used to estimate UAT performance when supporting air-ground applications of ADS-B.

Appendix E provides information and guidance regarding Aircraft Antenna Characteristics. The potential for sharing existing transponder antennas, which requires further validation, is reviewed.

Appendix F discusses Link Budgets and Scenario Dependent Ranges for the UAT System.

Appendix G describes the Standard Interference Environments that have been used to estimate UAT System performance. These environments are based upon internationally-developed traffic scenarios for future high and low density airspace and near-worst-case estimates of interference caused by other systems transmitting on or near the UAT intended operational frequency of 978 MHz.

Appendix H discusses UAT Synchronization Issues.

Appendix I discusses UAT Timing Performance, an aspect of the UAT System that underpins, for example, potential use of UAT for supplementary ranging and positioning.

Appendix J provides a Reference Upper-Layer External Interface Format that can be provided by the UAT System for use by ADS-B Applications.

Appendix K details the UAT System Performance Simulation Results, which summarizes results of UAT System performance evaluations in the Standard Interference Environments of Appendix G. Air-to-air and air-ground system performance is assessed. All performance estimates reflect broadcast of all State Vector (SV), Mode Status (MS), and Intent information (including Trajectory Change Reports) defined in the ADS-B MASPS, RTCA DO-242A.

Appendix L which is entitled "Supporting the Trajectory Change Reports Within the Established UAT Message Payload," describes UAT implementation of Trajectory

Change Reports as defined in RTCA DO-242A. While this document, consistent with RTCA DO-242A, does not require UAT equipment to broadcast messages supporting Trajectory Change Reports, this Appendix shows how such messages can be formatted and Appendix K reflects broadcast of those messages to support preliminary report update rates discussed in RTCA DO-242A.

Appendix M discusses UAT Error Detection and Correction Performance. The UAT link layer has been designed to improve UAT performance in high pulsed-interference environments as well as provide the underpinnings for any required future use of UAT for high integrity applications such as, for example, a cross-link for surveillance applications.

Appendix N provides exemplary setup files for UAT equipment bench test procedures.

Appendix O provides a summary of testing and analyses that verify UAT compatibility with Distance Measuring Equipment (DME) and that DME equipment will operate without degradation in the presence of UAT and Joint Tactical Information Distribution System /Multi-functional Information Distribution System (JTIDS/MIDS, also referred to as Link 16) signals at the levels of the Standard Interference Environment defined in Appendix G.

Appendix P addresses issues pertaining to the statistics of overlapping ADS-B signals in a multi-user environment.

Appendix Q describes the manner in which GNSS position sources, which do not output velocity accuracy, can be characterized so that a velocity accuracy value associated with the position source can be input into ADS-B equipment as part of the installation process.

Appendix R provides guidance for decoding of information from messages transmitted by ADS-B Version One (1) Transmitting Subsystems when received by a ADS-B Version Two (2) Receiving Subsystem.

Appendix S discusses the potential UAT broadcast of Meteorological (MET) data and Air-Reference Vector (ARV) data for potential next generation ADS-B applications such as wake vortex based separation procedures and implementation of next generation arrival management systems.

Several different avionics architectures are possible for airborne UAT ADS-B equipment. The supporting hardware could exist as separate, stand-alone equipment; or it could be incorporated within other on-board equipment. As a result, equipment designers and manufacturers have considerable latitude in configuring UAT to support various ADS-B applications, as well as tailoring those configurations to various classes of users.

The word “equipment” as used in this document includes all components and units necessary for UAT to properly perform its ADS-B and Ground Uplink receipt functions. For example, the “equipment” for UAT may include a computer processor, transceiver with associated antenna, power supplies, and interfaces to other equipment. It should not be inferred from this example, however, that each UAT design will necessarily include all of the foregoing components. Nor should it be inferred that integration of other features or functions is not allowed. Considerable design flexibility is given to the manufacturer provided applicable requirements are satisfied.

Conceptually, ADS-B can support a wide range of users and applications as described in RTCA DO-242A. Some applications are considered “advanced” in that they introduce new relationships between equipment, automation, pilots, and controllers. This document specifies both the *minimum* operational performance standards for UAT's basic ADS-B functions, as well as the more stringent standards expected of advanced applications. Performance standards that apply to capabilities beyond the stated minimum requirements are identified as optional features, and provisions have been made in UAT Message formats to accommodate such features.

1.2 ADS-B System Overview

ADS-B is a system by which aircraft, certain equipped surface vehicles, and fixed ground locations can share position, velocity, and other information with one another. The term “State Vector” (SV) is used to refer to an aircraft's position and velocity as conveyed by ADS-B, and is broken down into horizontal position and velocity, and vertical position and velocity. With such information made available by ADS-B from other proximate aircraft/vehicles, it is possible to establish the relative position and movement of those aircraft/vehicles with reference to one's own aircraft. It is also possible for ground-based facilities to monitor ADS-B broadcasts to enable basic surveillance capabilities, or to supplement existing surveillance systems. Other data that are shared using ADS-B include information related to the aircraft's intended flight path (“intent” data), aircraft type, and other information.

ADS-B is *automatic* in the sense that no pilot or controller action is required for the information to be broadcast. It is *dependent surveillance* in the sense that the aircraft State Vector and additional surveillance-type information is derived from on-board navigation equipment. ADS-B is distinguished from ADS-addressed (ADS-A, also called ADS-Contract (ADS-C) in Europe and some oceanic regions) in two ways. First, ADS-B systems broadcast State Vector and other data to be received by any suitable receiver and ADS-A uses an air-ground point-to-point communications system. Second, the ADS-A update rate is controlled by either the pilot or the ground while the ADS-B update rate is generally not so controlled. ADS-A is presently used in lieu of verbal position updates in areas without radar coverage, and the ADS-A data is used exclusively by Air Traffic Controllers and Airlines Operations Centers on the ground.

ADS-B is considered to be a key enabling technology to enhance safety and efficiency in airspace operations. RTCA Special Committee SC-186 has documented a wide range of applications of ADS-B focused on those goals in RTCA DO-242A. These include basic applications, such as the use of ADS-B to enhance the pilot's visual acquisition of other nearby aircraft, as well as more advanced applications, such as enabling enhanced closely-spaced parallel approach operations. Other applications involving airport surface operations, improved surveillance in non-radar airspace, and advanced conflict management are also described.

Some applications of ADS-B are focused on airport surface operations and suggest that it is appropriate for certain surface vehicles also to be equipped with ADS-B and to share their State Vector information with aircraft on the surface, or in-flight near the airport. Such vehicles might include, for example, snow removal equipment, crash/fire/rescue vehicles, or construction equipment near runways or taxiways. For simplicity in this document, the term "aircraft" will be used to refer, collectively, to aircraft and vehicles, as any necessary distinction can be readily established by context. Occasionally the term aircraft/vehicle (A/V) may also be used.

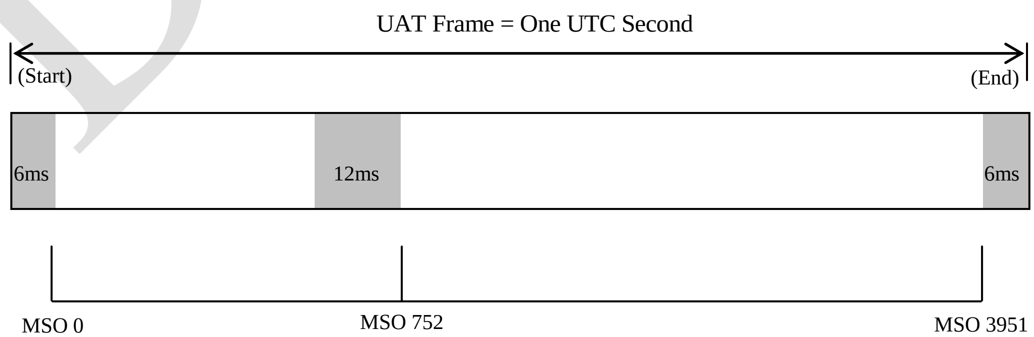
1.3 UAT System Overview

The UAT is a wideband multi-purpose data link intended to operate globally on a single channel with a channel signaling rate of just over 1Mbps. By design, UAT supports multiple broadcast services including FIS-B and TIS-B in addition to ADS-B. This is accomplished using a hybrid medium access approach that incorporates both time-slotted and random unslotted access. By virtue of its waveform, signaling rate, precise time reference, and message-starting discipline, UAT can also support independent measurement of range to most other participants in the medium.

There are two basic types of broadcast transmissions - or *messages* - on the UAT channel: the ADS-B Message, and the Ground Uplink Message. The ADS-B Message is broadcast by an aircraft to convey its State Vector and other information. The Ground Uplink Message is used by ground stations to uplink flight information such as text and graphical weather data, advisories, and other aeronautical information, to any aircraft that may be in the service volume of the ground station (see, for example RTCA DO-267). The allocation of Ground Uplink capacity to particular types of broadcast information will be made by the appropriate regulatory authority. Regardless of type, each message has two fundamental components: the message *payload* that contains user information, and message *overhead*, principally consisting of forward error correction code parity, that supports the transfer of the data.

1.3.1 UAT Medium Access for ADS-B and Ground Uplink Segments

UAT Message transmissions are governed by a combination of time-slotted and random-access techniques. Figure 1-1 illustrates the basic UAT Message timing structure called a UAT *frame*. A frame is one second long and begins at the start of each UTC second. Each frame is divided into two segments: a Ground Segment in which Ground Uplink Messages are broadcast in one or more of 32 slots (without significant interference from other UAT transmissions on the UAT medium, presuming appropriate ground system design), and an ADS-B Segment in which ADS-B Messages are broadcast by aircraft and, in the preferred UAT implementation of TIS-B, TIS-B ground stations. Guard times are incorporated between the segments to allow for signal propagation and timing drift. The UAT frame is further divided into Message Start Opportunities (MSOs) that are spaced at 250µs intervals. This spacing represents the smallest time increment used by UAT for scheduling message transmissions, and all such transmissions must start only at a valid MSO.



Ground Segment

176 ms

ADS-B Segment

800 ms

Message Start Opportunities (MSOs)

Note: *Shaded segments represent guard times for signal propagation and timing drift (not to scale).*

Figure 1-1: UAT Frame

As shown in Figure 1-1, 176 milliseconds in each 1-second UAT frame are devoted to Ground Uplink Message transmissions (providing an uplink payload capacity of over 100 kbps), and 800ms are devoted to ADS-B Message transmissions. MSOs start at the end of the initial 6ms guard time, are spaced at 250µs intervals, and are numbered sequentially from 0 through 3951.

1.3.2 Ground Uplink Message Transmissions

As mentioned above, Ground Uplink Messages are used to provide flight information such as text and graphical weather data, airspace advisories, and other aeronautical information to the flight deck. Ground Uplink Messages may also be used to provide TIS-B uplink information should high-volume TIS-B requirements during airspace transition to ADS-B exceed levels which are best broadcast in the ADS-B segment of UAT frames. Each Ground Uplink Message provides 432 bytes of payload data. Airborne UAT equipment receives and decodes these broadcast uplink messages, and then makes them available to other airborne applications such as cockpit displays or an on-board database that the pilot can later access to retrieve desired information.

In actual implementation, UAT-equipped aircraft will likely be in receiving range of more than one (and possibly several) ground uplink stations at any given time. To ensure that these multiple uplink broadcasts can be received by the airborne UAT equipment without significant interference from one another, a time-slotted scheduling discipline is applied to the uplinks. The Ground Uplink segment is therefore divided into 32 ground broadcast slots, and each ground station is assigned one or more of the slots to broadcast uplink message(s) into its coverage volume. Assignment of the ground broadcast slots to the ground stations is made on an a priori basis and allows for re-use of the slots by more distant stations similar to traditional radio frequency allocation techniques.

Each of the 32 Ground Uplink slots is 5.5 milliseconds in length, yielding a total of 176 milliseconds for the Ground Segment depicted in Figure 1-1. Section 2.2.3.2 describes the Ground Uplink Message format in more detail, but it should be noted that each Ground Uplink Message takes slightly over 4 milliseconds of the 5.5 milliseconds reserved for the uplink slot. The unused gaps provide propagation guard time for 200 nautical miles of protection for Ground Uplink Messages on adjacent time slots.

Adherence to the slot-based message-starting discipline for Ground Uplink Messages allows for efficient use of the Ground Uplink segment of each UAT frame, as well as enabling the airborne UAT equipment to determine range to each ground uplink station that is supplying messages to it. For this reason, Ground Uplink Messages are allowed to start only at pre-determined, fixed MSOs within each UAT frame, beginning with MSO 0. Because the Ground Uplink slot is 5.5 milliseconds long, each slot spans the equivalent of 22 MSOs (5.5 milliseconds divided by 250µs/MSO). Therefore, valid MSOs for the start of Ground Uplink Messages are 0, 22, 44, 66, and so on, up to MSO 682. With this MSO-based scheduling scheme, the airborne UAT equipment is able to determine the propagation delay for a Ground Uplink Message, and consequently the range to that ground station. When coupled with information on the position of multiple ground stations supplying Ground Uplink Messages (as provided in the uplink messages themselves), a back-up positioning/navigation capability may be made available.

Detailed description of payloads of specific Ground Uplink Messages is beyond the scope of this document. UAT enveloping of those payloads, however, is fully defined. RTCA DO-267 provides further information on potential FIS-B payloads.

1.3.3 ADS-B Message Transmissions

As shown in Figure 1-1, the ADS-B Segment of each UAT frame is 800 milliseconds long, and spans 3200 MSOs (i.e., from MSO 752 to MSO 3951). All aircraft-transmitted ADS-B Messages (as well as ground-transmitted TIS-B messages) are transmitted in this segment of the frame. Each UAT-equipped aircraft makes exactly one ADS-B Message transmission per frame, and makes a pseudo-random selection from among any of the 3200 MSOs in the segment to start transmission of the message. Approximately 6 milliseconds of guard time are appended after the ADS-B Segment to fill out the UAT frame to the end of the UTC second. This guard time serves two purposes: (1) it accommodates some clock drift in airborne equipment to reduce the risk of ADS-B transmission overlap with Ground Uplink Messages, and (2) it provides room for completion of ADS-B Message transmissions that are initiated on the last few valid MSOs in the ADS-B Segment.

The pseudo-random selection of an MSO within each UAT frame for the start of an aircraft's ADS-B Message is intended to prevent two aircraft from systematically interfering with each other's ADS-B Message transmissions. Adherence to the MSO-based timing scheme enables the receiving UAT equipment to determine range to the UAT equipment that transmitted the message. This information could be used in validity checks of the position data conveyed in the ADS-B Message itself. Appendix I provides more detail on UAT timing discipline, and how this aspect of UAT system design can be exploited for such range measurements.

1.3.4 Traffic Information Service - Broadcast (TIS-B) Transmission

Traffic Information Service - Broadcast (TIS-B) is a ground-based service to ADS-B-equipped aircraft to provide State Vector and other data on non-ADS-B-equipped aircraft. TIS-B may also be used in ADS-B implementations involving multiple ADS-B data links to provide a “gateway” between ADS-B equipped aircraft using different data links. The service is intended to provide ADS-B-equipped aircraft with a more-complete traffic picture in situations where not all aircraft are equipped with ADS-B (or with the same ADS-B data link). As commonly envisioned, TIS-B involves three major functions. First, another source of State Vector information on non-ADS-B aircraft (such as Secondary Surveillance Radar (SSR)) must be available. Second, this State Vector information must be converted and processed so as to be usable by ADS-B-equipped aircraft. And third, a broadcast facility and protocol is necessary to convey this information to ADS-B-equipped aircraft. The focus of this description is on the third function.

In the UAT implementation, TIS-B information is preferably transmitted by a ground-based broadcast facility in the ADS-B Segment of the UAT frame, adhering to the same basic medium access and message-starting disciplines as ADS-B Messages transmitted by airborne UAT equipment. In addition, State Vector and other data to be provided by TIS-B are encoded into the same ADS-B Message structure. This approach simplifies receiver design and processing. Provision is made in the ADS-B Message format to clarify when the message, itself, is being transmitted from a ground-based facility, rather than from the aircraft to which the State Vector information applies. This distinction is important in this case because range estimates based on time-of-arrival/propagation delay will be measured from the ground broadcast facility, rather than from the other aircraft.

1.3.5 UAT ADS-B Message Structure and Scheduling

In the flight environment, some of the information to be shared via ADS-B (such as aircraft position and velocity) change value rather rapidly, while other information (such as aircraft type) do not change value at all. RTCA DO-242A defines the various types of information that are required to be broadcast via ADS-B, as well as the timeliness and confidence with which the information must be received. This section provides a brief overview of how UAT's ADS-B Message structure and scheduling philosophy address these diverse requirements.

Figure 1-2 provides a conceptual illustration of the payload structures of the two defined types of UAT ADS-B Messages, namely the Basic ADS-B Message and the Long ADS-B Message (see Section 2.2.3.1). All UAT ADS-B Messages incorporate a message header (HDR), which provides one means to correlate different messages received from a given aircraft. The header also contains a five-bit field (among other data) to indicate the type of information provided in the message. This enables designation of up to 32 different payload types (labeled 0 to 31), which are shown parenthetically in Figure 1-2.

The Basic ADS-B Message (Payload Type Code "0") is comprised of the message header (HDR) and the aircraft's State Vector. Currently, 10 Long ADS-B Messages (Payload Type Codes "1" through "10") are defined and are comprised of the message header, the aircraft's State Vector, and an additional information field. For example, payload type code "1" indicates that the additional information field includes Mode Status (MS) data such as the flight identifier and what kind of A/V is transmitting the information. It should be noted that significant portions of defined payloads have been reserved for future use. Also, the remaining payload types (code "11" through "31") are all defined as Long ADS-B Messages comprised of the message header and one-or-more yet-to-be-defined information fields. These are intended for future or developmental applications. Detailed descriptions of the message payloads by type are provided in Section 2.2.4.3.

(0*) HDR	SV	← Basic ADS-B Message

Long ADS-B Messages

(1-6) HDR	SV	Mode Status/Intent Data
(7-10) HDR	SV	Reserved
(11-29)HDR	Reserved for Future Definition	
(30, 31)HDR	Reserved for Developmental/Experimental Use	

*Payload Type Codes are Part of the Message Header (HDR) and are indicated in parentheses.

Figure 1-2: UAT ADS-B Message Structures

In most scenarios, State Vector data are very dynamic - reflecting the high-speed movement of the aircraft transmitting the messages. By virtue of this message structure for the defined payload types, State Vector data are transmitted at an average 1Hz rate, regardless of whether they are conveyed by Basic or Long ADS-B Messages. This ensures that State Vector data is transmitted frequently and enables the UAT Receiving Subsystem to support ADS-B applications with fresh information. In addition, because the State Vector data are part of every defined ADS-B Message and provide an added element of uniqueness to the message, they might also be used to correlate various ADS-B Messages issued by a given aircraft.

The transmission rates of the various types of ADS-B Messages is derived from RTCA DO-242A ADS-B report update requirements according to the UAT equipment class and supported applications. A sixteen-second transmission epoch has been developed for each UAT equipment class which specifies an ordered sequence of ADS-B payload transmissions.

1.4 Operational Goals and Applications

UAT equipment requirements in this document are directed toward support of operational enhancements that the aviation industry considers critical in its pursuit of free flight operations, many of which are described in RTCA DO-242A. These operational enhancements are predicated on the proper and timely incorporation of technologies such as satellite navigation, broadcast and two-way addressed data links, airborne computer and database resources, and well-designed pilot-system interfaces. These technologies enable services such as TIS-B, FIS-B, and Controller-Pilot Data Link Communications (CPDLC), and when coupled with ADS-B will enlarge the set of tools that can be used to improve operations in the National Airspace.

This section provides a brief, operationally-oriented description of the major families of applications of ADS-B to be supported by UAT equipment. UAT equipment is also designed to support surveillance-related services such as FIS-B and TIS-B to produce early user benefit and support other operational enhancements. As noted earlier, performance standards for these other services are documented separately.

1.4.1 Applications Involving Cockpit Display of Traffic Information (CDTI)

Broadcast of State Vector and other information via ADS-B enables proximate equipped aircraft to determine the relative position and movement of the source aircraft. This information can be displayed to the pilot on a Cockpit Display of Traffic Information (CDTI), which could be a stand-alone, dedicated traffic display, or integrated with other plan-view information such as a moving map display with navigation, terrain, graphical weather, and airspace information. In addition, even though the term “CDTI” usually connotes a plan-view type display, it is possible that other cueing and indication mechanisms (such as aural cueing and heads-up displays) may also be employed by flight deck designers to provide traffic information to the pilot. Display/indication requirements are beyond the scope of this document; however, the requirements specified in Section 2 are intended to ensure that UAT equipment can support these CDTI applications in a wide range of installations.

1.4.1.1 Aid to Visual Acquisition

In airspace operations today, and for the foreseeable future, considerable reliance is placed on the pilot's ability to “see-and-avoid” other air traffic whenever prevailing weather conditions permit. This is the cornerstone of all flight operations conducted under Visual Flight Rules (VFR), and it is a streamlining agent for operations conducted under Instrument Flight Rules (IFR) where maintenance of visual separation responsibilities can be assigned to the flight crew in special conditions. In this application, the UAT Receiving Subsystem feeds proximate traffic information to the CDTI, from which the pilot can better focus an out-the-window visual search for neighboring aircraft. It also helps the pilot maintain visual contact with other traffic as his attention and visual focus is divided among several cockpit duties. The essence of this application, then, is to assist the pilot in his external scan to visually acquire other traffic, and maintain visual contact once acquired.

1.4.1.2 Enhanced Traffic Situational Awareness

As higher proportions of the aircraft in a given airspace domain are equipped with ADS-B, the CDTI provides the flight crew with an increasingly comprehensive picture of the traffic situation in all weather environments, and regardless of whether visual acquisition is possible, or not. To the extent that it is provided in current-generation TCAS/ACAS-based CDTIs, this increased traffic situational awareness has proved valuable in many different airspace environments. Having a better understanding of the traffic situation in the terminal environment, for example, enables the flight crew to be better prepared to understand and respond to ATC instructions.

1.4.1.3 Station Keeping and Maintenance of Established Separation

In these applications, the CDTI is used to maintain separation from other aircraft once that separation has been established by ATC. Examples include maintaining longitudinal separation from an aircraft ahead on the same track as might be implemented on a final approach course, or as part of an in-trail climb/descend procedure in an en route/oceanic airspace environment. Because the CDTI is now being used to manage the flight profile with respect another aircraft, it may be necessary to provide the pilot with additional information beyond that required to support only an enhanced situational awareness. Although operational procedures still need to be developed, such additional information might include, for example, a range indication and closure rate to the referenced aircraft. Requirements in this document are intended to support station keeping and maintenance of established separation applications for appropriate classes of users.

1.4.1.4 CDTI-Based Electronic Flight Rules (CEFR)

A further extension of the use of the CDTI is the notion of CDTI-based Electronic Flight Rules (CEFR). Under this concept, in certain airspace and by mutual pilot/controller agreement, responsibility for separation may be delegated to the pilot. The CDTI and other appropriate aids would then be used by the pilot to electronically "see and avoid" other aircraft, perhaps by applying the same right-of-way rules that are applied today under VFR operations.

1.4.2 Applications Involving Airborne Conflict Management and Future Collision Avoidance

As more operational experience is gained, it is likely that ADS-B will be tasked with various degrees of support for airborne conflict management and possibly future collision avoidance. This includes detection and resolution of potential collision/conflict situations in the tactical and strategic senses.

1.4.2.1 Future Airborne Collision Avoidance

ADS-B could be used to augment, or used in lieu of, current-generation airborne collision-avoidance technologies. This would include features to detect when another aircraft is posing a collision risk, as well as provision of advisories to the pilot to resolve such a hazard. These applications would be based primarily on State Vector data, and other relatively "near-term" intent information provided by ADS-B. Their implementation in the cockpit would likely be done in concert with other ADS-B Applications, such as those mentioned above dealing with CDTI.

1.4.2.2 Airborne Conflict Management

Many aircraft avionics architectures include a means to capture the aircraft's intent in terms of the future lateral and vertical path, as well as the speed profile. This information can be shared in an ADS-B environment to detect potential conflicts long before more aggressive avoidance measures are necessary. In this future application, such a potential conflict could be displayed along with a range of possible resolution choices. In addition, any change in intent could be quickly evaluated against the intent of other equipped aircraft, thereby increasing the flexibility and capacity of the airspace. In this family of applications, greater strides toward Free Flight operations can be made.

1.4.3 Airport Surface Applications

There are a number of potential applications for ADS-B on and near the airport surface. These include the use of ADS-B to maintain traffic situational awareness for surface operations, much akin to its use in airborne environments. However, this situational awareness could also be extended to include equipped surface vehicles such as snow-removal equipment, crash/fire/rescue vehicles, or other vehicles that may be frequently operating in the airport movement area. Another set of applications promotes pilot awareness of takeoff and landing operations, and whether the active runway is occupied, or in use by, another aircraft. These other applications are aimed directly at reducing the incidence of runway incursions.

1.4.4 Support of Ground-Based Surveillance Applications

Preliminary implementations of UAT technology are providing "radar-like" services in environments where no SSR coverage exists, and future expansion of this application is likely. In this family of applications, ground-based monitoring stations are situated in areas where IFR departure and arrival procedures are conducted but no SSR coverage is available. By receiving, processing, and forwarding ADS-B Messages to appropriate ATC facilities, the controller can be presented with traffic information that is very similar to what would be provided with traditional radar systems. Consequently, the controller can apply more efficient radar-based traffic separation techniques, thereby increasing traffic throughput and reducing delays. A variation of this application involves the use of ADS-B to provide a surface surveillance capability to ground controllers at towered airports, to aid in surface movement planning, monitoring, and runway occupancy.

1.4.5 Other Applications

RTCA DO-242A outlines several other secondary applications, such as use of ADS-B to enhance flight following, search-and-rescue, and others that may be beneficial in terms of safety, efficiency, increased utility, or cost savings.

1.5 Assumptions and Rationale

Throughput requirements for ADS-B Message receptions have been developed so that the UAT equipment can process the maximum number of messages that can be supplied in future high density scenarios on the UAT medium. The UAT report assembly function will similarly be required to be capable of accepting the applicable subset of these messages as output by the ADS-B Receiving Subsystem.

1.6 Test Procedures

The test procedures specified in this document are intended as one means of demonstrating compliance with the specified performance requirements. Although specific test procedures are cited, it is recognized that there are other suitable methods, and that these other procedures may be used if they provide at least equivalent confidence that the requirements are satisfied. In such cases, the test procedures in this document may be used as one criterion in evaluating the acceptability of the alternate procedures.

The specified order of tests suggests that the equipment be subjected to a succession of tests as it moves from design, and design qualification, into operational use. For example, compliance with the requirements of Section 2 shall have been demonstrated as a precondition to satisfactory completion of the installed system tests of Section 3.

a. Environmental Tests

   Environmental test requirements are specified in Section 2.3. The procedures and their associated limits are intended to provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations.

Unless otherwise specified, the environmental conditions and test procedures contained in RTCA Document DO-160D, *Environmental Conditions and Test Procedures for Airborne Equipment*, will be used to demonstrate equipment compliance.

b. Bench Tests

Bench test procedures are specified in Section 2.4. These tests provide a laboratory means of demonstrating compliance with the requirements of Sections 2.1 and 2.2. Test results may be used by equipment manufacturers as design guidance, for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design.

c. Installed Equipment Tests

The installed equipment test procedures and their associated limits are specified in Section 3. Although bench and environmental test procedures are not included in the installed equipment test, their successful completion is a precondition to completion of the installed test. In certain instances, however, installed equipment test may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from or to other equipment installed on the aircraft, etc. Installed tests are normally performed under two conditions:

1. With the aircraft on the ground and using simulated or operational system inputs.

2. With the aircraft in flight using operational system inputs appropriate to the equipment under test.

Test results may be used to demonstrate functional performance in the intended operational environment.

d. Operational Tests

The operational tests are specified in Section 4. These test procedures and their associated limits are intended to be conducted by operational personnel as one means of ensuring that the equipment is functioning properly and can be reliably used for its intended function(s).

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2 Equipment Performance Requirements and Test Procedures

2.1 General Requirements

2.1.1 Airworthiness

In the design and manufacture of the equipment, the manufacturer **shall** provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment **shall** perform its intended function(s), as defined by the manufacturer, and its proper use **shall** not create a hazard to other users of the National Airspace System.

2.1.3 Federal Communications Commission Rules

All equipment **shall** comply with the applicable rules of the Federal Communication Commission.

2.1.4 Fire Protection

All materials used **shall** be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

Note: *One means of showing compliance is contained in Federal Aviation Regulations (FAR), Part 25, Appendix F.*

2.1.5 Operation of Controls

The equipment **shall** be designed so that controls intended for use during flight cannot be operated in any position, combination or sequence that would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.6 Accessibility of Controls

Controls that do not require adjustment during flight **shall** not be readily accessible to flight personnel.

2.1.7 Equipment Interfaces

The interfaces with other aircraft equipment **shall** be designed such that normal or abnormal UAT equipment operation **shall** not adversely affect the operation of other equipment, nor **shall** normal or abnormal operation of other equipment adversely affect the UAT equipment, except as specifically allowed.

2.1.8 Effects of Test

The equipment **shall** be designed so that the application of specified test procedures **shall** not be detrimental to equipment performance following the application of the tests, except as specifically allowed.

2.1.9 Integration with Other Avionics Equipment

In the event that UAT functions are partially or wholly incorporated within other avionics equipment, the design **shall** be partitioned such that any abnormal equipment operation does not adversely affect other function unrelated to UAT. Loss of UAT capability **shall** not inhibit other functions of the equipment.

2.1.10 Design Assurance

The equipment **shall** be designed to the appropriate design assurance level(s) based on the intended application of the equipment and aircraft class in which it is to be installed. The appropriate design assurance level(s) are determined by an analysis of the failure modes of the equipment and a categorization of the effects of the failure on the operation of the aircraft. For the purpose of this analysis, a failure is defined as either a loss of function or the output of misleading information. Guidance can be found in AC 23.1309-1C and AC 25.1309-1A.

Software included as part of the equipment **shall** be developed in compliance with the appropriate software level as defined in RTCA DO-178B.

2.1.11 Equipage Classes

UAT equipment is categorized into aircraft system equipage classes as defined in Table 3-1 of RTCA DO-242A (ADS-B MASPS). For UAT equipment, the installed performance of these equipment classes **shall** be defined by Table 2-1.

The ADS-B MASPS "A1" equipment has been divided into three classes, based on the maximum altitude that the aircraft is operated under. For A1 aircraft that always operate below 18,000 feet MSL, the "A1 Low" class and "A1 Single Antenna class are created, and abbreviated throughout this document as "A1L" and "A1S," respectively. For A1 aircraft that have no altitude operating restrictions, the "A1 High" class is created, and abbreviated throughout this document as "A1H." The only equipment performance difference between classes A1L and A1H is the Transmitter RF output power, as shown in Table 2-1.

The remainder of the interactive aircraft/vehicle classes (A0, A2, and A3) are as defined in RTCA DO-242A. It is recognized that since Class "A" includes both transmitting and receiving subsystems, there may very well be implementations that consist of separate equipment for the transmit and receive functions. Implementing the transmitter function of Class "A" can be satisfied by providing the capabilities included in §2.1.12. Similarly, implementing the receiver function of Class "A" can be satisfied by providing the capabilities included in §2.1.13.

For "B" class aircraft that always operate below 18000 feet MSL, the "B0" and "B1S" classes is created. For "B" class aircraft that have no altitude operating restrictions, the "B1" class is available. The ADS-B MASPS "B0" class (broadcast-only aircraft) is defined as having transmitter characteristics and payload capability identical to the UAT A0 interactive aircraft class. The ADS-B MASPS "B1S" class (broadcast-only aircraft) is defined as having transmitter characteristics and payload capability identical to the UAT A1S interactive aircraft class. The ADS-B MASPS "B1" class (broadcast-only aircraft) is defined as having transmitter characteristics and payload capability identical to the UAT A1H interactive aircraft class.

The characteristics of the ADS-B MASPS "B2" class (broadcast-only ground vehicle) are defined in Table 2-1.

The characteristics of the ADS-B MASPS "B3" class (broadcast-only fixed or moveable obstacle) are defined in Table 2-1. The payload capability supports the surface position, height of highest point, and identification (including Emitter Category) of the obstacle, so that both State Vector and Mode Status reports must be supported. Moveable obstacles require a position source. A moveable obstacle is one that can change its position, but only slowly, such that its horizontal velocity may be ignored. See §2.2.6.1.2 of this document for the payload characteristics.

Requirements for Class "C" ground-based receive-only equipment are not addressed in this document. See Appendix D for guidance in ground-based receiver performance.

Table 2-1: UAT Installed Equipment Classes

Description	**Equipage Class**	**Tx RF Power Delivered to Antenna System**	**Intended Antenna Diversity (when Airborne for Classes A & B0-B1)**	
			Transmit	**Receive**
Aircraft	A0	Low Power *(Altitude always below 18000 feet)*	Single Antenna (see Note 4)	Single Antenna (see Note 4)
	A1L		Alternating every 2 sec.	Alternating every second
	A1S	Medium Power *(Altitude always below 18000 feet)*	Single Antenna (see Note 4)	Single Antenna (see Note 4)
	A1H	Medium Power	Alternating every 2 sec.	Alternating every second
	A2	Medium Power	Alternating every 2 sec.	Dual Receiver
	A3	High Power	Alternating every 2 sec.	Dual Receiver
Transmit-Only Aircraft / Vehicle	B0	Low Power *(Altitude always below 18000 feet)*	Single Antenna (see Note 4)	n/a
	B1S	Medium Power	Single Antenna (see Note 4)	n/a
	B1	Medium Power	Alternating every 2 sec.	n/a
Surface Vehicle	B2	+28 to +32 dBm	Single Antenna	n/a
Obstacle	B3	+30 dBm (minimum)	Single Antenna	n/a

Notes:

1. *See* §2.1.12 *for definition of Transmitter RF power levels.*

2. *Transmitter RF power requirement depends on the aircraft maximum altitude capability. Low-altitude aircraft (< 18,000 feet max altitude) need not support the higher-power transmitter requirements due to line-of-site limitations.*

3. *Top antenna is not required if use of a single antenna does not degrade signal propagation. This allows for single antenna installation on radio-transparent airframes.*

4. *For a single-antenna A1S/B1S installations, antenna gain pattern performance will need to be shown at least equivalent to that of a quarter-wave resonant antenna mounted on the fuselage bottom surface. For single-antenna A0/B0 installations, such an analysis should be performed.*

5. *See* §2.2.6.1.2 *for definition of payload transmission requirements for each equipment class.*

2.1.12 Transmitting Subsystem

A UAT Transmitting Subsystem is classified according to the unit's range capability and the set of parameters that it is capable of transmitting. Table 2-2 **shall** define the transmitter power levels. Power levels are measured in terms of power presented to the transmitting antenna.

<u>Table 2-2:</u> Transmitter Power Requirements

Power Classification	**Minimum Power at Antenna**	**Maximum Power at Antenna**
Low	7.0 watts (+38.5 dBm)	18 watts (+42.5 dBm)
Medium	16 watts (+42 dBm)	40 watts (+46 dBm)
High	100 watts (+50 dBm)	250 watts (+54 dBm)

Note: *These transmitter power requirements are referenced to the power delivered to the antenna, and assume transmit antenna gain of 0 dB. Alternate means that demonstrates equivalent performance can be approved. Refer to Appendix E for guidance.*

Performance is specified over full environmental range for desired equipment application.

Each Transmitting Subsystem equipage class requires the broadcast of certain ADS-B message payload types as specified in Table 2-10 and Table 2-63. Requirements that are specific to the transmitting subsystem are contained in §2.2.2, §2.2.3, §2.2.4, §2.2.5, §2.2.6 and §2.2.7.

2.1.13 Receiving Subsystem

No distinction in receiver sensitivity by category is made; all receivers have the same sensitivity requirements. The receiver sensitivity is –93 dBm at the receiver antenna for 90% Message Success Rate for Long ADS-B Messages, and –91 dBm at the receiver antenna for 90% Message Success Rate of Ground Uplink (ground-to-air) messages.

Performance is specified over full environmental range for desired equipment application.

Requirements that are specific to the Receiving Subsystem are contained in §2.2.8, §2.2.9, and §2.2.10.

2.1.14 Antenna Subsystem

Throughout this document, requirements have been derived presuming the use of antennas having omni-directional pattern and 0 dB of gain. The use of gain antennas for ADS-B is permitted and discussed in RTCA DO-242A (ADS-B MASPS) in section §3.3.1 and Appendix H, and in Appendix E of this document. Antenna azimuthal gain patterns **shall** not contain intentional nulls. Nulls created by airframe blockages should be minimized when antenna locations are selected.

2.2 Equipment Performance – Standard Conditions

2.2.1 Definition of Standard Conditions

2.2.1.1 Signal Levels

Unless otherwise noted, the signal levels specified for transmitting devices in this subsection exist at the antenna end of an equipment-to-antenna transmission line of loss equal to the maximum for which the transmitting function is designed.

Likewise, unless otherwise noted, the signal levels specified for receiving devices in this subsection exist at the antenna end of an antenna-to-equipment transmission line of loss equal to the maximum for which the receiving function is designed.

Note: *Transmitting or receiving equipment may be installed with less than the designed maximum transmission line loss. Nevertheless, the standard conditions of this document are based on the maximum design value. Insertion losses internal to the antenna should be included as part of the net antenna gain.*

2.2.1.2 Desired Signals

Unless otherwise specified, the desired signal specified as part of receiver performance requirements is any valid ADS-B Long Type message.

2.2.1.3 Data Quantization

Message data fields **shall** be encoded and decoded in a manner that preserves the original data to an accuracy of ±½ LSB.

2.2.2 ADS-B Transmitter Characteristics

2.2.2.1 Transmission Frequency

The transmission frequency f_0 **shall** be 978 MHz, ±20 PPM.

Note: *All transmissions from ground stations will operate at the same transmission frequency and frequency tolerance.*

2.2.2.2 Modulation Rate

The nominal modulation rate is 1.041667 megabits per second.

Notes:

1. *Each bit period = 0.96 microseconds.*

2. *Ground Uplink Messages will use the same modulation type.*

3. *Adherence to this rate is assured as part of the requirement of §2.2.2.4.*

2.2.2.3 Modulation Type

Data **shall** be modulated onto the carrier using binary Continuous Phase Frequency Shift Keying. The modulation index, *h*, **shall** be 0.6; this implies that if the data rate is R_b, then the nominal frequency separation between "mark" (binary 1) and "space" (binary 0) is $\Delta f = h \bullet R_b$. A binary 1 **shall** be indicated by a shift up in frequency from the nominal carrier frequency of Δf/2 (+312.5 kHz) and a binary 0 by a shift of -Δf/2 (-312.5 kHz). These frequency deviations apply at the optimum sampling points for the bit interval.

Notes:

1. *Filtration of the transmitted signal (at base band and/or after frequency modulation), will be required to meet the spectral containment requirement of* §2.2.2.6. *This filtration will cause the deviation to exceed these values at points other than the optimum sampling points.*

2. *The optimum sampling point of a received bit stream is at the nominal center of each bit period, when the frequency deviation is either plus or minus 312.5 kHz.*

3. *Due to filtering of the transmitted signal, the received frequency offset varies continuously between the nominal values of ±312.5 kHz (and beyond), and the optimal sampling point may not be easily identified. This point can be defined in terms of the so-called "eye diagram" of the received signal. The eye diagram is a superposition of samples of the post-detection waveform shifted by multiples of the bit period (0.96 microseconds). The optimum sampling point is the point during the bit period at which the opening of the eye diagram (i.e., the minimum separation between positive and negative frequency offsets at very high signal-to-noise ratios) is maximized.*

2.2.2.4 Modulation Distortion

The minimum vertical opening of the eye diagram of the transmitted signal (measured at the optimum sampling points) **shall** be no less than 560 kHz when measured over an entire Long ADS-B Message containing pseudorandom payload data.

The minimum horizontal opening of the eye diagram of the transmitted signal (measured at 978 MHz) **shall** be no less than 0.624 microseconds (0.65 symbol periods) when measured over an entire Long ADS-B Message containing pseudorandom payload data.

2.2.2.5 Transmitter Power Output

The Time/Amplitude profile of an ADS-B Message Transmission **shall** fall within the following limits relative to a *reference time* defined as 0.48 microseconds prior to the center of the first bit of the synchronization sequence (§2.2.3.1.1) appearing at the output port of the equipment.

All power measurements for subparagraphs "**a**" through "**f**" below apply to the selected antenna port for installations that support transmitter diversity (§2.2.6.1.3). The RF power output on the non-selected antenna port **shall** be at least 20 dB below the level on the selected port.

All power measurements for subparagraphs "**a**" and "**f**" assume a 300 kHz bandwidth. All power measurements for subparagraphs "**b**," "**c**," "**d**" and "**e**" assume a 2 MHz bandwidth.

a. Prior to 8 bit periods before the reference time, the average RF output power **shall** not exceed –80 dBm.

   Note: *This unwanted power requirement is necessary to ensure that the ADS-B Transmitting Subsystem does not prevent closely located UAT receiving equipment from meeting its requirements. It assumes that the isolation between transmitter and receiver equipment exceeds 20 dB.*

b. Between 8 and 6 bit periods prior to the reference time, the RF output power **shall** remain at least 20 dB below the minimum power requirement for the appropriate equipment class per Table 2-1.

c. During the Active state, defined as beginning at the reference time and continuing for the duration of the message (276 bit periods for the Basic Message and 420 bit periods for the Long Message), the RF output power **shall** comply with Table 2-2.

d. The RF output power **shall** not exceed the maximum limits of Table 2-2 at any time during the ADS-B Message Transmission Interval, as shown in Figure 2-1.

e. Within 6 bit periods after the end of the Active state, the RF output power **shall** be at a level at least 20 dB below the minimum power requirement for the appropriate equipment class per Table 2-1.

f. Within 8 bit periods after the end of the Active state, the average RF output power **shall** fall to a level not to exceed –80 dBm.

   Note: *This unwanted power requirement is necessary to ensure that the ADS-B Transmitting Subsystem does not prevent closely located UAT receiving* *equipment from meeting its requirements. It assumes that the isolation between transmitter and receiver equipment exceeds 20 dB.*

These requirements are depicted graphically in Figure 2-1.

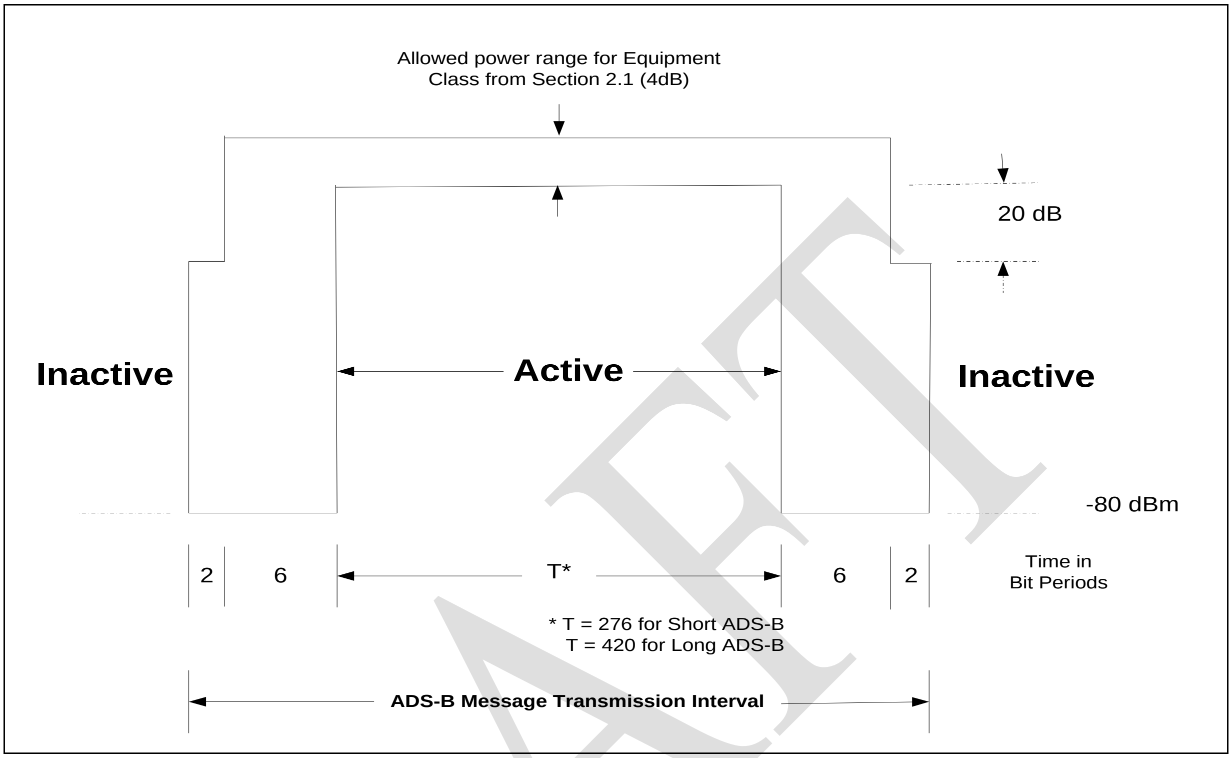


Figure 2-1: Time/Amplitude Profile of ADS-B Message Transmission Interval

2.2.2.6 In Band Transmission Spectrum

The average spectrum of a UAT message transmission modulated with pseudo-random payload data **shall** fall within the limits specified in Table 2-3 and Figure 2-2 when measured in a 100 kHz bandwidth.

Table 2-3: UAT Transmit Spectrum

Frequency Offset From Center	Required Attenuation from Maximum (dB)
All frequencies in the range 0 – 0.5 MHz	0
All frequencies in the range 0.5 – 1.0 MHz	Based on linear* interpolation between these points
1.0 MHz	18
All frequencies in the range 1.0 – 2.25 MHz	Based on linear* interpolation between these points
2.25 MHz	50
All frequencies in the range 2.25 – 3.25 MHz	Based on linear* interpolation between these points
3.25 MHz	60

** based on amplitude in dB and a linear frequency scale*

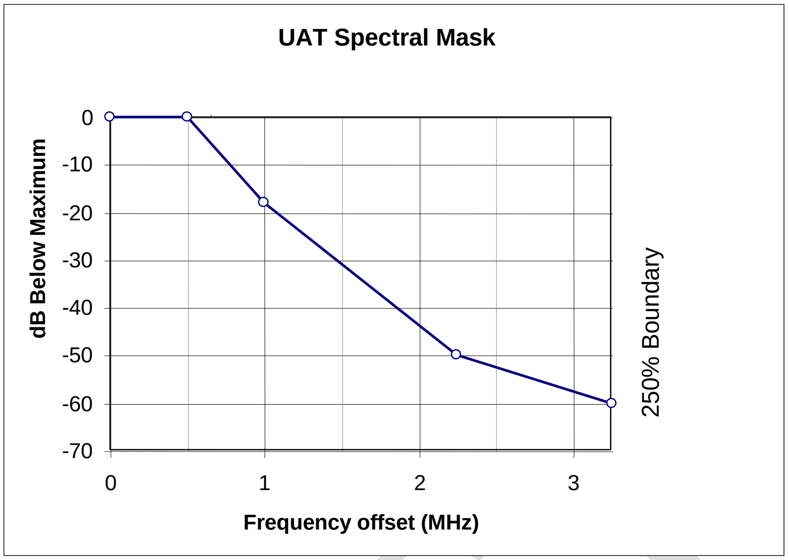


Figure 2-2: **UAT Transmit Spectrum**

Notes:

1. *99% of the power of the UAT spectrum is contained in 1.3 MHz (±0.65 MHz). This is roughly equivalent to the 20 dB bandwidth.*

2. *Spurious transmission requirements begin at ±250% of the 1.3 MHz value, therefore the transmit mask requirement extends to ±3.25 MHz.*

3. *The mask shown in Figure 2-2 should be verified by measuring the spectrum over the entire message transmission, including any ramp up and ramp down transmission outside the Active interval shown in Figure 2-1.*

2.2.2.7 Out-of-Band Emissions

Out-of-Band emissions **shall** comply with applicable FCC regulations beyond 250% of the authorized bandwidth, that is, 3.25 MHz from the center frequency. Reference 47 CFR, §87.139.

2.2.3 Broadcast Message Characteristics

Subparagraphs §2.2.3.1 through §2.2.3.2.4 define the format for the ADS-B and the Ground Uplink Message types. Each of these messages types will normally occur in separate portions of the UAT frame as described in Section 1.

2.2.3.1 ADS-B Message Format

The ADS-B Message format is shown in Figure 2-3. Each message element is described in detail in §2.2.3.1.1 through §2.2.3.2.3.

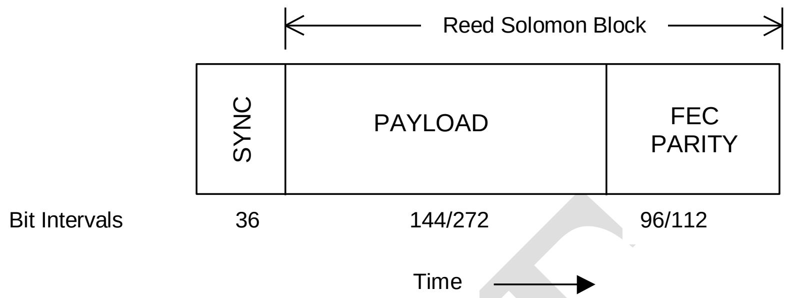


Figure 2-3: ADS-B Message Format

Notes:

1. *All bit intervals depicted in Figure 2-3 comprise the ACTIVE state of the transmitter as defined in §2.2.2.5.c.*

2. *Traffic Information Services-Broadcast (TIS-B) transmissions use the ADS-B Message format — including use of the same synchronization pattern. Therefore, there is actually no need for a "TIS-B Message" and none is referred to in these MOPS.*

2.2.3.1.1 Synchronization

Following ramp up, the message **shall** include a 36-bit synchronization sequence. For the ADS-B Messages the sequence **shall** be:

111010101100110111011010010011100010

with the left-most bit transmitted first.

2.2.3.1.2 Payload

The format, encoding and transmission order of the payload message element is defined in §2.2.4.

2.2.3.1.3 FEC Parity

2.2.3.1.3.1 Code Type

The FEC Parity generation **shall** be based on a systematic Reed-Solomon (RS) 256-ary code with 8-bit code word symbols. FEC Parity generation **shall** be per the following code:

a. Basic ADS-B Message: Parity **shall** be per a RS (30, 18) code.

Note: *This results in 12 bytes (code symbols) of parity capable of correcting up to 6 symbol errors per block.*

b. Long ADS-B Message: Parity **shall** be per a RS (48, 34) code.

Note: *This results in 14 bytes (code symbols) of parity capable of correcting up to 7 symbol errors per block.*

For either message length the primitive polynomial of the code **shall** be as follows:

$$p(x) = x^8 + x^7 + x^2 + x + 1.$$

The generator polynomial **shall** be as follows:

$$\prod_{i=120}^{P} (x - \alpha^i).$$

P = 131 for RS (30,18) code and P = 133 for RS (48,34) code

α is a primitive element of a Galois field of size 256 (i.e., GF(256)).

Note: *See Appendix C for more information on the implementation of the Reed Solomon code.*

2.2.3.1.3.2 Generation and Transmission Order of FEC Parity

FEC Parity bytes **shall** be ordered most significant to least significant in terms of the polynomial coefficients they represent. The ordering of bits within each byte **shall** be most significant to least significant. FEC Parity bytes **shall** follow the message payload.

Note: *See Appendix C for a message generation and encoding example.*

2.2.3.2 Ground Uplink Message Format

The Ground Uplink Message format is shown in Figure 2-4. Each message element is described in detail in §2.2.3.2.1 through §2.2.3.2.4.

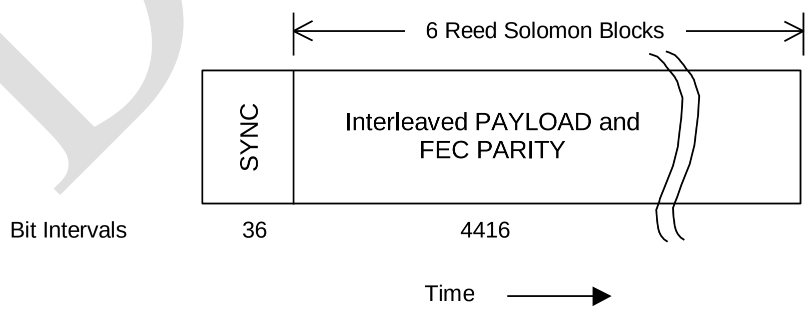


Figure 2-4: Ground Uplink Message Format

2.2.3.2.1 Synchronization

The polarity of the bits of the synchronization sequence used for Ground Uplink Messages is inverted from that used for the ADS-B Message, that is, the ONEs and ZEROs are interchanged. This synchronization sequence is:

000101010011001000100101101100011101

with the left-most bit transmitted first.

Note: *Because of the close relationship between the synchronization sequences used for the ADS-B and Ground Uplink Messages, the same correlator can search for both simultaneously.*

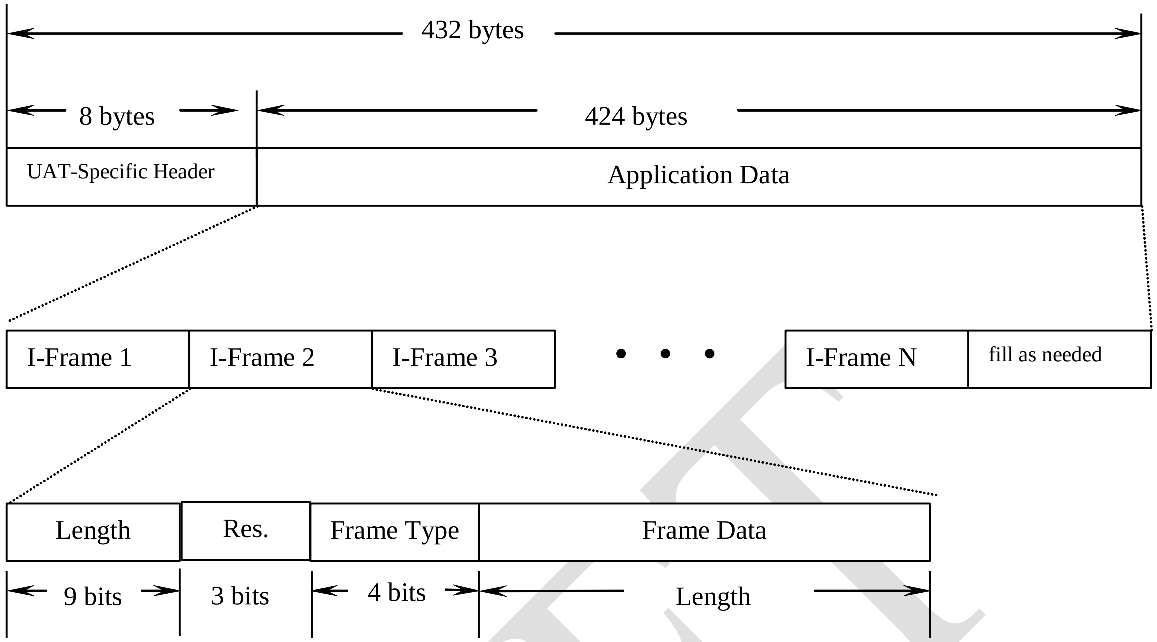
2.2.3.2.2 Payload (Before Interleaving and After De-interleaving)

The Payload consists of two components: the first eight bytes that comprise UAT-Specific Header and bytes 9 through 432 that comprise the Application Data as shown in Table 2-4. Bytes and bits are fed to the interleaving process with the most significant byte, byte #1, transmitted first, and within each byte, the most significant bit, bit #1, transmitted first.

Table 2-4: Format of the Ground Uplink Message Payload

Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
1	(MSB)							
2				GROUND STATION LATITUDE (WGS-84)				
3							(LSB)	(MSB)
4								
5				GROUND STATION LONGITUDE (WGS-84)				
6							(LSB)	**P Valid**
7	UTC COUPLED	Reserved	APPLICATION DATA VALID	(MSB)		**SLOT ID**		(LSB)
8	(MSB)	**TIS-B SITE ID**		(LSB)		**Reserved**		
9				**Application Data**				
432								

The Ground Uplink Payload is composed of an eight-byte UAT Specific Header, followed by 424 bytes of Application Data. The Application Data field is further composed of one or more *Information Frames (I-Frames)* of uplink service data, as shown in Figure 2-5.



<u>Figure 2-5:</u> Ground Uplink Information Frame

2.2.3.2.2.1 UAT-Specific Header

The UAT-Specific Header is an 8-byte field that contains information on the location of the uplink site, the time slot used to send the present message, validity flags for position and time, and application data, as described in the subparagraphs that follow.

2.2.3.2.2.1.1 "GROUND STATION LATITUDE" Field Encoding

The "GROUND STATION LATITUDE" field is a 23-bit (bit 1 of byte 1 through bit 7 of byte 3) field used to identify the latitude of the ground station. The encoding of this field by the ground station will be the same as defined for latitude information in the ADS-B Message (§2.2.4.5.2.1).

<u>Note:</u> *The resolution of this field has been selected to support a potential passive ranging function.*

2.2.3.2.2.1.2 "GROUND STATION LONGITUDE" Field Encoding

The "GROUND STATION LONGITUDE" field is a 24-bit (bit 8 of byte 3 through bit 7 of byte 6) field used to identify the longitude of the ground station. The encoding of this field by the ground station will be the same as defined for longitude information in the ADS-B Message (§2.2.4.5.2.1).

<u>Note:</u> *The resolution of this field has been selected to support a potential passive ranging function.*

2.2.3.2.2.1.3 "POSITION VALID" Field Encoding

The "POSITION VALID" field is a 1-bit (bit 8 of byte 6) flag used to indicate whether or not the position in the header is valid. An encoding of ONE represents a VALID position. An encoding of ZERO represents an INVALID position.

2.2.3.2.2.1.4 "UTC COUPLED" Field Encoding

"UTC COUPLED" flag is a 1-bit (bit 1 of byte 7) flag used to indicate whether or not the ground station 1 Pulse Per Second timing is valid. An encoding of ONE represents that the Ground Station is UTC-Coupled (§2.2.5.1). An encoding of ZERO represents that the Ground Station is not UTC-Coupled (§2.2.5.2).

2.2.3.2.2.1.5 Reserved Bit

Bit 2 of byte 7 is reserved for future use and will always be set to ZERO.

2.2.3.2.2.1.6 "APPLICATION DATA VALID" Field Encoding

The "APPLICATION DATA VALID" field is a 1-bit (bit 3 of byte 7) flag used to indicate whether or not the Application Data is valid for operational use. An encoding of ONE represents VALID Application Data. An encoding of ZERO represents INVALID Application Data.

Notes:

1. *Airborne applications should ignore the Application Data flag when this bit is set to INVALID.*

2. *This flag will allow testing and demonstration of new products without impact to operational airborne systems.*

2.2.3.2.2.1.7 "SLOT ID" Field Encoding

The "SLOT ID" field is a 5-bit (bit 4 through bit 8 of byte 7) field used to identify the time slot within which the Ground Uplink Message transmission took place. This field is encoded as a 5-bit unsigned binary numeral.

Note: *The Slot for certain ground station messages may be continually shifted for maximum interference tolerance to other users sharing the band. Airborne receivers do not need a priori knowledge of this shifting scheme; this is for ground service providers to coordinate. The actual Slot ID in use for each Uplink Message will always be properly encoded by the ground station.*

2.2.3.2.2.1.8 "TIS-B SITE ID" Field Encoding

The "TIS-B SITE ID" field is a 4-bit (bits 1, through 4 of byte 8) field used to convey the reusable TIS-B Site ID that is also encoded with each TIS-B transmission as shown in Table 2-5 below:

Table 2-5: Encoding of TIS-B SITE ID

Encoding	Meaning
0000	No TIS-B information transmitted from this site
0001	Assigned to ground stations that provide TIS-B information by TIS-B administration authority
through	
1111	

Note: *This field supports TIS-B applications that verify TIS-B transmissions were transmitted from the site located at the Latitude/Longitude encoded in the UAT-Specific Header portion of the Ground Uplink payload. The width of the field was selected based upon analysis of the needs of a potential passive ranging function.*

2.2.3.2.2.1.9 Reserved Bits

Bits 5 through 8 of byte 8 are reserved for future use and will be set to ALL ZEROs.

2.2.3.2.2.2 Ground Uplink Application Data

As illustrated in Figure 2-5, the Application Data is a fixed-length field of 424 bytes. The Application Data consists of *Information Frames*, and always consists of an integral number of bytes. Any remaining unused portion of the field will be filled with all ZEROs.

Each *Information Frame* consists of "**N**" bytes, comprising three fields formatted as described in Table 2-6.

Table 2-6: The Information Frame

Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
1	MSB	**Length**						
2	LSB	**Reserved**			MSB	**Frame Type**		LSB
3 - N	**Frame Data**							

Note: *The Byte numbers in Table 2-6 are relative to the beginning of the current Information Frame.*

2.2.3.2.2.2.1 The Length Subfield Encoding

The **Length** field (bit 1 of byte 1 through bit 1 of byte 2) is a 9-bit field that contains the length of the Frame Data field in bytes. Values range from ZERO (0) through 422 (decimal). The **Length** value is always equal to "**N**-2."

2.2.3.2.2.2.2 The Reserved Subfield Encoding

The **Reserved** field (bits 2 – 4 of byte 2) is a 3-bit field that is reserved for future use, and will be set to ZERO (binary 000) in equipment that complies with these MOPS.

2.2.3.2.2.2.3 The Frame Type Subfield Encoding

The **Frame Type** field (bits 5 – 8 of byte 2) is a 4-bit field that contains the indication for the format of the Frame Data field. The **Frame Types** are defined in Table 2-7.

Table 2-7: Frame Types

Coding (binary) MSB LSB	**Coding** (decimal)	**Frame Data Format**
0000	0	FIS-B APDU
0001	1	Reserved for Developmental Use
0010	2	Reserved for Future Use
through	through	
1110	14	
1111	15	TIS-B/ADS-R Service Status

Note: *Frame Type 1 is intended for developmental use, such as to support on-air flight testing of new Ground Uplink Frame Types, prior to their adoption in future MOPS versions.*

2.2.3.2.2.2.4 The Frame Data Content

Each **Frame Data** format is described in the following paragraphs. The **Frame Data** field is always an integral number of bytes in length.

2.2.3.2.2.2.4.1 FIS-B APDU

When the **Frame Type** is ZERO (binary 0000), the **Frame Data** contains an APDU Header, followed by the APDU Data, as described in §3.6, Appendix D, and Appendix E of RTCA DO-267.

2.2.3.2.2.2.4.2 Other Potential Future Frame Data Content

Fifteen (15) reserved values remain for future use. Examples of possible use include **Frame Types** for the following functions:

- TIS-B Management Information that describes such items as service boundaries and target counts
- TIS-B target information in a compressed format as an alternative to the standard approach that conveys TIS-B target information in an ADS-B Message format
- Frames of differential GPS information
- Frames of addressed (unicast) data

2.2.3.2.3 FEC Parity (Before Interleaving and After De-interleaving)

2.2.3.2.3.1 Code Type

The FEC Parity generation is based on a systematic RS 256-ary code with 8 bit code word symbols. FEC Parity generation for each of the six blocks is per RS (92,72) code.

Note: *This results in 20 bytes (symbols) of parity capable of correcting up to 10 symbol errors per block. The additional use of interleaving for the Ground Uplink Message allows additional robustness against concentrated burst errors.*

The primitive polynomial of the code is as follows:

$$p(x) = x^8 + x^7 + x^2 + x + 1.$$

The generator polynomial is as follows:

$$\prod_{i=120}^{P} (x - \alpha^i).$$

Where P = 139

α is a primitive element of a Galois field of size 256 (i.e., GF(256)).

Note: *See Appendix C for more information on Reed Solomon encoding.*

2.2.3.2.3.2 Generation and Transmission Order of FEC Parity

FEC Parity bytes are ordered most significant to least significant in terms of the polynomial coefficients they represent. The ordering of bits within each byte will be most significant to least significant. FEC Parity bytes will follow the message payload.

Note: *See Appendix C for a message generation and encoding example. Even though the example is for an ADS-B Message, the procedure applies to any Reed Solomon block being encoded/decoded.*

2.2.3.2.4 Interleaved Payload and FEC Parity

Ground Uplink Messages are interleaved and transmitted by the Ground Station, as listed below:

a. Interleaving Procedure: The part of the burst labeled “Interleaved Payload and FEC Parity” in Figure 2-4 consists of 6 interleaved Reed-Solomon blocks. The interleaver is represented by a 6 by 92 matrix, where each entry is a RS 8-bit symbol. Each row comprises a single RS (92,72) block as shown in Table 2-8. In Table 2-8, Block numbers prior to interleaving are represented as “A” through “F.” The information is ordered for transmission column by column, starting at the upper left corner of the matrix.

Table 2-8: Ground Uplink Interleaver Matrix

RS Block	Payload Byte # (From §2.2.3.2)						FEC Parity (Block /Byte #)			
A	1	2	3	…	71	72	A/1	…	A/19	A/20
B	73	74	75	…	143	144	B/1	…	B/19	B/20
C	145	146	147	…	215	216	C/1	…	C/19	C/20
D	217	218	219	…	287	288	D/1	…	D/19	D/20
E	289	290	291	…	359	360	E/1	…	E/19	E/20
F	361	362	363	…	431	432	F/1	…	F/19	F/20

Note: *In Table 2-8, Payload Byte #1 through #72 are the 72 bytes (8 bits each) of payload information carried in the first RS (92,72) block. FEC Parity A/1 through A/20 are the 20 bytes of FEC parity associated with that block (A).*

b. Transmission Order: The bytes are then transmitted in the following order:

1,73,145,217,289,361,2,74,146,218,290,362,3,. . .,C/20,D/20,E/20,F/20.

Note: *On reception these bytes must be de-interleaved so that the RS blocks can be reassembled prior to error correction decoding.*

2.2.4 The ADS-B Message Payload

2.2.4.1 Payload Type

Each transmitted ADS-B Message contains a payload that the receiver first identifies by the "PAYLOAD TYPE CODE" encoded in the first 5 bits of the payload. The Payload Type Code allows the receiver to interpret the contents of the ADS-B Message payload per the definition contained in §2.2.4.2 through §2.2.4.5.8.

2.2.4.2 Payload Elements

For convenience, the ADS-B Message payload is organized into *payload elements*. These elements contain the individual message *fields* (e.g., LATITUDE, ALTITUDE, etc) that correspond to the various report elements issued by an ADS-B Receiving Subsystem to an application system as defined in the ADS-B MASPS, RTCA Document DO-242A. Payload elements and their lengths are shown in Table 2-9.

Table 2-9: ADS-B Payload Elements

Payload Element	Payload Bytes	Applicable DO-242A Reports	Subparagraph References
HEADER (HDR)	4	All	2.2.4.5.1
STATE VECTOR (SV)	13	State Vector	2.2.4.5.2
MODE STATUS (MS)	12	Mode Status	2.2.4.5.4
AUX. STATE VECTOR (AUX SV)	5	State Vector, Air Reference Velocity	2.2.4.5.5
TARGET STATE (TS)	4	Target State	2.2.4.5.6 2.2.4.5.7
TRAJECTORY CHANGE +0 (TC+0)	12	Trajectory Change	2.2.4.5.8
TRAJECTORY CHANGE +1 (TC+1)	12	Trajectory Change	2.2.4.5.8

2.2.4.3 ADS-B Payload Composition by Payload Type Code

Table 2-10 provides the assignment of payload elements to each Payload Type Code.

<u>Table 2-10:</u> Composition of ADS-B Payload

<table>
<tr><th rowspan="2">Payload Type Code</th><th colspan="8">ADS-B Message Payload Byte Number</th></tr>
<tr><th>1 ---- 4</th><th>5 ---- 17</th><th colspan="2">18 --------- 24</th><th>25 ---- 28</th><th>29</th><th>30 --- 33</th><th>34</th></tr>
<tr><td>0 (Note 1)</td><td>HDR</td><td>SV</td><td>Res</td><td colspan="5">Byte 19-34 Not present in Type 0</td></tr>
<tr><td>1</td><td>HDR</td><td>SV</td><td colspan="4">MS</td><td colspan="2">AUX SV</td></tr>
<tr><td>2</td><td>HDR</td><td>SV</td><td colspan="4">Reserved (Note 2)</td><td colspan="2">AUX SV</td></tr>
<tr><td>3</td><td>HDR</td><td>SV</td><td colspan="4">MS</td><td>TS</td><td>Res</td></tr>
<tr><td>4</td><td>HDR</td><td>SV</td><td colspan="4">Reserved for TC+0 (Note 2)</td><td>TS</td><td>Res</td></tr>
<tr><td>5</td><td>HDR</td><td>SV</td><td colspan="4">Reserved for TC+1 (Note 2)</td><td colspan="2">AUX SV</td></tr>
<tr><td>6</td><td>HDR</td><td>SV</td><td colspan="2">Res. (Note 2)</td><td>TS</td><td>Res</td><td colspan="2">AUX SV</td></tr>
<tr><td>7</td><td>HDR</td><td>SV</td><td colspan="6" rowspan="4">Reserved (Note 3)</td></tr>
<tr><td>8</td><td>HDR</td><td>SV</td></tr>
<tr><td>9</td><td>HDR</td><td>SV</td></tr>
<tr><td>10</td><td>HDR</td><td>SV</td></tr>
<tr><td>11 through 29</td><td>HDR</td><td colspan="7">Reserved (Note 2)</td></tr>
<tr><td>30, 31</td><td>HDR</td><td colspan="7">Reserved for Developmental Use (Note 4)</td></tr>
</table>

<u>Notes</u>:

1. *Payload Type 0 is conveyed in the Basic ADS-B Message; byte 18 is reserved for future definition.*

2. *Not defined in this MOPS. Reserved for definition in future versions.*

3. *Payload Types 7 – 10 will allow a degree of backward compatibility with future message definition for receivers operating according to these MOPS.*

4. *Payload Types 30 and 31 are intended for developmental use, such as to support on-air flight testing of new payload types, prior to their adoption in future MOPS versions. These payload types should be ignored by equipment compliant to these MOPS.*

2.2.4.4 Payload Transmission Order

The ADS-B Message payload **shall** be transmitted in byte order with byte #1 first. Within each byte, bits **shall** be transmitted in order with bit #1 transmitted first. Bit-level definition of the payload is provided in §2.2.4.5 through §2.2.4.5.8.

2.2.4.5 Payload Contents

2.2.4.5.1 HEADER Element

Format for the HEADER element is defined in Table 2-11. This encoding **shall** apply to ADS-B Messages with PAYLOAD TYPE CODES of “0” through “31.” Each of the fields shown is defined in §2.2.4.5.1.1 through §2.2.4.5.1.3.6.

Table 2-11: Encoding of HEADER Element into ADS-B Payload

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
1	(MSB)		PAYLOAD TYPE CODE		(LSB)		ADDRESS QUALIFIER	
2	(MSB)A1	A2	A3	. . .				
3					ADDRESS			
4					. . .	A22	A23	A24(LSB)

.

.

2.2.4.5.1.1 “PAYLOAD TYPE CODE” Field Encoding

The “PAYLOAD TYPE CODE” field is a 5-bit (bit 1 of byte 1 through bit 5 of byte 1) field used to identify the payload for decoding by the receiver. Definition of the “PAYLOAD TYPE CODE” field encoding that **shall** be used for all ADS-B Messages is provided in Table 2-10.

2.2.4.5.1.2 “ADDRESS QUALIFIER” Field Encoding

The “ADDRESS QUALIFIER” field is a 3-bit (bit 6 of byte 1 through bit 8 of byte 1) field used to indicate what the 24-bit “ADDRESS” field represents. Definition of the “ADDRESS QUALIFIER” field encoding that **shall** be used for all ADS-B Messages is provided in Table 2-12. The Address Selection Input (ICAO versus Temporary) is used to determine whether to transmit using the ICAO Address or a self-assigned Temporary Address.

If the Address Selection Input is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-64, then the “ADDRESS QUALIFIER” **shall** default to a value of ALL ZEROs.

Table 2-12: “ADDRESS QUALIFIER” Encoding

Address Qualifier (binary)			Address Qualifier (decimal)	Address Type	Reference subparagraph
Bit 6	Bit 7	Bit 8			
0	0	0	0	ADS-B target with ICAO 24-bit address	§2.2.4.5.1.3.1
0	0	1	1	ADS-B target with self-assigned temporary address	§2.2.4.5.1.3.2
0	1	0	2	TIS-B or ADS-R target with ICAO 24-bit address	§2.2.4.5.1.3.3
0	1	1	3	TIS-B target with track file identifier	§2.2.4.5.1.3.4
1	0	0	4	Surface Vehicle	§2.2.4.5.1.3.5
1	0	1	5	Fixed ADS-B Beacon	§2.2.4.5.1.3.6
1	1	0	6	ADS-R target with non-ICAO address	§2.2.4.5.1.3.7
1	1	1	7	(Reserved)	

2.2.4.5.1.3 "ADDRESS" Field Encoding

The "ADDRESS" field is a 24-bit (bit 1 of byte 2 through bit 8 of byte 4) field used in conjunction with the "ADDRESS QUALIFIER" field to identify the participant. The meaning of the "ADDRESS" field depends on the "ADDRESS QUALIFIER" field as described in §2.2.4.5.1.3.1 through §2.2.4.5.1.3.6.

2.2.4.5.1.3.1 ICAO 24-bit Aircraft Address of Transmitting Aircraft

An "ADDRESS QUALIFIER" value of ZERO (binary 000) **shall** indicate that the message is an ADS-B Message from an aircraft, and that the "ADDRESS" field holds the ICAO 24-bit address that has been assigned to that particular aircraft. The ICAO Aircraft Address **shall** be stored (or "latched") in the UAT Transmitting System upon Power Up.

If the Address Selection Input is set to the "ICAO" value, then the ADS-B Transmitting Subsystem **shall** declare a device failure in the event that its own ICAO 24-bit Address (i.e., the Mode-S Address) is invalid, unavailable, or set to all "ZEROs" or all "ONEs."

Note: *The world-wide method for allocating and assigning the 24-bit ICAO aircraft addresses is described in Annex 10 to the Convention on International Civil Aviation, Volume III, Chapter 9. [ICAO Annex 10, Vol. III, Ch. 9].*

2.2.4.5.1.3.2 Self-Assigned Temporary Address of Transmitting Aircraft

An "ADDRESS QUALIFIER" value of ONE (binary 001) **shall** indicate that the message is an ADS-B Message from an aircraft that is not receiving ATC services, and that the "ADDRESS" field holds the transmitting aircraft's self-assigned ownship temporary address. An "ADDRESS QUALIFIER" value of ONE **shall not** be used when the "Receiving ATC Services Flag" (§2.2.4.5.4.13.3) is set to ONE, indicating that the Participant is receiving ATC services.

The self-assigned temporary address **shall** be generated as follows:

Let:	$ADDR_P$	=	the ICAO 24-bit address that has been assigned to the aircraft;
	$ADDR_T$	=	the temporary address that is to be generated;
	M(1)	=	the 12 least significant bits (LSBs) of the ownship "LATITUDE" field (per §2.2.4.5.2.1) the first time the temporary address option is selected;
	M(2)	=	the 12 least significant bits (LSBs) of the ownship "LONGITUDE" field (per §2.2.4.5.2.1) the first time the temporary address option is selected;
	M(3)	=	$4096 \times M(1) + M(2)$; and
	TIME	=	the number of seconds that have elapsed since UTC midnight the first time the temporary address option is selected, represented as a 24-bit number.

Also, let "⊕" denote the modulo 2 bit-by-bit addition (or "exclusive OR") operation.

a. If the transmitting aircraft's ICAO 24-bit address $ADDR_P$ is available, then the temporary address $ADDR_T$ **shall** be the modulo 2, bit-by-bit summation of the permanent address and M(3), that is:

$$ADDR_T = ADDR_P \oplus M(3).$$

b. If the aircraft's 24-bit ICAO address $ADDR_P$ is not available, then time of day **shall** be used as an additional randomizer. In that case, the temporary address $ADDR_T$ **shall** be the modulo 2, bit-by-bit summation of TIME and M(3), that is,

$$ADDR_T = TIME \oplus M(3).$$

Note: *Analysis indicates that the probability of two aircraft in the same operational area having identical $ADDR_T$ values should be well below the observed probability of having duplicate ICAO 24-bit addresses owing to installation errors.*

2.2.4.5.1.3.3 ICAO 24-bit Aircraft Address of TIS-B or ADS-R Target Aircraft

An "ADDRESS QUALIFIER" value of TWO (binary 010) is used to indicate that the message is for a TIS-B or ADS-R target and the "ADDRESS" field holds the ICAO 24-bit address that has been assigned to the target aircraft being described in the message.

Note: *The world-wide scheme for allocating and assigning the 24-bit ICAO aircraft addresses is described in Annex 10 to the Convention on International Civil Aviation, Volume III, Chapter 9. [ICAO Annex 10, Vol. III, Ch. 9]*

2.2.4.5.1.3.4 TIS-B Track File Identifier

An "ADDRESS QUALIFIER" value of THREE (binary 011) is used to indicate that the message is for a TIS-B target and that the "ADDRESS" field holds a TIS-B track file identifier by which the TIS-B data source identifies the target aircraft being described in the message.

Note: *It is beyond the scope of these MOPS to specify the method by which a TIS-B service provider would assign track file identifiers for those TIS-B targets for which the ICAO 24-bit address is unknown.*

2.2.4.5.1.3.5 Surface Vehicle Address

An "ADDRESS QUALIFIER" value of FOUR (binary 100) is used to indicate that the "ADDRESS" field holds the address of a surface vehicle authorized to operate in the airport's surface movement area.

Note: *It is beyond the scope of these MOPS to specify the method by which ADS-B surface vehicle addresses are assigned.*

2.2.4.5.1.3.6 Fixed ADS-B Beacon Address

An "ADDRESS QUALIFIER" value of FIVE (binary 101) is used to indicate that the "ADDRESS" field holds the address assigned to a fixed ADS-B beacon or "parrot."

Note: *It is beyond the scope of these MOPS to specify the method by which ADS-B beacon addresses are assigned.*

2.2.4.5.1.3.7 ADS-R Target with Non-ICAO Address

An "ADDRESS QUALIFIER" value of SIX (binary 110) is used to indicate that the "ADDRESS" field holds the address of an ADS-R target with a non-ICAO address.

2.2.4.5.2 STATE VECTOR Element

Format for the STATE VECTOR element is defined in Table 2-13. This encoding **shall** apply to ADS-B Messages with PAYLOAD TYPE CODES of "0" through "10," when the ADDRESS QUALIFIER value is "0," "1," "4" or "5." Each of the fields shown is defined in §2.2.4.5.2.1 through §2.2.4.5.2.10.

Table 2-13: Format of STATE VECTOR Element

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
.								
5	(MSB)							
6				LATITUDE (WGS-84)				
7							(LSB)	(MSB)
8								
9				LONGITUDE (WGS-84)				
10							(LSB)	Alt Type
11	(MSB)			ALTITUDE				
12				(LSB)	(MSB)	NIC		(LSB)
13	(MSB) A/G STATE (LSB)		Reserved	HORIZONTAL VELOCITY				
14								
15								
16		VERTICAL VELOCITY or A/V SIZE						
17					UTC	UPLINK FEEDBACK		
.								
.								

When more than one position source is provided to the ADS-B Transmitting Subsystem, the transmitter **shall** select a single source to provide horizontal position, horizontal velocity, and their associated quality metrics. Heading used to populate the Track Angle/Heading Field on the surface may be supplied by a different source than that which supplies horizontal position and ground speed.

Notes:

1. *The source selection logic should be designed to prevent the selection from alternating between valid sources. One acceptable way to ensure this is to allow the source selection to switch sources only after an alternate source has consistently exceeded the performance of the currently selected source for several seconds.*

2. *Source selection logic may include criteria specific to the sources available on the aircraft. When selecting among sources with equal Source Integrity Level (SIL) values, the source with the smallest Radius of Containment should be selected. It is anticipated that regulatory guidance will be provided to govern source selection among sources with different non-zero SIL values.*

2.2.4.5.2.1 "LATITUDE" and "LONGITUDE" Field Encoding

a. The "LATITUDE" field is a 23-bit (bit 1 of byte 5 through bit 7 of byte 7) field used to encode the latitude provided to the ADS-B Transmitting Subsystem in WGS-84. The encoding of this field **shall** be as indicated in Table 2-14. Also see Figure 2-6.

b. The "LONGITUDE" field is a 24-bit (bit 8 of byte 7 through bit 7 of byte 10) field used to encode the longitude provided to the ADS-B Transmitting Subsystem in WGS-84. The encoding of this field **shall** be as indicated in Table 2-14. Also see Figure 2-6.

c. The encoding of ALL ZEROs in the "LATITUDE" and "LONGITUDE" and "NIC" (§2.2.4.5.2.4) fields **shall** indicate that Latitude/Longitude information is "unavailable."

Note: *Since the encoding of ALL ZEROs is a valid location on the earth, ADS-B Receiving Subsystems will interpret this as Latitude/Longitude information "unavailable" only if the NIC field is also set to ZERO.*

If either the Latitude Input or the Longitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the LATITUDE, LONGITUDE and NIC fields **shall** default to a value of ALL ZEROs.

Table 2-14: Angular Weighted Binary Encoding of Latitude and Longitude

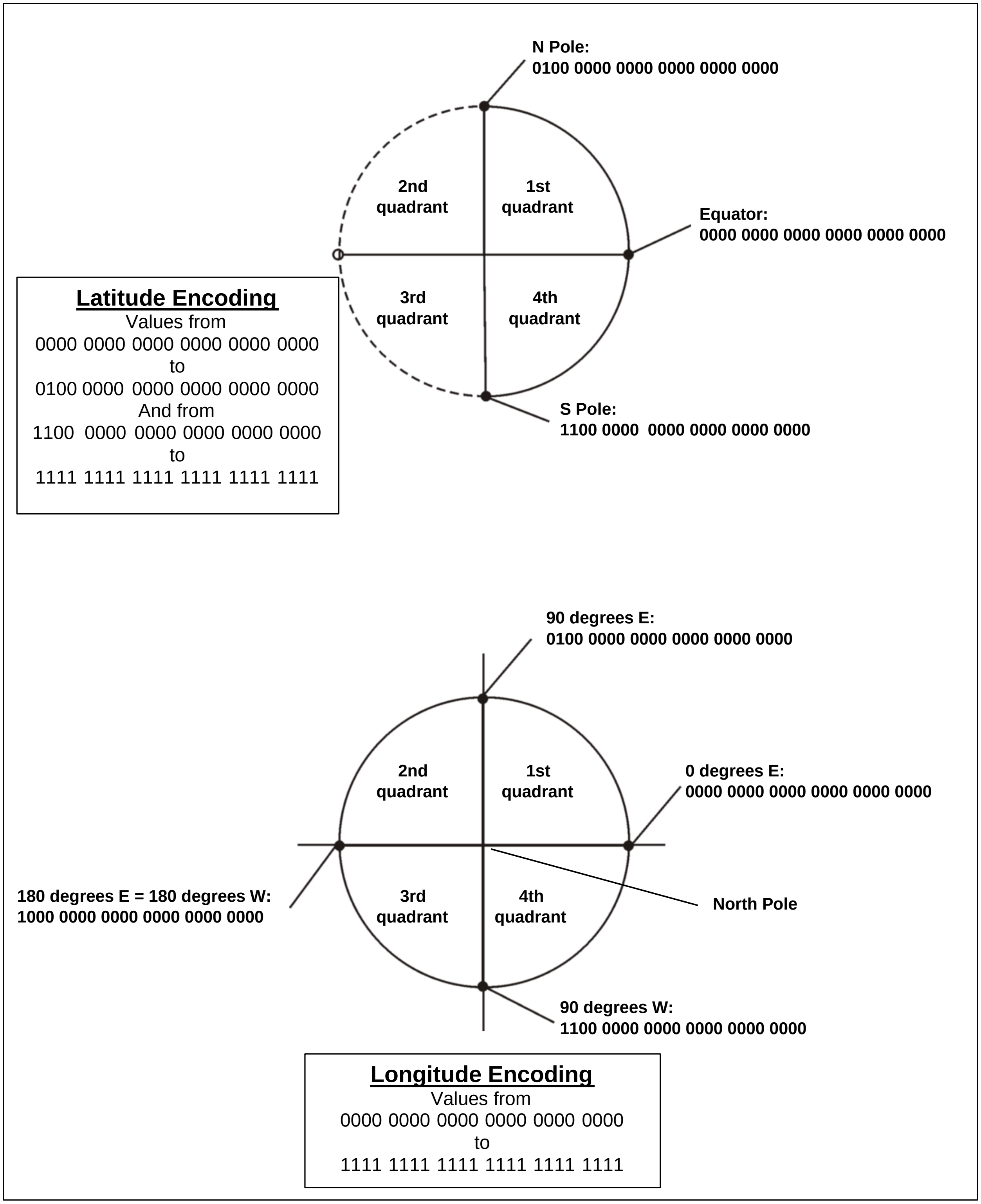
Quadrant	"LATITUDE" or "LONGITUDE" bits	Meaning ($LSB = 360 / 2^{24} = 2.1457672 \times 10^{-5}$ degrees)	
	MSB LSB	**Latitude**	**Longitude**
	0000 0000 0000 0000 0000 0000	ZERO degrees (Equator)	ZERO degrees (Prime Meridian)
1st	0000 0000 0000 0000 0000 0001	*LSB* degrees North	*LSB* degrees East
quadrant	…	…	…
	0011 1111 1111 1111 1111 1111	(90-*LSB*) degrees North	(90-*LSB*) degrees East
	0100 0000 0000 0000 0000 0000	90 degrees (North Pole)	90 degrees East
2nd	0100 0000 0000 0000 0000 0001	<Illegal Values>	(90+*LSB*) degrees East
quadrant	…	<Illegal Values>	…
	0111 1111 1111 1111 1111 1111	<Illegal Value>	(180-*LSB*) degrees East
	1000 0000 0000 0000 0000 0000	<Illegal Value>	180 degrees East or West
3rd	1000 0000 0000 0000 0000 0001	<Illegal Value>	(180-*LSB*) degrees West
quadrant	…	<Illegal Values>	…
	1011 1111 1111 1111 1111 1111	<Illegal Values>	(90+LSB) degrees West
	1100 0000 0000 0000 0000 0000	90 degrees (South Pole)	90 degrees West
4th	1100 0000 0000 0000 0000 0001	(90-*LSB*) degrees South	(90-*LSB*) degrees West
quadrant	…	…	…
	1111 1111 1111 1111 1111 1111	*LSB* degrees South	*LSB* degrees West

Notes:

1. *The most significant bit (MSB) of the angular weighted binary "LATITUDE" is omitted from the transmitted message. This is because all valid Latitudes, other than the Latitude of the North pole (exactly 90 degrees North), have the same value in their 2 most significant bits. The application using the ADS-B reports has the responsibility to differentiate the North and South Poles.*

2. *Raw data used to establish the Latitude or Longitude fields will normally have more resolution (i.e., more bits) than that required by the Latitude or Longitude fields. When converting such data to the Latitude or Longitude subfields, the accuracy of*

the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the Latitude or Longitude field.



<u>Figure 2-6:</u> Angular Weighted Binary Encoding of Latitude and Longitude

2.2.4.5.2.2 "ALTITUDE TYPE" Field Encoding

The "ALTITUDE TYPE" field is a 1-bit (bit 8 of byte 10) field used to identify the source of information in the "ALTITUDE" and "SECONDARY ALTITUDE" fields. The encoding of this field is reflected in Table 2-15.

If the Altitude Type Selection Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "ALTITUDE TYPE" **shall** default to a value of ZERO if Pressure Altitude is available.

Table 2-15: "ALTITUDE TYPE" Encoding

Altitude Type	"ALTITUDE" Field (§2.2.4.5.2.3)	"SECONDARY ALTITUDE" Field (§2.2.4.5.5.1)
0	Pressure Altitude	Geometric Altitude
1	Geometric Altitude	Pressure Altitude

Note: *"Pressure Altitude" refers to "Barometric Pressure Altitude" relative to a standard atmosphere at a standard pressure of 1013.2 millibars (29.92 in Hg) and specifically* ***DOES NOT*** *refer to "Barometric Corrected Altitude."*

A means **shall** be provided to operationally inhibit the broadcast of Pressure Altitude information, making it unavailable for transmission. If an Altitude Type Selection Input is available, it **shall** be used to operationally select the preferred ALTITUDE TYPE that is reported if more than one ALTITUDE TYPE is available. If only one altitude source is available, then the use of that Altitude **shall** be refelected in both the "ALTITUDE TYPE" and "ALTITUDE" fields.

Note: *The means to operationally inhibit the broadcast of pressure altitude information can be used at the request of ATC, or when altitude is determined to be invalid by the pilot. This is similar to the means defined in 14 CFR, §91.217(a).*

If the Altitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then that Altitude **shall** be deemed unavailable for the purposes of encoding the "ALTITUDE TYPE" field.

2.2.4.5.2.3 "ALTITUDE" Field Encoding

The "ALTITUDE" field is a 12-bit (bit 1 of byte 11 through bit 4 of byte 12) field used to encode the altitude of the ADS-B Transmitting Subsystem. The encoding of this field **shall** be as indicated in Table 2-16.

If the Altitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then that Altitude **shall** be deemed unavailable for the purposes of encoding the "ALTITUDE" field.

Table 2-16: "ALTITUDE" Encoding

Coding (binary) MSB LSB	Coding (decimal)	Meaning
0000 0000 0000	0	Altitude information unavailable
0000 0000 0001	1	Altitude = -1000 feet
0000 0000 0010	2	Altitude = -975 feet
…	…	…
0000 0010 1000	40	Altitude = -25 feet
0000 0010 1001	41	Altitude = ZERO feet
0000 0010 1010	42	Altitude = 25 feet
…	…	…
1111 1111 1110	4094	Altitude = 101325 feet
1111 1111 1111	4095	Altitude > 101337.5 feet

Notes:

1. *Raw data used to establish the "ALTITUDE" field will normally have more resolution (i.e., more bits) than that required by the "ALTITUDE" field. When converting such data to the "ALTITUDE" field, the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the "ALTITUDE" field.*

2. *Geometric Altitude is derived from the height above the WGS-84 ellipsoid by the GPS/GNSS navigation receiver.*

2.2.4.5.2.4 "NIC" Field Encoding

The Navigation Integrity Category ("NIC") field is a 4-bit (bits 5 through 8 of byte 12) field used to allow surveillance applications to determine whether the reported geometric position has an acceptable integrity containment region for the intended use. The value of the NIC parameter specifies an integrity containment region. The NIC integrity containment region is described horizontally using the R_C parameter. The encoding of this field **shall** be as indicated in Table 2-17. The value of the NIC parameter **shall** be the highest value in Table 2-17 consistent with the NIC Input with the exception that if the NIC Input is consistent with a value of "9," "10" or "11" and the ADS-B equipment does not support the timing requirements for the Precision condition (§2.2.7.2.2), a NIC value of "8" **shall** be transmitted.

If the NIC Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "NIC" **shall** default to a value of ALL ZEROs.

Table 2-17: "NIC" Encoding

NIC (binary) MSB … LSB	NIC (decimal)	Horizontal Containment Bounds
0000	0	R_C Unknown
0001	1	R_C < 37.04 km (20 NM)
0010	2	R_C < 14.816 km (8 NM)
0011	3	R_C < 7.408 km (4 NM)
0100	4	R_C < 3.704 km (2 NM)
0101	5	R_C < 1852 m (1 NM)
0110	6	R_C < 1111.2 m (0.6 NM)
0111	7	R_C < 370.4 m (0.2 NM)
1000	8	R_C < 185.2 m (0.1 NM)
1001	9	R_C < 75 m
1010	10	R_C < 25 m
1011	11	R_C < 7.5 m
1100	12	(Reserved)
1101	13	(Reserved)
1110	14	(Reserved)
1111	15	R_C < 555.6 m (0.3 NM)

Notes:

1. *The "NIC" field is closely associated with the "SIL" field (defined in §2.2.4.5.4.6).*

2. *Normally, the NIC parameter can be directly determined from the Horizontal Protection Limit (HPL) or Horizontal Integrity Limit (HIL) output of the GPS/GNSS receiver. However, in the case of a non-excluded satellite failure, the containment radius may continue to be output but should not be used. In this situation, the position data has been determined to be invalid, and the NIC and NAC_P (see §2.2.4.5.4.9) parameters must be set to ZERO. For example, air transport category aircraft using the ARINC 743A interface standard, bit 11 of Label 130 would be monitored to detect a non-excluded GPS fault condition.*

2.2.4.5.2.5 "A/G STATE" Field Encoding

The Air/Ground State ("A/G STATE") field is a 2-bit (bits 1 and 2 of byte 13) field that indicates the format used for representing horizontal velocity. The value of this field determines the encoding of the "HORIZONTAL VELOCITY" field. The "A/G STATE" field is composed of two (2) 1-bit fields used as follows:

1. The Vertical Status bit (bit 1 of byte 13) is used to reflect the AIRBORNE or ON-GROUND condition as determined in §2.2.4.5.2.5.1.

2. The Subsonic/Supersonic bit (bit 2 of byte 13) is used to indicate the scale factor for the velocity information. The Subsonic/Supersonic bit (bit 2 of byte 13) **shall** be set to ONE (1) if either the East – West velocity OR the North – South velocity, exceeds 1022 knots. The Subsonic/Supersonic bit (bit 2 of byte 13) **shall** be reset to ZERO (0) if the East - West and the North - South velocities, drop below 1000 knots.

The encoding of "A/G STATE" field **shall** be as indicated in Table 2-18.

Table 2-18: "A/G STATE" Field Encoding

Ownship Conditions	"A/G STATE" Field Encoding			**Resulting "HORIZONTAL VELOCITY" Subfield Formats**	
	MSB	LSB			
	Vertical Status (bit 1 of byte 13)	Subsonic/Supersonic (bit 2 of byte 13)	(decimal)	"North Velocity **or** Ground Speed" Subfield Meaning	"East Velocity **or** Track Angle/Heading" Subfield Meaning
AIRBORNE condition. Subsonic condition.	0	0	0	North Velocity (LSB = 1 kt)	East Velocity (LSB = 1 kt)
AIRBORNE condition. Supersonic condition.	0	1	1	North Velocity (LSB = 4 kts)	East Velocity (LSB = 4 kts)
ON GROUND condition.	1	0	2	Ground Speed (LSB = 1 kt)	Track/Heading
< Reserved >	1	1	3		

2.2.4.5.2.5.1 Determination of Vertical Status

The UAT ADS-B Transmitting Subsystem **shall** determine its Vertical Status (i.e., AIRBORNE or ON-GROUND condition) using the following procedures:

a. If a UAT ADS-B Transmitting Subsystem participant is equipped with a means to determine whether it is airborne or on the surface, then such information **shall** be used to determine the Vertical Status.

   Note: *An "automatic" means of determining Vertical Status could come from a weight-on-wheels or strut switch, etc. Landing gear deployment is not considered a suitable automatic means.*

b. If a UAT ADS-B Transmitting Subsystem participant is not equipped with a means to determine whether it is airborne or on the surface, and that participant's Emitter Category is one of the following, then that participant **shall** set its Vertical Status to "AIRBORNE:"

   - Glider or Sailplane
   - Lighter Than Air
   - Parachutist or Skydiver
   - Ultralight, Hang Glider or Paraglider
   - Unmanned Aerial Vehicle
   - Point Obstacle (includes tethered balloons)
   - Cluster Obstacle
   - Line Obstacle

Notes:

1. *Because of the unique operating capabilities of "Lighter-than-Air" vehicles, e.g., balloons, an operational "Lighter-than-Air" vehicle will always report the AIRBORNE condition unless the ON-GROUND condition is specifically declared in compliance with subparagraph "a." above.*

2. *For the Point, Cluster and Line Obstacles, the Vertical Status reported should be appropriate to the situation. In any case, the Altitude is always present in the transmitted message.*

c. If a UAT ADS-B Transmitting Subsystem participant's Emitter Category is one of the following, then that participant **shall** set its Vertical Status to the "ON-GROUND" condition:

- Surface Vehicle – Emergency Vehicle
- Surface Vehicle – Service Vehicle

d. If a UAT ADS-B Transmitting Subsystem participant is <u>not</u> equipped with a means to determine whether it is airborne or on the surface, and that participant's Emitter Category is "Rotorcraft," then that participant **shall** set its Vertical Status to "AIRBORNE."

Note: *Because of the unique operating capabilities of rotorcraft, i.e., hover, etc., an operational rotorcraft will always report the AIRBORNE condition unless the ON-GROUND condition is specifically declared in compliance with subparagraph "a." above.*

e. If a UAT ADS-B Transmitting Subsystem participant is <u>not</u> equipped with a means to determine whether it is airborne or on the surface, and that participant's Emitter Category is "Light Aircraft," then that participant **shall** set its Vertical Status to "AIRBORNE," unless the participant can alternatively determine that it is on the surface using the following test: If the participant's Ground Speed (GS) is available and is less than an aircraft specific Threshold Level (TL) value, the participant may set its Vertical Status to "ON-GROUND." The Ground Speed Threshold Level chosen for an aircraft type must reliably indicate "ON-GROUND" conditions.

Note: *The appropriate Ground Speed Threshold Level is chosen to provide, except under unusual operating conditions, a reasonable assurance that the participant will not set the AIRBORNE/ON-GROUND condition to "AIRBORNE" while taxiing on the airport surface and will not give false indications of being in the "ON-GROUND" condition while still "AIRBORNE."*

f. If a UAT ADS-B Transmitting Subsystem participant is not equipped with a means to determine whether it is airborne or on the surface, and that Participant's Emitter Category is not one of those listed in tests "b," "c," "d," or "e" above (i.e., the Participant Emitter Category is either Small, Large, High Vortex Large, Heavy, Highly Maneuverable, or Space/Trans-Atmospheric), then the following tests will be performed to determine the Vertical Status:

1. If the UAT ADS-B Transmitting Subsystem participant's Radio Height (RH) parameter is available, and RH < 50 feet, and at least Ground Speed (GS) or Airspeed (AS) is available, and the available GS < 100 knots, or the available AS < 100 knots, then that participant **shall** set its Vertical Status to "ON-GROUND."

   Note: *If all three parameters are available, the Vertical Status may be determined by the logical "AND" of all three parameters.*

2. Otherwise, if Radio Height (RH) is not available, and if the participant's Ground Speed (GS) and Airspeed (AS) are available, and GS < 50 knots and AS < 50 knots, then that participant **shall** set its Vertical Status to "ON-GROUND."

3. Otherwise, the participant **shall** set its Vertical Status to "AIRBORNE."

If any of the inputs used to derive the "ON-GROUND" condition as specified above are "unavailable" for the "Data Lifetime" timeout duration listed in Table 2-64, then the input **shall** no longer be used for the purposes of determining the "ON-GROUND" condition.

2.2.4.5.2.5.2 Validation of Vertical Status

With the exception of "Rotorcraft," when an automatic means of determining Vertical Status indicates the "ON-GROUND," condition, then the following additional tests **shall** be performed to validate the "ON-GROUND" condition:

If one or more of the following parameters is available to the UAT ADS-B Transmitting Subsystem participant:

Ground Speed (GS), or
Airspeed (AS), or
Radio Height (RH) from radio altimeter

And, of the following parameters that are available:

GS > 100 knots, or
AS > 100 knots, or
RH > 50 feet

Then, the participant **shall** set its Vertical Status to the "AIRBORNE" condition.

Otherwise, the participant **shall** set its Vertical Status to the "ON-GROUND" condition.

If any of the inputs used to derive the override of the "ON-GROUND" condition as specified above are "unavailable" for the "Data Lifetime" timeout duration listed in Table 2-64, then the input **shall** no longer be used for the purposes of overriding the "ON-GROUND" condition.

Notes:

1. *The Vertical Status can be used by ADS-B Transmitting Subsystems to select only the TOP antenna when in the ON-GROUND condition. A false indication of the automatic means could therefore impact signal availability. To minimize this possibility, this validation procedure has been established.*

2. *Modern aircraft with integrated avionics suites commonly contain sophisticated algorithms for determining the air/ground state based on multiple aircraft sensors. These algorithms are customized to the airframe and designed to overcome individual sensor failures. These algorithms are an acceptable means to determine the air/ground state and do not require additional validation.*

2.2.4.5.2.6 "HORIZONTAL VELOCITY" Subfields

The "HORIZONTAL VELOCITY" Field is composed of two components:

a. The "North Velocity or Ground Speed" component is represented by an 11-bit subfield from bit 4 of byte 13 through bit 6 of byte 14.

b. The "East Velocity or Track/Heading" component is an 11-bit subfield from bit 7 of byte 14 through bit 1 of byte 16.

Each component can assume multiple formats depending on the "A/G STATE" field. Subparagraphs §2.2.4.5.2.6.1 through §2.2.4.5.2.6.4 describe the encoding for each form of each component.

2.2.4.5.2.6.1 Encoding as "North Velocity" Form

When the "A/G STATE" field is set to "0," or "1," the "North Velocity or Ground Speed" component **shall** assume the "North Velocity" format indicated in Table 2-19.

Table 2-19: "North Velocity" Format

Byte 13					Byte 14					
Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6
N/S Sign	(MSB)				**--North Velocity Magnitude--**					(LSB)

a. The "N/S Sign" subfield (bit 4 of byte 13) **shall** be used to indicate the direction of the North/South velocity vector as shown in Table 2-20.

Table 2-20: "North/South Sign" Encoding

Coding	Meaning
0	NORTH
1	SOUTH

b. The "North Velocity Magnitude" subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) subfield that **shall** be used to report the magnitude of the North/South velocity of the ADS-B Transmitting Subsystem. The Range, Resolution and Not Available encoding of the “North Velocity Magnitude” subfield **shall** be as shown in Table 2-21.

Table 2-21: “North Velocity Magnitude” Encoding

Coding MSB(binary)LSB	**Coding** (decimal)	**Meaning (Subsonic Scale)** (A/G STATE = 0)	**Meaning (Supersonic Scale)** (A/G STATE = 1)
00 0000 0000	0	N/S Velocity not available	N/S Velocity not available
00 0000 0001	1	N/S Velocity is ZERO	N/S Velocity is ZERO
00 0000 0010	2	N/S Velocity = 1 knots	N/S Velocity = 4 knots
00 0000 0011	3	N/S Velocity = 2 knots	N/S Velocity = 8 knots
…	…	…	…
11 1111 1110	1022	N/S Velocity = 1021 knots	N/S Velocity = 4,084 knots
11 1111 1111	1023	N/S Velocity > 1021.5 knots	N/S Velocity > 4,086 knots

Notes:

1. *The encoding represents Positive Magnitude data only. Direction is given completely by the N/S Sign Bit.*

2. *Raw data used to establish the “North Velocity Magnitude” subfield will normally have more resolution (i.e., more bits) than that required by the “North Velocity Magnitude” subfield. When converting such data to the “North Velocity Magnitude subfield,” the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the “North Velocity Magnitude” subfield.*

If the North Velocity Magnitude Input is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-64, then the “North Velocity Magnitude” subfield **shall** default to a value of ALL ZEROs.

2.2.4.5.2.6.2 Encoding as “Ground Speed” Form

When the “A/G STATE” field is set to “2,” the “North Velocity or Ground Speed” component **shall** assume the “Ground Speed” format, if Ground Speed is available, as indicated in Table 2-22.

Table 2-22: “Ground Speed” Format

Byte 13					Byte 14					
Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6
Reserved	(MSB)				**--Ground Speed--**					(LSB)

a. The 1-bit subfield (bit 4 of byte 13) **shall** be “Reserved” and set to ZERO (0).

b. The “Ground Speed” subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) subfield that **shall** be used to report the Ground Speed of the ADS-B Transmitting Subsystem (in knots). The Range, Resolution and Not Available encoding of the “Ground Speed” subfield **shall** be as shown in Table 2-23.

<u>Table 2-23:</u> "Ground Speed" Encoding

Coding $_{MSB}$(binary)$_{LSB}$	**Coding** (decimal)	**Meaning (A/G STATE = 2)**
00 0000 0000	0	Ground Speed information not available
00 0000 0001	1	Ground Speed is ZERO
00 0000 0010	2	Ground Speed = 1 knots
00 0000 0011	3	Ground Speed = 2 knots
…	…	…
11 1111 1110	1022	Ground Speed = 1021 knots
11 1111 1111	1023	Ground Speed > 1021.5 knots

<u>Note:</u> *Raw data used to establish the "Ground Speed" subfield will normally have more resolution (i.e., more bits) than that required by the "Ground Speed" subfield. When converting such data to the "Ground Speed" subfield, the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the "Ground Speed" subfield.*

If the Ground Speed Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "Ground Speed" subfield **shall** default to a value of ALL ZEROs.

2.2.4.5.2.6.3 Encoding as "East Velocity" Form

When the "A/G STATE" field is set to "0" or "1," the "East Velocity or Track Angle/Heading" component **shall** assume the "East Velocity" format indicated in Table 2-24.

<u>Table 2-24:</u> "East Velocity" Format

Byte 14		Byte 15								Byte 16
Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1
E/W Sign	(MSB)				**--East Velocity Magnitude--**					(LSB)

a. The "E/W Sign" subfield (bit 7 of byte 14) **shall** be used to indicate the direction of the East/West velocity vector as shown in Table 2-25.

<u>Table 2-25:</u> "East/West Sign" Encoding

Coding	**Meaning**
0	EAST
1	WEST

b. The "East Velocity Magnitude" subfield is a 10-bit (bit 8 of byte 14 through bit 1 of byte 16) subfield that **shall** be used to report the East/West velocity of the ADS-B Transmitting Subsystem (in knots). The Range, Resolution and Not Available encoding of the "East Velocity Magnitude" subfield **shall** be as shown in Table 2-26.

Table 2-26: "East Velocity Magnitude" Encoding

Coding $_{MSB}$(binary)$_{LSB}$	**Coding** (decimal)	**Meaning (Subsonic Scale) (A/G STATE = 0)**	**Meaning (Supersonic Scale) (A/G STATE = 1)**
00 0000 0000	0	E/W Velocity not available	E/W Velocity not available
00 0000 0001	1	E/W Velocity is ZERO	E/W Velocity is ZERO
00 0000 0010	2	E/W Velocity = 1 knots	E/W Velocity = 4 knots
00 0000 0011	3	E/W Velocity = 2 knots	E/W Velocity = 8 knots
…	…	…	…
11 1111 1110	1022	E/W Velocity = 1021 knots	E/W Velocity = 4,084 knots
11 1111 1111	1023	E/W Velocity > 1021.5 knots	E/W Velocity > 4,086 knots

Notes:

1. *The encoding represents Positive Magnitude data only. Direction is given completely by the E/W Sign Bit.*

2. *Raw data used to establish the "East Velocity Magnitude" subfield will normally have more resolution (i.e., more bits) than that required by the "East Velocity Magnitude" subfield. When converting such data to the "East Velocity Magnitude" subfield, the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the "East Velocity Magnitude" subfield.*

If the East Velocity Magnitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "East Velocity Magnitude" subfield **shall** default to a value of ALL ZEROs.

2.2.4.5.2.6.4 Encoding as "Track Angle/Heading" Form

When the "A/G STATE" field is set to "2" the "East Velocity or Track Angle/Heading" component **shall** assume the "Track Angle/Heading" format indicated in Table 2-27. Heading **shall** be encoded if available; otherwise Track Angle **shall** be encoded, if available.

Table 2-27: "Track Angle/Heading" Format

Byte 14		Byte 15								Byte 16
Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1
TA/H Type		(MSB)				**--Track Angle/Heading--**				(LSB)

a. The Track Angle/Heading Type ("TA/H Type") is a 2-bit subfield (bit 7 and 8 of byte 14) that **shall** be used to distinguish Track Angle from Heading as shown in Table 2-28.

Table 2-28: "Track Angle/Heading Type" Encoding

Coding	**Meaning**
00	Data Not Available
01	True Track Angle
10	Magnetic Heading
11	True Heading

b. The "Track Angle/Heading" subfield is a 9-bit (bit 1 of byte 15 through bit 1 of byte 16) subfield that **shall** be used to report the Track Angle or Heading of the ADS-B Transmitting Subsystem as shown in Table 2-29.

Table 2-29: "Track Angle/Heading" Encoding

Coding MSB(binary)LSB	**Coding** (decimal)	**Meaning**
0 0000 0000	0	Track Angle/Heading is ZERO
0 0000 0001	1	Track Angle/Heading = 0.703125 degrees
0 0000 0010	2	Track Angle/Heading = 1.406250 degrees
0 0000 0011	3	Track Angle/Heading = 2.109375 degrees
…	…	…
1 1111 1110	510	Track Angle/Heading = 358.593750 degrees
1 1111 1111	511	Track Angle/Heading = 359.296875 degrees

Note: *Raw data used to establish the "Track Angle/Heading" subfield will normally have more resolution (i.e., more bits) than that required by the "Track Angle/Heading" subfield. When converting such data to the "Track Angle/Heading" subfield, the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the "Track Angle/Heading" subfield.*

If either the Track Angle/Heading Type or the Track Angle/Heading Inputs are "unavailable" for the "Data Lifetime" value listed for these inputs in Table 2-64, then the "Track Angle/Heading Type" and the "Track Angle/Heading" subfields **shall** default to values of ALL ZEROs.

2.2.4.5.2.7 "VERTICAL VELOCITY or A/V SIZE" Field

2.2.4.5.2.7.1 Encoding as "Vertical Velocity" Form

When the ADS-B Transmitting Subsystem is in the AIRBORNE condition, the format for the "VERTICAL VELOCITY or A/V SIZE" field **shall** assume the "Vertical Velocity" form as shown in Table 2-30.

Table 2-30: "Vertical Velocity" Format

Byte 16							Byte 17			
Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4
VV Src	**VV Sign**	(MSB) **--Vertical Rate--** (LSB)								

2.2.4.5.2.7.1.1 "VV Src" Subfield Encoding

The Vertical Velocity Source ("VV Src") subfield is a 1-bit (bit 2 of byte 16) field that **shall** be used to indicate the source of Vertical Rate information as defined in Table 2-31.

Table 2-31: "Vertical Velocity Source" Encoding

Coding	**Meaning**
0	Vertical Rate information from Geometric Source (GNSS or INS)
1	Vertical Rate information from Barometric Source

Note: *Guidance on selecting the appropriate source of the vertical rate is expected to be provided in future installation guidance materials.*

2.2.4.5.2.7.1.2 "VV Sign" Subfield Encoding

The Sign Bit for Vertical Rate ("VV Sign") subfield is a 1-bit (bit 3 of byte 16) field used to indicate the direction of the "Vertical Rate" subfield. Encoding of this subfield **shall** be as indicated in Table 2-32.

Table 2-32: "Sign Bit for Vertical Rate" Encoding

Coding	Meaning
0	UP
1	DOWN

2.2.4.5.2.7.1.3 "Vertical Rate" Subfield Encoding

The "Vertical Rate" subfield is a 9-bit (bit 4 of byte 16 through bit 4 of byte 17) field is used to report the Vertical Rate (in feet/minute) of the ADS-B transmission device.

Range, Resolution, and Not Available encoding of the "Vertical Rate" subfield **shall** be as shown in Table 2-33.

Table 2-33: "Vertical Rate" Encoding

Coding $_{MSB}$(binary)$_{LSB}$	Coding (decimal)	Meaning
0 0000 0000	0	Vertical Rate information is Not Available
0 0000 0001	1	Vertical Rate is ZERO
0 0000 0010	2	Vertical Rate = 64 feet / minute
0 0000 0011	3	Vertical Rate = 128 feet / minute
…	…	…
1 1111 1110	510	Vertical Rate = 32,576 feet / minute
1 1111 1111	511	Vertical Rate > 32,608 feet / minute

Notes:

1. *The encoding shown represents Positive Magnitude data only. Direction is given completely by the VV Sign Subfield.*

2. *Raw data used to establish the "Vertical Rate" subfield will normally have more resolution (i.e., more bits) than that required by the "Vertical Rate" subfield. When converting such data to the "Vertical Rate" subfield, the accuracy of the data is maintained such that it is not worse than ±½ LSB where the LSB is that of the "Vertical Rate" subfield.*

3. *For codes "0" and "1," the VV Sign Subfield is encoded as ZERO.*

If the Vertical Rate Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "Vertical Rate" subfield **shall** default to a value of ALL ZEROs.

2.2.4.5.2.7.2 Encoding as "A/V Size" Form

When the ADS-B Transmitting Subsystem is in the ON-GROUND condition, the "VERTICAL VELOCITY or A/V SIZE" field **shall** assume the "A/V Size" form as shown in Table 2-34. Once the actual Length and Width of the A/V has been determined, each A/V **shall** be assigned the smallest A/V Length and Width Code from Table 2-35 for which the actual length is less than or equal to the upper bound length for that Length/Width Code, and for which the actual width is less than or equal to the upper bound width for that Length/Width Code. The encoding of the "Position Offset Applied" (POA) flag shown in Table 2-36 indicates whether the reported position reflects application of a position offset to normalize the ownship navigation sensor position to the ADS-B reference point.

Table 2-34: "A/V Size" Format

Byte 16							Byte 17			
Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4
A/V Length and Width				**POA**	**GPS Antenna Offset**					

Table 2-35: "Aircraft Length and Width" Encoding

A/V - L/W Code (decimal)	Length Code			Width Code	Upper-Bound Length and Width for Each Length/Width Code	
	Bit 2	Bit 3	Bit 4	Bit 5	Length (meters)	Width (meters)
0	0	0	0	0	No Data or Unknown	
1	0	0	0	1	15	23
2	0	0	1	0	25	28.5
3				1		34
4	0	1	0	0	35	33
5				1		38
6	0	1	1	0	45	39.5
7				1		45
8	1	0	0	0	55	45
9				1		52
10	1	0	1	0	65	59.5
11				1		67
12	1	1	0	0	75	72.5
13				1		80
14	1	1	1	0	85	80
15				1		90

Note: *If the aircraft or vehicle is longer than 85 meters, or wider than 90 meters, use Length / Width Code 15.*

Table 2-36: "Position Offset Applied" Encoding

Coding	Meaning
0	Position Offset Not Applied
1	Position Offset Applied (POA)

The “GPS Antenna Offset” field is a 6-bit field used to alternately define the lateral and longitudinal offset of the GPS antenna from the wingtip and nose of the aircraft respectively.

Bit 7 of byte 16 is the “Axis” subfield which **shall** be encoded as ZERO (0) to indicate that the remaining bits of the GPS Antenna Offset field represent the upper bound of the GPS antenna offset along the lateral (pitch) axis, and encoded as ONE (1) to indicate that the remaining bits of the GPS Antenna Offset field represent the upper bound of the GPS antenna offset along the longitudinal (roll) axis aft from aircraft nose.

When in the ON GROUND condition, the UAT Transmitting Subsystem **shall** alternate the transmission of the lateral and longitudinal offsets each second.

a. Lateral Axis GPS Antenna Offset:

Bit 8 of Byte 16 through Bit 1 of Byte 17 **shall** be used to encode the lateral distance of the GPS Antenna from the longitudinal axis (Roll) axis of the aircraft. Encoding **shall** be established in accordance with Table 2.2.4.5.2.7.2A.

Bits 2 through 4 of Byte 17 are reserved in the lateral encoding case and **shall** be set to ALL ZEROs (0).

Table 2.2.4.5.2.7.2A: Lateral Axis GPS Antenna Offset Encoding

Byte 16/Byte 17			**Upper Bound of the GPS Antenna Offset Along Lateral (Pitch) Axis Left or Right of Longitudinal (Roll) Axis**	
Bit 7	**Bit 8**	**Bit 1**		
0 = left 1 = right	**Encoding**			
	Bit 1	**Bit 0**	**Direction**	**(meters)**
0	0	0	**LEFT**	**NO DATA**
	0	1		2
	1	0		4
	1	1		6
1	0	0	**RIGHT**	0
	0	1		2
	1	0		4
	1	1		6

Notes:

1. *Left means toward the left wing tip moving from the longitudinal center line of the aircraft.*
2. *Right means toward the right wing tip moving from the longitudinal center line of the aircraft.*
3. *Maximum distance left or right of aircraft longitudinal (roll) axis is 6 meters or 19.685 feet.*

b. Longitudinal Axis GPS Antenna Offset:

Bit 8 of byte 16 through Bit 4 of Byte 17 **shall** be used to encode the longitudinal distance of the GPS Antenna from the NOSE of the aircraft. Encoding **shall** be established in accordance with Table 2.2.4.5.2.7.2B.

Table 2.2.4.5.2.7.2B: Longitudinal Axis GPS Antenna Offset Encoding

Byte 16/Byte 17					Upper Bound of the GPS Antenna Offset Along Longitudinal (Roll) Axis Aft From Aircraft Nose
Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	
Encoding					
Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	(meters)
0	0	0	0	0	NO DATA
0	0	0	0	1	2
0	0	0	1	0	4
0	0	0	1	1	6
0	0	1	0	0	8
*	*	*	*	*	***
*	*	*	*	*	***
*	*	*	*	*	***
1	1	1	1	1	62

Note: *Maximum distance aft from aircraft nose is 62 meters or 203.412 feet.*

2.2.4.5.2.8 "UTC" Field Encoding

The "UTC" field is a 1-bit field (bit 5 of byte 17) that indicates whether the ADS-B Transmitting Subsystem is in the "UTC Coupled" condition or the "Non-UTC Coupled" condition (§2.2.5). The encoding of this field **shall** be as indicated in Table 2-37.

If the UTC 1-PPS Timing Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "UTC" field **shall** default to a value of ZERO.

Table 2-37: "UTC" Encoding

Coding	Meaning
0	Non UTC Coupled Condition
1	UTC Coupled Condition

2.2.4.5.2.9 Uplink Feedback Encoding

The "Uplink Feedback" field is a 3-bit field (bits 6 through 8 of byte 17) that **shall** be transmitted whenever the "ADDRESS QUALIFIER" field is set to "0," "1," "4" or "5." This field reports on the number of successful Ground Uplink Messages that were successfully received on a particular Data Channel (see below) in the previous 32 seconds. The identity of the Data Channel to be reported on in any given second and the method for determining the success rate **shall** be based on the prescribed "time slot rotation" as follows:

> The ground stations use the 32 uplink slots in the Ground Segment (see §1.3.2) on a rotating basis. A rotating set of time slots is called a Data Channel. A ground station that is assigned Data Channel "N" will transmit in time slot "N" in UTC second 0, time slot "N+1" in second 1 and so on. After reaching time slot 32, it will "wrap around" and resume its rotation in time slot "1" in the following second. During any second in which Data Channel "N" is scheduled to be transmitted in time slot "1" the "Uplink Feedback" field contains information on the recent performance of Data Channel "N," so that the relationship between the UTC second (T) and the Data Channel (N) being reported on is given by the following:

$$(T+N) \bmod 32 = 1$$

In UTC second T, the UAT reports the Code for $Score\ (T)$, which can be defined as follows:

$$Score\ (T) = \sum_{k=1}^{32} S(T - 33 + k, k)$$

The function S(,) is defined as:

$S(t,s) = 1$ if there was a successful Uplink decode in Time Slot=s in UTC second t

and

$S(t,s) = 0$ if there wasn't a successful Uplink decode in Time Slot=s in UTC second t

For example, in UTC second 3217 the Data Channel being reported on is #16 and the definition of the Score value is

$$Score\ (3217) = \sum_{k=1}^{32} S(3184 + k, k)$$

Note: *This procedure obviates the need to use extra bits to identify explicitly the Data Channel to which the feedback pertains. It also ensures that each participant will report on each of the 32 possible Data Channels once each 32 seconds --- providing timely feedback.*

The format of this field **shall** be as shown in Table 2-37A.

Table 2-37A: "Uplink Feedback" Encoding

Feedback Code	Score
111	32
110	31
101	29 to 30
100	26 to 28
011	22 to 25
010	14 to 21
001	1 to 13
000	0

Note: *The **Score** is the number of successful Ground Uplink Messages received on a particular Data Channel out of a possible 32.*

Transmit-only Equipage Classes (B0 through B3) **shall** set this field to ALL ZEROs.

2.2.4.5.2.10 Reserved Byte 18 of Payload Type Zero

Byte 18 of the ADS-B Message Payload definition in Table 2-10, when the Payload Type is ZERO (0) is reserved for future use, and **shall** be set to ALL ZEROs.

2.2.4.5.3 STATE VECTOR Element (For TIS-B)

Format for the STATE VECTOR element used for a TIS-B is defined in Table 2-38. This encoding applies to ADS-B Messages with PAYLOAD TYPE CODES of “0” through “10” <u>only</u> when a TIS-B target is being reported (ADDRESS QUALIFIER value is “2” or “3”). Each of the fields shown is defined in §2.2.4.5.3.1 and §2.2.4.5.3.2.

<u>Table 2-38:</u> Format of STATE VECTOR Element (For TIS-B)

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
. . .								
5	LATITUDE (WGS-84)							
6								
7								LONGITUDE (WGS-84)
8								
9								
10								Alt Type
11	ALTITUDE							
12					NIC			
13	A/G STATE		Reserved	HORIZONTAL VELOCITY				
14								
15								
16		VERTICAL VELOCITY OR A/V LENGTH/WIDTH CODE						
17					**TIS-B SITE ID**			
. . .								

<u>Note:</u> *Design of the TIS-B Ground Subsystem is in a preliminary phase. The message structure in Table 2-38 may be changed as this design matures.*

2.2.4.5.3.1 “TIS-B SITE ID” Field Encoding

The “TIS-B SITE ID” field is a 4-bit (bits 5 through 8 of byte 17) field with the MSB as bit 5 and the LSB as bit 8. See Table 2-5 for the encoding of this field.

<u>Notes:</u>

1. *The “UTC” field shown in Table 2-13 for the State Vector Element is not provided for TIS-B transmissions. The “UTC Coupled” status of the Ground Station transmitting TIS-B information is available in the UAT Ground Uplink Message (§2.2.3.2.2.1.4).*

2. *The application that uses TIS-B reports is assumed to make appropriate checks for a TIS-B Site ID of value ZERO. If the Address Qualifier shown in Table 2-12 indicates that this is a TIS-B Message, and the TIS-B SITE ID indicates a value of ZERO, an error condition is indicated.*

2.2.4.5.3.2 Encoding for All Other Fields

The encoding of all other fields in the STATE VECTOR Element for TIS-B shown in Table 2-38 is consistent with that of §2.2.4.5.2.1 through §2.2.4.5.2.7.2.

2.2.4.5.4 MODE STATUS Element

Format for the MODE STATUS element is defined in Table 2-39. This encoding **shall** apply to ADS-B Messages with PAYLOAD TYPE CODES of “1” and “3.” Each of the fields shown is defined in the following subparagraphs.

Table 2-39: Format of MODE STATUS Element

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
⋮								
18	(MSB)	**Emitter Category and Call Sign/Flight Plan ID Characters#1 and #2**						
19				(Base-40 encoding)				(LSB)
20	(MSB)	**Call Sign/Flight Plan ID Characters #3, #4, and #5**						
21				(Base-40 Encoding)				(LSB)
22	(MSB)	**Call Sign/Flight Plan ID Characters #6, #7, and #8**						
23				(Base 40 Encoding)				(LSB)
24	**EMERGENCY/PRIORITY STATUS**			**UAT MOPS VERSION**			**SIL**	
25	(MSB)		**TRANSMIT MSO**			(LSB)	**SDA**	
26	**NAC$_P$**				**NAC$_V$**			**NIC$_{BARO}$**
27	**CAPABILITY CODES**			**OPERATIONAL MODES**			**CSID**	**SIL$_{SUPP}$**
28	**Geo Vert Acc**		**SA Flag**	**Reserved**				
29	**Reserved**							
⋮								

Note: *In the above table, where MSB and LSB are not specifically noted, the MSB is the leftmost bit and the LSB is the rightmost bit.*

2.2.4.5.4.1 “EMITTER CATEGORY” Field

The “EMITTER CATEGORY” field is encoded as a radix 40 value in the range of 0-39. The “EMITTER CATEGORY” field **shall** be encoded as shown in Table 2-40.

Table 2-40: "EMITTER CATEGORY" Encoding

Base-40 Digit (decimal)	Meaning	Base-40 Digit (decimal)	Meaning
0	No aircraft type information	20	Cluster Obstacle
1	Light (ICAO) < 15500 lbs	21	Line Obstacle
2	Small - 15500 to 75000 lbs	22	(reserved)
3	Large - 75000 to 300000 lbs	23	(reserved)
4	High Vortex Large (e.g., aircraft such as B757)	24	(reserved)
5	Heavy (ICAO) - > 300000 lbs	25	(reserved)
6	Highly Maneuverable > 5G acceleration and high speed	26	(reserved)
7	Rotorcraft	27	(reserved)
8	(Unassigned)	28	(reserved)
9	Glider/sailplane	29	(reserved)
10	Lighter than air	30	(reserved)
11	Parachutist/sky diver	31	(reserved)
12	Ultra light/hang glider/paraglider	32	(reserved)
13	(Unassigned)	33	(reserved)
14	Unmanned aerial vehicle	34	(reserved)
15	Space/transatmospheric vehicle	35	(reserved)
16	(Unassigned)	36	(reserved)
17	Surface vehicle — emergency vehicle	37	(reserved)
18	Surface vehicle — service vehicle	38	(reserved)
19	Point Obstacle (includes tethered balloons)	39	(reserved)

2.2.4.5.4.2 "CALL SIGN/FLIGHT PLAN ID" Field

The "CALL SIGN/FLIGHT PLAN ID" field consists of eight characters. Each character of the "CALL SIGN/FLIGHT PLAN ID" field **shall** be encoded as Base-40 code values as shown in Table 2-41. The left-most character of the "CALL SIGN/FLIGHT PLAN ID" field (as depicted on a cockpit display unit) corresponds to Character #1; the right-most corresponds to Character #8.

The CSID field (see §2.2.4.5.4.14) identifies which type of data is contained in the "CALL SIGN/FLIGHT PLAN ID" field.

When representing the Call Sign, if the Call Sign input is not available, then all eight characters of the "CALL SIGN" Field **shall** be set to the Base-40 digit code 37.

Note 1: *A Call Sign of less than 8 characters should be padded with spaces in the right-most (trailing) positions. The first character should not be a space.*

Table 2-41: "Call Sign" Character Encoding

Base-40 Digit (decimal)	Character		Base-40 Digit (decimal)	Character
0	0		20	K
1	1		21	L
2	2		22	M
3	3		23	N
4	4		24	O
5	5		25	P
6	6		26	Q
7	7		27	R
8	8		28	S
9	9		29	T
10	A		30	U
11	B		31	V
12	C		32	W
13	D		33	X
14	E		34	Y
15	F		35	Z
16	G		36	SPACE
17	H		37	Not Available
18	I		38	(reserved)
19	J		39	(reserved)

When representing a Flight Plan ID, characters 1 through 4 of the Flight Plan ID **shall** be selected from the Base-40 encoding for the digits 0 through 7. Characters 5 and 6 of the Flight Plan ID **shall** be either the Base-40 digit code 37, or a digit from the range 0 through 7, as appropriate for the intended application. Characters 7 and 8 of the Flight Plan ID **shall** be set to the Base-40 digit code 37. If the Flight Plan ID input is not available, then all eight characters of the field **shall** be set to the Base-40 digit code 37.

Note 2: *This encoding of the Flight Plan ID allows for the first 4 characters to convey the 12-bit Mode 3/A code. The Mode 3/A code contains 12 bits labeled* $A_4A_2A_1B_4B_2B_1C_4C_2C_1D_4D_2D_1$. *When representing the Mode 3/A code in the Flight Plan ID field, the Base-40 digits are derived from the sum of the subscripts of the code pulses. Character 1 consists of the sum of code group "A" subscripts, character 2 consists of the sum of code group "B" subscripts, and so forth. The next two characters allow for expansion of the Mode 3/A code to 18 bits, where this may be desirable and allowed. The Mode 3/A code is assigned to the aircraft for transponder identity code reporting to ATC. When a Mode 3/A code is assigned to an aircraft, the same value should be used for the Flight Plan ID.*

Note 3: *The Mode Status Element always contains the Emitter Category, encoded as defined in §2.2.4.5.4.1 and Table 2-40, regardless of whether the Call Sign or the Flight Plan ID is being conveyed.*

2.2.4.5.4.3 Compressed Format Encoding for "EMITTER CATEGORY" and "CALL SIGN /FLIGHT PLAN ID"

Six bytes (byte 18 through byte 23) are used to encode the "EMITTER CATEGORY" and "CALL SIGN/FLIGHT PLAN ID" fields. Each of three byte pairs are encoded as the binary equivalent of the Base-40 numeral generated as:

$$B_2 x 40^2 + B_1 x 40 + B_0$$

Where the values B_2, B_1 and B_0 are given in §2.2.4.5.4.3.1 through §2.2.4.5.4.3.3.

2.2.4.5.4.3.1 Bytes 18 and 19

Bytes 18 and 19 **shall** be encoded such that:

B_2 - Represents the "EMITTER CATEGORY" field (§2.2.4.5.4.1)

B_1 - Represents Character #1 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_0 - Represents Character #2 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

2.2.4.5.4.3.2 Bytes 20 and 21

Bytes 20 and 21 **shall** be encoded such that:

B_2 - Represents Character #3 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_1 - Represents Character #4 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_0 - Represents Character #5 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

2.2.4.5.4.3.3 Bytes 22 and 23

Bytes 22 and 23 **shall** be encoded such that:

B_2 - Represents Character #6 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_1 - Represents Character #7 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_0 - Represents Character #8 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

2.2.4.5.4.4 "EMERGENCY/PRIORITY STATUS" Field Encoding

The "EMERGENCY/PRIORITY STATUS" field is a 3-bit (bits 1 through 3 of byte 24) field. The encoding of this field **shall** be as indicated in Table 2-42.

If the Emergency/Priority Status Selection Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "EMERGENCY/PRIORITY STATUS" field **shall** default to a value of ALL ZEROs.

Table 2-42: "EMERGENCY/PRIORITY STATUS" Encoding

Status Code bits MSB(Binary)LSB	Status Code bits (Decimal)	Meaning
000	0	No emergency/Not reported
001	1	General emergency
010	2	Lifeguard/medical emergency
011	3	Minimum fuel
100	4	No communications
101	5	Unlawful interference
110	6	Downed Aircraft
111	7	(Reserved)

2.2.4.5.4.5 "UAT MOPS VERSION" Field Encoding

The "UAT MOPS VERSION" field is a 3-bit (bits 4 through 6 of byte 24) field. The encoding of this field **shall** be internally hard coded to ONE (binary 001) by all ADS-B Transmitting Subsystems for equipment complying with this version of these MOPS.

Table 2-43: UAT MOPS Version Number

UAT MOPS VN bits MSB(Binary)LSB	UAT MOPS Version # (Decimal)	Meaning
000	0	Reserved
001	1	Conformant to RTCA DO-282A
010	2	Conformant to these MOPS (RTCA DO-282B)
011	3	Reserved
100	4	Reserved
101	5	Reserved
110	6	Reserved
111	7	Reserved

Notes:

1. *The UAT MOPS Version Number of TWO (binary 010) corresponds to an ADS-B MASPS Version Number of TWO.*

2. *It is assumed that future changes to these UAT MOPS will be backward-compatible with previous versions. Given this, the function of the UAT MOPS Version Number is to support forward compatibility with future revisions of these MOPS. For example, future MOPS Version UAT equipment may safely assume that it may ignore any "reserved" data fields in received messages from the earlier versions of these MOPS.*

Also, future MOPS Version equipment should ignore the content of all reserved fields shown in the original RTCA DO-282 and RTCA DO-282A, until the receiving equipment obtains a participant's MOPS Version Number. Fields which are defined in an earlier version of these MOPS may be relied upon to remain consistent with later MOPS versions.

2.2.4.5.4.6 "SIL" Field Encoding

The Source Integrity Level ("SIL") field is a 2-bit (bits 7 and 8 of byte 24) field used to define the probability of the the reported horizontal position exceeding the radius of containment defined by the NIC, without alerting, assuming no avionics faults. Although the SIL assumes there are no unannunciated faults in the avionics system, the SIL must consider the effects of a faulted Signal-in-Space, if a Signal-in-Space is used by the position source.

The SIL probability can be defined as either "per sample" or "per hour" as defined in the SIL Supplement (SIL_{SUPP}) in §2.2.4.5.4.16.

Notes:

1. *For GNSS position sources the HIL or HPL is provided with a probability of $1x10^{-7}$ per hour, which should be used to set the SIL to 3.*
2. *The GPS defined HPL probability rate of 10^{-7} per hour is based on the GPS constellation fault rate of 10^{-4} per hour and a 10^{-3} probability of missed detection, given that the fault occurs. Different containment radii indicated by the HPL are all defined at the missed detection probability of 10^{-3}.*
3. *Fault detection is an essential consideration in determining the SIL parameter. Fault detection assures, at a specified probability of missed detection, that the error is no greater than a specified limit without an alert.*
4. *For alternate ADS-B position sources to report integrity, they will need to be certified for their fault detection characteristics.*

The encoding of the "SIL" field **shall** be as indicated in Table 2-44. For installations where the SIL value is being dynamically updated, if the "SIL" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "SIL" field **shall** default to a value of ALL ZEROs.

Note: *The SIL and NIC should be set to unknown if the ADS-B position source does not supply an output certified to provide an indication of the integrity of the reported position (e.g., such as HPL from GNSS systems).*

Table 2-44: "SIL" Encoding

SIL (binary)	SIL (decimal)	Probability of Exceeding the NIC Containment Radius (R_C)
00	0	Unknown
01	1	$\leq 1 \times 10^{-3}$ per flight hour or per sample
10	2	$\leq 1 \times 10^{-5}$ per flight hour or per sample
11	3	$\leq 1 \times 10^{-7}$ per flight hour or per sample

Notes:

1. *The RTCA DO-242 definition of SIL has been updated in this version of these MOPS. These updates will be incorporated in §2.1.2.15 of the ADS-B MASPS, RTCA DO-242B.*

2. *Implementers should not arbitrarily set the SIL to ZERO (0) just because SIL is not provided by the position source. Implementers should perform an off-line analysis of the installed position source to determine the appropriate SIL.*

2.2.4.5.4.7 "TRANSMIT MSO" Field Encoding

The "TRANSMIT MSO" field is a 6-bit (bits 1 through 6 of byte 25) field that **shall** be used to encode the 6 LSBs of the Message Start Opportunity (§2.2.6.2.1) determined for this message transmission.

2.2.4.5.4.8 "System Design Assurance" (SDA) Field Encoding

The "System Design Assurance" (SDA) field is a 2-bit (bits 7 and 8 of byte 25) field that **shall** define the failure condition that the ADS-B system is designed to support as defined in Table 2.2.4.5.4.8.

The supported failure condition will indicate the probability of an ADS-B system fault causing false or misleading information to be transmitted. The definitions and probabilities associated with the supported failure effect are defined in AC 25.1309-1A, AC 23-1309-1C, and AC 29-2C. All relevant systems attributes should be considered including software and complex hardware in accordance with RTCA DO-178B (EUROCAE ED-12B) or RTCA DO-254 (EUROCAE ED-80).

The ADS-B system includes the ADS-B transmission equipment, ADS-B processing equipment, position source, and any other equipment that processes the position data transmitted by the ADS-B system.

Table 2.2.4.5.4.8: System Design Assurance (SDA) Field Encoding

SDA Value		Supported Failure Condition [Note 2]	Probability of Undetected Fault causing transmission of False or Misleading Information [Note 3,4]	Software & Hardware Design Assurance Level [Note 1,3]
(decimal)	(binary)			
0	00	Unknown/ No safety effect	$> 1X10^{-3}$ per flight hour or Unknown	N/A
1	01	Minor	$\leq 1X10^{-3}$ per flight hour	D
2	10	Major	$\leq 1X10^{-5}$ per flight hour	C
3	11	Hazardous	$\leq 1X10^{-7}$ per flight hour	B

Notes:

1. *Software Design Assurance per RTCA DO-178B (EUROCAE ED-12B). Airborne Electronic Hardware Design Assurance per RTCA DO-254 (EUROCAE ED-80).*
2. *Supported Failure Classification defined in AC-23.1309-1C, AC-25.1309-1A, and AC 29-2C.*
3. *Because the broadcast position can be used by any other ADS-B equipped aircraft or by ATC, the provisions in AC 23-1309-1C that allow reduction in failure probabilities and design assurance level for aircraft under 6,000 pounds do not apply.*
4. *Includes probability of transmitting false or misleading latitude, longitude, velocity, or associated accuracy and integrity metrics.*

2.2.4.5.4.9 “NAC_P” Field Encoding

The Navigation Accuracy Category for Position (“NAC_P”) field is a 4-bit (bits 1 through 4 of byte 26) field used for applications to determine if the reported State Vector has sufficient position accuracy for the intended use. The encoding of the “NAC_P” field **shall** be as indicated in Table 2-45. The value of the NAC_P parameter **shall** be the highest value in Table 2-45 consistent with the NAC_P Input with the exception that if the NAC_P Input is consistent with a value of “10” or “11” and the ADS-B equipment does not support the timing requirements for the Precision condition (§2.2.7.2.2), then a NAC_P value of “9” **shall** be transmitted.

If the “NAC_P” field is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-64, then the “NAC_P” field **shall** default to a value of ALL ZEROs.

Table 2-45: “NAC_P” Encoding

NAC_P (binary) MSB LSB	NAC_P (decimal)	95% Horizontal Accuracy Bound (EPU)	Comment	Notes
0000	0	EPU ≥ 18.52 km (10 NM)	Unknown accuracy	
0001	1	EPU < 18.52 km (10 NM)	RNP-10 accuracy	1
0010	2	EPU < 7.408 km (4 NM)	RNP-4 accuracy	1
0011	3	EPU < 3.704 km (2 NM)	RNP-2 accuracy	1
0100	4	EPU < 1852 m (1NM)	RNP-1 accuracy	1
0101	5	EPU < 926 m (0.5 NM)	RNP-0.5 accuracy	1
0110	6	EPU < 555.6 m (0.3 NM)	RNP-0.3 accuracy	1
0111	7	EPU < 185.2 m (0.1 NM)	RNP-0.1 accuracy	1
1000	8	EPU < 92.6 m (0.05 NM)	e.g., GPS (with SA)	
1001	9	EPU < 30 m	e.g., GPS (SA off)	2
1010	10	EPU < 10 m	e.g., WAAS	2
1011	11	EPU < 3 m	e.g., LAAS	2
1100	12	(Reserved)		
1101	13	(Reserved)		
1110	14	(Reserved)		
1111	15	(Reserved)		

Notes:

1. *RNP accuracy includes error sources other than sensor error, whereas horizontal error for NAC_P only refers to horizontal position error uncertainty.*

2. *The Estimated Position Uncertainty (EPU) used in is a 95% accuracy bound on horizontal position. EPU is defined as the radius of a circle, centered on the reported position, such that the probability of the actual position being outside the circle is 0.05. When reported by a GPS or GNSS system, EPU is commonly called HFOM (Horizontal Figure of Merit).*

3. *A non-excluded satellite failure requires that the NAC_P parameter be set to ZERO (binary 0000) along with the NIC parameter to indicate that the position cannot be confirmed to be valid (see §2.2.4.5.2.4).*

2.2.4.5.4.10 “NAC_V” Field Encoding

The Navigation Accuracy Category for Velocity (“NAC_V”) field is a 3-bit (bits 5 through 7 of byte 26) field used for applications to determine if the reported State Vector has sufficient velocity accuracy for the intended use. The “NAC_V” field reflects the least accurate velocity component being transmitted. The “NAC_V” field **shall** be encoded as indicated in Table 2-46.

Appendix Q describes the manner in which GNSS position sources, which do not output velocity accuracy, can be characterized so that a velocity accuracy value associated with the position source can be input into ADS-B equipment as part of the installation process.

If the “NAC_V” field is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-64, then the “NAC_V” field **shall** default to a value of ALL ZEROs.

Table 2-46: “NAC_V” Encoding.

NAC_V (binary) MSB LSB	**NAC_V** (decimal)	**Horizontal Velocity Error (95%)**	**Vertical Geometric Velocity Error (95%)**
000	0	Unknown or ≥ 10 m/s	Unknown or ≥ 50 feet (15.24 m) per second
001	1	< 10 m/s	< 50 feet (15.24 m) per second
010	2	< 3 m/s	< 15 feet (4.57 m) per second
011	3	< 1 m/s	< 5 feet (1.52 m) per second
100	4	< 0.3 m/s	< 1.5 feet (0.46 m) per second
101	5	(Reserved)	(Reserved)
110	6	(Reserved)	(Reserved)
111	7	(Reserved)	(Reserved)

Note: *Appendix Q contains information on how GNSS position sources which do not output a velocity accuracy can be certified to provide a NAC_V of 1 or 2 so that the appropriate value of NAC_V can be provided to the UAT equipment as an installation parameter. Additionally, Appendix Q discusses the conservatism of GNSS velocity accuracy as characterized by this certification process compared to the expected GNSS velocity accuracy during stable flight--the latter accuracy should be expected to be better than 1 meter/second.*

2.2.4.5.4.11 “NIC_{BARO}” Field Encoding

The Barometric Altitude Integrity Code (“NIC_{BARO}”) field is a 1-bit (bit 8 of byte 26) field that indicates whether or not the barometric pressure altitude provided in the State Vector element of the payload has been cross checked against another source of pressure altitude. The “NIC_{BARO}” field **shall** be encoded as indicated in Table 2-47.

If the “NIC_{BARO}” field is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-64, then the “NIC_{BARO}” field **shall** default to a value of ZERO.

Table 2-47: “NIC_{BARO}” Encoding

Coding	**Meaning**
0	Barometric Pressure Altitude has NOT been cross checked
1	Barometric Pressure Altitude has been cross checked

2.2.4.5.4.12 "CAPABILITY CODES" Field Encoding

The "CAPABILITY CODES" field is a 2-bit (bits 1 – 3 of byte 27) field used to indicate the capability of a participant to support engagement in various operations. The "CAPABILITY CODES" field **shall** be encoded as indicated in Table 2-48.

Note: *The Target State (TS) Report Capability flag, the TC Report capability level and the ARV Report Capability flag can be derived from the UAT transmissions of A1, A2 and A3 system participants. Reference RTCA DO-242A, Table 3.4(d) and 3.4(e).*

Table 2-48: "CAPABILITY CODES" Encoding

Byte #	Bit #	Encoding
Byte 27	Bit 1	UAT IN = Aircraft has UAT Receive Capability. 0 = NO 1 = YES
	Bit 2	1090ES IN = Aircraft has 1090ES Receive Capability 0 = NO 1 = YES
	Bit 3	TCAS/ACAS Operational. 0 = NO 1 = YES

2.2.4.5.4.12.1 "UAT IN Capability" Subfield Encoding

The "UAT IN Capability" field **shall** be set to ONE (1) if the transmitting aircraft has the capability to receive ADS-B UAT Messages. Otherwise, this field **shall** be set to ZERO (0).

If the "UAT IN Capability" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "UAT IN Capability" field **shall** default to a value of ZERO (0).

Note: *If the aircraft is fitted with ADS-B UAT receive equipment but such equipment is not functional, then the encoding should be set to ZERO (0), e.g., the same as if the aircraft were NOT fitted with the receive capability.*

2.2.4.5.4.12.2 "1090ES IN Capability" Subfield Encoding

The "1090ES IN Capability" subfield denotes whether the aircraft is equipped with the capability to receive ADS-B 1090 MHz Extended Squitter (1090ES) Messages. The "1090ES IN Capability" subfield **shall** be set to ONE (1) if the aircraft has the capability to receive 1090ES ADS-B Messages. Otherwise, this field **shall** be set to ZERO (0).

If the "1090ES IN Capability" subfield is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "1090ES IN Capability" subfield **shall** default to a value of ZERO (0).

Note: *If the aircraft is fitted with ADS-B 1090ES receive equipment but such equipment is not functional, then the encoding should be set to ZERO (0), e.g., the same as if the aircraft were NOT fitted with the receive capability.*

2.2.4.5.4.12.3 "TCAS/ACAS Operational" Subfield Encoding

The Capability Code for "TCAS/ACAS Operational" (byte 27, bit 3) is used to indicate whether the TCAS/ACAS System is Operational, or NOT Operational.

a. The ADS-B Transmitting Subsystem **shall** accept information from an appropriate interface that indicates whether or not the TCAS/ACAS System is Operational.

b. The ADS-B Transmitting Subsystem **shall** set the TCAS/ACAS Operational bit to ONE (1) if the TCAS/ACAS System is Operational.

c. The ADS-B Transmitting Subsystem shall set the TCAS/ACAS Operational bit to ZERO (0) if the TCAS/ACAS System is NOT Operational.

Note: *As a reference point, RTCA DO-181D Mode-S Transponders consider that the TCAS System is operational when "MB" bit 16 of Register 10_{16} is set to "ONE" (1). This occurs when the transponder / TCAS interface is operational and the transponder is receiving TCAS RI=2, 3 or 4. (Refer to RTCA DO-181D [EUROCAE ED-73C], Appendix B, Table B-3-16.*

d. If the input for the "TCAS/ACAS Operational" flag is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "TCAS/ACAS Installed and Operational" flag **shall** default to a value of ZERO (0).

2.2.4.5.4.13 "OPERATIONAL MODES" Field Encoding

The "OPERATIONAL MODES" field is a 3-bit (bits 3 through 5 of byte 27) field used to indicate the capability of a participant to support engagement in various operations. The "OPERATIONAL MODES" field **shall** be encoded as indicated in Table 2-49.

Table 2-49: "OPERATIONAL MODES" Encoding

Byte #	Bit #	Encoding
Byte 27	Bit 4	TCAS/ACAS Resolution Advisory Active Flag. 0 = NO 1 = YES
	Bit 5	IDENT Switch Active Flag. 0 = NOT Active (> 20 seconds since activated by pilot) 1 = Active (<= 20 seconds since activated by pilot)
	Bit 5	"Reserved for Receiving ATC Services" Flag 0 = NOT Receiving ATC Services 1 = Receiving ATC Services

2.2.4.5.4.13.1 "TCAS/ACAS Resolution Advisory" Flag

A transmitting ADS-B participant **shall** set the TCAS/ACAS Resolution Advisory Active Flag (byte 27, bit 4) to ONE (1) in the messages that it transmits to support the MS report so long as a TCAS/ACAS Resolution Advisory is in effect. At all other times, the transmitting ADS-B participant **shall** set the TCAS/ACAS Resolution Advisory Active Flag to ZERO (0).

If the input for the "TCAS/ACAS Resolution Advisory" flag is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "TCAS/ACAS Resolution Advisory" flag **shall** default to a value of ZERO (0).

2.2.4.5.4.13.2 "IDENT Switch Active" Flag

The "IDENT Switch Active" Flag (byte 27, bit 5) is activated by an IDENT switch. Initially, the "IDENT switch active" code is ZERO. Upon activation of the IDENT switch, this flag **shall** be set to ONE in all scheduled ADS-B Messages containing the MODE STATUS element for an interval of 20 seconds ±4 seconds. After the time interval expires, the flag **shall** be set to ZERO.

Note: *This allows an ATC ground station 4-5 reception opportunities to receive the IDENT indication.*

If the input for the "IDENT Switch Active" flag is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-64, then the "IDENT Switch Active" flag **shall** default to a value of ZERO.

2.2.4.5.4.13.3 "Reserved for Receiving ATC Services" Flag

The "Reserved for Receiving ATC Services" flag (byte 27, bit 6) is reserved for future use. In this version of these MOPS, this field **shall** be set to ZERO (0).

Note: *This "Reserved for Receiving ATC Services" flag provides for a future ground ATC system to identify an aircraft that is receiving ATC services, similar to an SSR transponder providing a squawk code of other than "1200," at such time in the future when Mode A Code is no longer used.*

2.2.4.5.4.14 Call Sign Identification (CSID) Flag

The requirements of this section **shall** apply only when the UAT transmitter is configured for the CSID Logic ENABLED state as described in §2.2.4.5.4.15 below.

The Call Sign Identification (CSID) Flag in the Mode Status Element is a one-bit flag (bit 7 of byte 27) which is used to identify the contents of the "CALL SIGN//FLIGHT PLAN ID" field. When the CSID Flag is set to the value ONE (1), then the "CALL SIGN/FLIGHT PLAN ID" field **shall** contain the Call Sign. When the CSID Flag is set to the value ZERO (0), then the "CALL SIGN/FLIGHT PLAN ID" field **shall** contain the Flight Plan ID.

Note: *Performance estimates for air-to-air and air-to-ground acquisition when alternating between the Call Sign and the Flight Plan ID may be found in §K.4.4.*

2.2.4.5.4.15 CSID Logic Configuration Item

The UAT Transmitting Subsystem **shall** provide an installer configuration item that will place the UAT Transmitting Subsystem in one of 2 states:

a. CSID Logic ENABLED: Causes the UAT Transmitting Subsystem to satisfy the requirements of §2.2.4.5.4.14 "Call Sign Identification (CSID) Flag."

b. CSID Logic DISABLED: Causes the UAT Transmitting Subsystem to ignore the requirements of §2.2.4.5.4.14 "Call Sign Identification (CSID) Flag" with Call Sign ALWAYS encoded in the CALL SIGN field and with the CSID field ALWAYS encoded as ONE.

2.2.4.5.4.16 Source Integrity Level (SIL) Supplement (SIL_{SUPP}) Flag Encoding

The "SIL Supplement" (SIL_{SUPP}) Flag in the Mode-Status Element is a one-bit flag (bit 8 of byte 27), that **shall** define whether the reported SIL probability is based on a per hour probability or a per sample probability as defined in Table 2.2.4.5.4.16.

Table 2.2.4.5.4.16: SIL Supplement (SIL_{SUPP}) Flag Encoding

Coding	Meaning
0	Probability of exceeding NIC radius of containment is based on "per hour"
1	Probability of exceeding NIC radius of containment is based on "per sample"

► **Per Hour:** The probability of the reported geometric position laying outside the NIC containment radius in any given hour without an alert or an alert longer than the allowable time-to-alert.

Note: *The probability of exceeding the integrity radius of containment for GNSS position sources are based on a per hour basis, as the NIC will be derived from the GNSS Horizontal Protection Level (HPL) which is based on a probability of $1X10^{-7}$ per hour.*

► **Per Sample:** The probability of a reported geometric position laying outside the NIC containment radius for any given sample.

Note: *The probability of exceeding the integrity radius of containment for IRU, DME/DME and DME/DME/LOC position sources may be based on a per sample basis.*

2.2.4.5.4.17 "Geometric Vertical Accuracy" (GVA) Field Encoding

The Geometric Vertical Accuracy (GVA) field is a 2-bit field (bits 1 and 2 of byte 28) that **shall** be set by using the Vertical Field of Merit (VFOM) (95%) from the GNSS position source used to encode the geometric altitude field per Table 2.2.4.5.17.

Table 2.2.4.5.17: Geometric Vertical Accuracy (GVA) Field Encoding

GVA Encoding (decimal)	**Meaning** (meters)
0	Unknown or > 45 meters
1	≤ 45 meters
2	Reserved
3	Reserved

Note: *For the purposes of these MOPS (RTCA DO-282B) values for 0 and 1 are encoded. Decoding values for 2 and 3 should be treated as < 45 meters until future versions of these MOPS redefine the values.*

2.2.4.5.4.18 "Single Antenna" Flag Encoding

The Single Antenna (SA) Flag is a 1-bit (bit 8 of byte 27) field that **shall** be used to indicate that the ADS-B Transmitting Subsystem is operating with a single antenna.

a. Non-Diversity, i.e., those transmitting subsystems that use only one antenna, **shall** set the Single Antenna subfield to "ONE" (1) at all times.

b. Diversity, i.e., those transmitting functions designed to use two antennas, **shall** set the Single Antenna subfield to ZERO (0) at all times that both antenna channels are functional.

At any time that the diversity configuration cannot guarantee that both antenna channels are functional, then the "Single Antenna" subfield **shall** be set to ONE (1).

Note: *Certain applications may require confirmation that each participant has functioning antenna diversity for providing adequate surveillance coverage.*

2.2.4.5.4.19 Reserved Bits

This Reserved Bits field is a 13-bit (bit 4 of byte 28 through bit 8 of byte 29) field used that may be used in the future to indicate the capability of a participant to support engagement in various operations. This Reserved Bits field is reserved for future use and **shall** be set to ALL ZEROs.

2.2.4.5.5 AUXILIARY STATE VECTOR Element

Format for the AUXILIARY STATE VECTOR element is defined in Table 2-50. This encoding **shall** apply to ADS-B Messages with "PAYLOAD TYPE CODES" of "1," "2," "5," and "6." Each of the fields shown is defined in the following subparagraphs.

Table 2-50: Format of AUXILIARY STATE VECTOR Element

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
⋮								
30	(MSB)			SECONDARY ALTITUDE				
31				(LSB)				
32								
33				Reserved				
34								
⋮								

2.2.4.5.5.1 "SECONDARY ALTITUDE" Field Encoding

The "SECONDARY ALTITUDE" field is a 12-bit (bit 1 of byte 30 through bit 4 of byte 31) field used to encode either the geometric altitude or barometric pressure altitude depending on the setting of the "ALTITUDE TYPE" field (§2.2.4.5.2.2). The altitude encoded in the "SECONDARY ALTITUDE" field is the opposite type to that specified by the "ALTITUDE TYPE" field. The encoding **shall** be consistent with that used for "ALTITUDE" described in Table 2-16.

2.2.4.5.5.2 Reserved Bits

Bit 5 of byte 31 through bit 8 of byte 34 are reserved for future use, and **shall** be set to ALL ZEROs.

Note: *This field is reserved for future definition to contain either Air-Referenced Velocity or perhaps wind vector and temperature.*

2.2.4.5.6 TARGET STATE Element (Payload Type Codes "3" and "4")

Format for the TARGET STATE element is defined in Table 2-51. This encoding **shall** apply to ADS-B Messages with "PAYLOAD TYPE CODES" of "3" and "4." Each of the fields show is defined in the following subparagraphs.

Table 2-51: Format of TARGET STATE Element (Payload Type Codes "3" and "4")

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
30	SAT	(MSB)				Selected Altitude		
31				(LSB)	(MSB)			
32		Barometric Pressure Setting			(LSB)	Status	Sign	(MSB)
33				Selected Heading			(LSB)	ST
34	AP	VNAV	ALT	APP		(Reserved)		

2.2.4.5.6.1 "Selected Altitude Type (SAT)" Field Encoding

The "Selected Altitude Type (SAT)" subfield is a 1-bit (Bit 1 of Byte 30) field that **shall** be used to indicate the source of Selected Altitude data that is being used to encode Bit 2 of Payload Byte 30, through Bit 4 of Payload Byte 34. Encoding of the "Selected Altitude Type" **shall** be in accordance with Table 2-52.

If the source for the SAT field is unavailable, or if the "Data Lifetime" timeout listed for the SAT field in Table 2-64 has expired, then the SAT field **shall** default to a value of ZERO (0).

Table 2-52: "Selected Altitude Type" Field

Coding	Meaning
0	Data being used to encode Bit 2 of Payload Byte 30, through Bit 4 of Payload Byte 34, is derived from the Mode Control Panel / Flight Control Unit (MCP / FCU) or equivalent equipment.
1	Data being used to encode Bit 2 of Payload Byte 30, through Bit 4 of Payload Byte 34, is derived from the Flight Management System (FMS).

Note: *On many airplanes, the ADS-B Transmitting Subsystem does not receive selected altitude data from the FMS and will only transmit Selected Altitude data received from a Mode Control Panel / Flight Control Unit (MCP / FCU). Users of this data are cautioned that the selected altitude value transmitted by the ADS-B Transmitting Subsystem does not necessarily reflect the true intention of the airplane during certain flight modes (e.g., during certain VNAV or Approach modes), and does not necessarily correspond to the target altitude (the next altitude level at which the aircraft will level off).*

2.2.4.5.6.2 "Selected Altitude" Field Encoding

The "Selected Altitude" field (bit 2 of byte 30 through bit 4 of byte 31) **shall** contain the Selected Altitude of the ADS-B Transmitting Subsystem as defined in Table 2-53.

If a source for the Selected Altitude field is unavailable, or if the "Data Lifetime" timeout listed for the Selected Altitude field in Table 2-64 has expired, then the Selected Altitude field **shall** default to a value of ALL ZEROs.

Table 2-53: "Selected Altitude" Format

Coding (Binary)	Coding (Decimal)	Meaning
000 0000 0000	0	**NO Data *or* INVALID Data**
000 0000 0001	1	0 feet
000 0000 0010	2	32 feet
000 0000 0011	3	64 feet
*** **** ****	***	*** **** ****
*** **** ****	***	*** **** ****
*** **** ****	***	*** **** ****
111 1111 1110	2046	65440 feet
111 1111 1111	2047	65472 feet

Notes:

1. When converting raw source data into the Selected Altitude field encoding, the accuracy of the data is maintained such that it is not worse than ±16 ft (±1/2 LSB).

2. *On many airplanes, the ADS-B Transmitting Subsystem does not receive selected altitude data from the FMS and will only transmit Selected Altitude data received from a Mode Control Panel / Flight Control Unit (MCP / FCU). Users of this data are cautioned that the selected altitude value transmitted by the ADS-B Transmitting Subsystem does not necessarily reflect the true intention of the airplane during certain flight modes (e.g., during certain VNAV or Approach modes), and does not necessarily correspond to the target altitude (the next altitude level at which the aircraft will level off).*

2.2.4.5.6.3 "Barometric Pressure Setting" (Minus 800 millibars) Field Encoding

a. The "Barometric Pressure Setting (Minus 800 millibars)" subfield is a 9-bit (bit 5 of byte 31 through bit 5 of byte 32) field that **shall** contain Barometric Pressure Setting data that has been adjusted by subtracting 800 millibars from the data received from the Barometric Pressure Setting source.

b. After adjustment by subtracting 800 millibars, the Barometric Pressure Setting **shall** be encoded in accordance with Table 2-54.

c. If a source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the Barometric Pressure Setting **shall** default to a value of ALL ZEROs.

Table 2-54: "Barometric Pressure Setting (Minus 800 millibars) Field Encoding

Coding		Meaning
(Binary)	(Decimal)	
0 0000 0000	0	**NO Data *or* INVALID Data**
0 0000 0001	1	0 millibars
0 0000 0010	2	0.8 millibars
0 0000 0011	3	1.6 millibars
* **** ****	***	*** **** ****
* **** ****	***	*** **** ****
* **** ****	***	*** **** ****
1 1111 1110	510	407.2 millibars
1 1111 1111	511	408.0 millibars

Note: *When converting raw source data into the Barometric Pressure Setting (Minus 800 millibars) field encoding, the accuracy of the data is maintained such that it is not worse than ±0.4 millibars (±1/2 LSB).*

2.2.4.5.6.4 "Selected Heading" Field Encoding

The Selected Heading field (bit 6 of byte 32 through bit 7 of byte 33) contains the Selected Heading of the ADS-B Transmitting Subsystem.

The Selected Heading Status (bit 6 of byte 32) **shall** be set to ONE (1) if the contents of the Selected Heading sign and magnitude subfields are VALID, or set to ZERO (0) otherwise.

The Selected Heading Sign (bit 7 of byte 32) **shall** be set to ZERO (0) if the Selected Heading is a positive angle, or to ONE (1) if the Selected Heading is a negative angle.

The magnitude of the Selected Heading subfield (bit 8 of byte 32 through bit 7 of byte 33) **shall** be encoded as defined in Table 2-55.

If a source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the entire Selected Heading field **shall** default to a value of ALL ZEROs.

Table 2-55: "Selected Heading" Magnitude Subfield Encoding

Coding MSB(binary)LSB	Coding (decimal)	Meaning when Status = ONE (Valid)
0000 0000	0	0.000 degrees
0000 0001	1	0.703 degrees (180/256)
0000 0010	2	1.406 degrees (2*180/256)
…	…	…
1111 1111	255	179.3 degrees (255*180/256)

Notes:

1. *When converting raw source data into the Selected Altitude field encoding, the accuracy of the data is maintained such that it is not worse than ±(180/512) degrees (±1/2 LSB).*

2. *On many airplanes, the ADS-B Transmitting Subsystem receives Selected Heading from a Mode Control Panel / Flight Control Unit (MCP / FCU). Users of this data are cautioned that the Selected Heading value transmitted by the ADS-B Transmitting Subsystem does not necessarily reflect the true intention of the airplane during certain flight modes (e.g., during LNAV mode).*

2.2.4.5.6.5 "Status of MCP/FCU Mode Bits" (ST) Field Encoding

The "Status of MCP/FCU Mode Bits (ST)" field (bit 8 of byte 33) **shall** be set to ONE (1) when any of the "Mode:" fields defined in §2.2.4.5.6.6 through §2.2.4.5.6.9 are valid, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the ST field **shall** default to a value of ZERO (0).

2.2.4.5.6.6 "Mode Indicators: Autopilot Engaged" (AP) Field Encoding

The "Mode Indicators: Autopilot Engaged (AP)" field (bit 1 of byte 34) **shall** be set to ONE (1) when the MCP/FCU source indicates that the Autopilot function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the AP field **shall** default to a value of ZERO (0).

2.2.4.5.6.7 "Mode Indicators: VNAV Mode Engaged" (VNAV) Field Encoding

The "Mode Indicators: VNAV Mode Engaged (VNAV)" field (bit 2 of byte 34) **shall** be set to ONE (1) when the MCP/FCU source indicates that the VNAV function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the “Data Lifetime” timeout listed for this field in Table 2-64 has expired, then the VNAV field **shall** default to a value of ZERO (0).

2.2.4.5.6.8 “Mode Indicators: Altitude Hold Mode” (ALT) Field Encoding

The “Mode Indicators: Altitude Hold Mode (ALT)” field (bit 3 of byte 34) **shall** be set to ONE (1) when the MCP/FCU source indicates that the Altitude Hold function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the “Data Lifetime” timeout listed for this field in Table 2-64 has expired, then the ALT field **shall** default to a value of ZERO (0).

2.2.4.5.6.9 “Mode Indicators: Approach Mode” (APP) Field Encoding

The “Mode Indicators: Approach Mode (APP)” field (bit 4 of byte 34) **shall** be set to ONE (1) when the MCP/FCU source indicates that the Approach Mode function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the “Data Lifetime” timeout listed for this field in Table 2-64 has expired, then the APP field **shall** default to a value of ZERO (0).

2.2.4.5.7 TARGET STATE Element (Payload Type Code “6”)

Format for the TARGET STATE element is defined in Table 2-62. This encoding **shall** apply to ADS-B Messages with “PAYLOAD TYPE CODES” of “6.” Each of the fields that are shown are defined in §2.2.4.5.6.1 through §2.2.4.5.6.9 with the exception of the byte offset that is indicated in Table 2-62.

Table 2-62: Format of TARGET STATE Element

Payload Byte #	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
25	SAT	(MSB)				Selected Altitude		
26				(LSB)	(MSB)			
27		Barometric Pressure Setting			(LSB)	Status	Sign	(MSB)
28				Selected Heading			(LSB)	ST
29	AP	VNAV	ALT	APP	(Reserved)			

2.2.4.5.8 TRAJECTORY CHANGE Element

This element contains 96 bits (bytes 18 through 29) that are reserved for future definition. Equipment conforming to these MOPS **shall** insert ALL ZEROs in this element whenever present in a transmitted message. See Appendix L to see how this reserved field could be used to meet the requirements of reporting TCR+0 and TCR+1 in the future.

2.2.5 Procedures for Processing of Time Data

UAT equipment derives its timing for transmitter and receiver functions from GPS/GNSS (or equivalent) time sources. The Time of Applicability of the PVT data is presumed to be within ±5 milliseconds of the Leading Edge of the Time Mark signal to which it applies. Time Mark information is utilized by the UAT equipment in the following ways:

a. Any extrapolation of Position data **shall** comply with the requirements of §2.2.7.2.1 and §2.2.7.2.2.

b. The UAT transmit message timing **shall** comply with the requirements of §2.2.6.2.1 and §2.2.6.2.2.

c. The UAT receiver time processing **shall** comply with the requirements of §2.2.8.3.5.

Notes:

1. *A possible implementation of the GPS/GNSS Time Mark pulse is illustrated in Figure 2-7, adapted from ARINC Characteristic 743A.*

2. *Determination of time source "equivalence" will be made by appropriate Certification Authorities. Useful information concerning recommended accuracy of such a time source may be found in Appendix I.*

2.2.5.1 UTC Coupled Condition

The "UTC Coupled" subfield **shall** be set to ONE, except under the conditions discussed in §2.2.5.2.

Note: *Operation of the UAT system in normal mode presumes GNSS, or equivalent, equipage on system participants to, for example, prevent media access conflict with the UAT ground up-link transmissions. Short term GNSS outages are mitigated by UAT ground infrastructure providing timing information and/or by the ability of UAT avionics to prevent Airborne UAT Transmitting Subsystems from transmitting in the Ground Uplink Segment for a minimum of 20 minutes in the absence of GNSS (§2.2.5.2[d]). In areas without ground up-link transmissions, there is no media access conflict.*

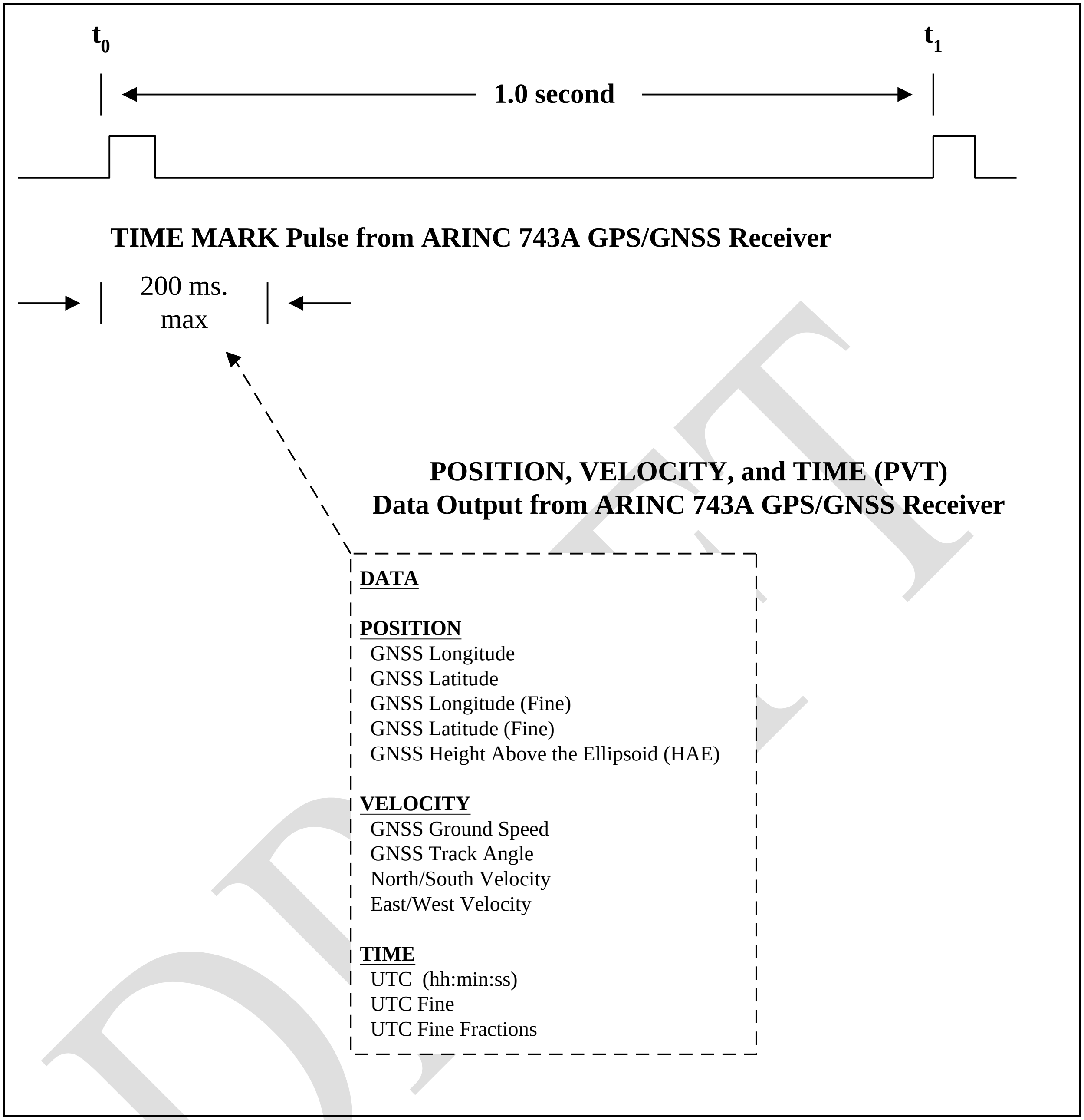


Figure 2-7: GPS/GNSS Time Mark Pulse

2.2.5.2 Non-UTC Coupled Condition

a. This condition **shall** be entered when the ADS-B equipment has not been provided a GPS/GNSS, or equivalent, time mark. This is not the normal condition; it is a degraded mode of operation.

b. Within 2 seconds of entering the Non-UTC Coupled condition, the UAT equipment **shall** set the “UTC Coupled” subfield to ZERO in any transmitted messages.

c. While in the non-UTC Coupled Condition, Class A0, A1, A2 and A3 equipment with operational receivers **shall** be capable of aligning to within ±6 milliseconds of UTC time based upon successful message reception of any Ground Uplink Message with the "UTC Coupled" bit set.

Note: *This assumes that the Ground Uplink Message is referenced to UTC 1-second epoch.*

d. While in the non-UTC Coupled Condition when Ground Uplink Messages cannot be received, the UAT transmitter **shall** estimate — or "coast" — time through the outage period such that the drift rate of estimated time, relative to actual UTC-coupled time, is no greater than 12 milliseconds in 20 minutes.

e. While in the non-UTC Coupled Condition, ADS-B transmissions **shall** continue.

f. The UAT equipment **shall** change state to the UTC coupled condition within 2 seconds of availability of the UTC coupled source.

Notes:

1. *Item "d" above is consistent with an initial drift rate of 10 PPM in the baud clock over the 12 millisecond air-ground segment guard time. Clock drift can be compensated up to the time coasting begins.*

2. *In the non-UTC Coupled Condition, the estimated 1 second UTC epoch signal does NOT indicate the time of validity of Position, Velocity and Time (PVT) information.*

3. *Any installations of Class A equipment involving separated transmitters and receivers must provide a mechanism to fulfill the requirement stated in subparagraph (c) above.*

4. *This reversionary timing exists for the following reasons:**(a)** to support ADS-B Message transmission using an alternate source of position and velocity, <u>if available</u>; **(b)** to support ADS-B Message transmission in absence of position and velocity data in order that any available fields are conveyed (e.g., barometric altitude) and **(c)** to ensure that a signal is provided in the event the ground network can perform an ADS-B-independent localization of the A/V (e.g., multilateration).*

2.2.6 Procedures for ADS-B Message Transmission

2.2.6.1 Scheduling of ADS-B Message Types

2.2.6.1.1 Payload Selection Cycle

A payload selection cycle is defined to ensure the timely transmission of ADS-B Messages of up to four different payload types: Payload Selection (PS)-A, PS-B, PS-C, and PS-D.

Note: *Allowing each of the four Payload Selections to propagate over each of four possible transmit/receive antenna combinations requires a transmission period of at least 16 seconds (i.e., 16 = 4 x 4).*

2.2.6.1.2 ADS-B Payload Type Allocation

One of the ADS-B Payload Type Codes in the range of "0" through "6"specified in Table 2-10 **shall** be assigned to each of the 4 Payload Selections (PS) as shown in Table 2-63.

Table 2-63: Payload Type Code Allocation

Equipment Class	PS-A	PS-B	PS-C	PS-D
A0, A1L, A1S, A1H, B0, B1S, B1	1	0	2	0
A1H, B1 (see Note 2)	3	6	0	6
A2	1	4	4	4
A3	1	4	5	4
B2, B3	1	0	0	0

Notes:

1. *This schedule is to be followed regardless of the unavailability of any payload fields.*

2. *Optional Payload Type Code assignment if the installation can support transmission of Target State information.*

2.2.6.1.2.1 Event-Driven ADS-B Payload Allocation

Immediately following any modification of the Fight Plan ID (see §2.2.4.5.4.2), the Payload Selection sequences specified in §2.2.6.1.2 **shall** be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all Equipment Classes **shall** be Payload Type Codes 1 or 3, as appropriate for the equipment class. During this interval, the Flight Plan ID **shall** be transmitted in every message and the CSID Flag (see §2.2.4.5.4.14) will be set to the value ZERO (0).

Immediately following any modification of the Emergency/Priority Status Selection Input (see §2.2.4.5.4.4), the Payload Selection sequences specified in §2.2.6.1.2 **shall** be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all Equipment Classes **shall** be Payload Type Code 1 or 3, as appropriate for the equipment class.

After the transmission of 6 Event-Driven Messages is completed, the transmission sequence specified in §2.2.6.1.2 **shall** be resumed unless one or more triggering events occurred during the 6 seconds. In that case, the transmission of only Payload Type 1 or 3, as appropriate for the equipment class, **shall** continue until no triggering event has occurred within the most recent 6 seconds.

Note: *The revised sequence provides for the transmission of a Mode Status Element containing the Flight Plan ID in every ADS-B message whenever the Flight ID is changed. The Mode Status Element also contains the EMERGENCY/PRIORITY STATUS field. Transmission of the MS Element at a high rate allows recipients to rapidly update the Flight Plan ID and/or Emergency/Priority Status in the event of a change.*

2.2.6.1.3 Message Transmission Cycle

A message transmission cycle of 16 seconds is defined to ensure a proper mix of message payloads. When an aircraft is determined to be in the AIRBORNE condition (§2.2.4.5.2.5.1), transmissions **shall** occur through Top (T) (if so equipped) and Bottom (B) antennas each Message Transmission Cycle as shown in Figure 2-8.

Antenna	T	T	B	B	T	T	B	B	T	T	B	B	T	T	B	B
PS #	A	B	C	D	D	A	B	C	C	D	A	B	B	C	D	A
Seconds	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

|← Message Transmission Cycle →|

Time →

Figure 2-8: Transmitter Antenna Use for Diversity Installations

Notes:

1. *There is no requirement that transmission cycle boundaries be aligned among A/Vs; it is used only to ensure proper mix of transmitted message types.*

2. *For receivers with antenna diversity provided by switching according to §2.2.8.1, this transmission pattern ensures that each payload type is communicated via each possible transmit/receive antenna combination (T/T, T/B, B/T, B/B) once during each 16 second cycle. It also minimizes the maximum spacing between any two transmissions of the same type.*

When an aircraft is determined to be in the ON-GROUND condition (§2.2.4.5.2.5.1), the Top antenna (if so equipped) **shall** be selected for all transmissions. The transmission sequences are as shown in Figure 2-8, second and third rows.

2.2.6.2 ADS-B Message Transmit Timing

2.2.6.2.1 The Message Start Opportunity (MSO)

ADS-B Messages **shall** be transmitted at discrete Message Start Opportunities (MSO) chosen by a pseudo-random process. The specific pseudo-random number (R) chosen by an aircraft depends on the most recent valid position estimate available at the beginning of each second and on the previously chosen random number $R(m\text{-}1)$. Let:

$N(0)$ = 12 L.S.B.'s of the most recent valid "LATITUDE"
$N(1)$ = 12 L.S.B.'s of the most recent valid "LONGITUDE"

where the "LATITUDE" and "LONGITUDE" are as defined in §2.2.4.5.2.1.

Using $N(0)$ and $N(1)$ the procedure below **shall** be employed to establish the transmission timing for the current UAT frame m.

When $m = 0$, $R(0) = N(0) \bmod 3200$

When $m >= 1$, $R(m) = \{ 4001\ R(m\text{-}1) + N(m \bmod 2) \} \bmod 3200$

1. When in the first frame after power up, and whenever the Vertical Status is determined to be in the AIRBORNE condition, the transmitter **shall** be in the *full MSO range* mode, where the MSO is determined as follows:

   MSO = 752 + R(m)

2. Under all other conditions the transmitter **shall** be in the *restricted MSO range* mode, where the MSO is determined as follows:

   MSO = 752 + R* + R(m)mod800

   With R* = R(k) – R(k)mod800, where "k" is the frame just prior to entering the *restricted MSO range* mode.

Notes:

1. *Retention of N(0) and N(1) in non-volatile memory is required to prevent common MSO selections amongst A/Vs when no valid latitude and longitude is currently available.*

2. *The latitude and longitude alternate in providing a changing "seed" for the pseudo-random number generation. In most cases the most recent valid "LATITUDE" and "LONGITUDE" available at the very beginning of each second is the position from the previous second. (If the navigation source is temporarily unavailable, the available position data might be older.) Other acceptable definitions include (a) the position from the previous second extrapolated to the current second, (b) the position estimate from the current second (if available at the time of MSO determination) or (c) any equivalent.*

3. *The restricted range MSO mode makes the choice of MSO more nearly periodic in order to support certain surface applications.*

2.2.6.2.2 Relationship of the MSO to the Modulated Data

The optimum sample point of the first bit of the UAT synchronization sequence at the antenna terminal of the UAT equipment **shall** occur at T_{TX} microseconds after the 1 second UTC epoch, as supplied to the UAT Transmitting Subsystem, according to the following formula:

$$T_{TX} \text{ (microseconds)} = 6000 + (250 * \text{MSO})$$

within the following tolerances:

a. ±500 nanoseconds for UAT equipment with an internal UTC coupled time source,

b. ±500 nanoseconds for UAT equipment with an external UTC coupled time source.

Notes:

1. *This is required to support ADS-B range validation by a receiving application. This requirement sets the ultimate timing accuracy of the transmitted messages under the*

UTC Coupled condition. See Appendix I for a discussion of UAT Timing Considerations.

2. *Referencing this measurement to the optimum sampling point is convenient since this is the point in time identified during the synchronization process.*

3. *There is no requirement to demonstrate this relationship when in the non-UTC Coupled condition.*

2.2.6.3 Report Assembly on Transmission of Ownship ADS-B Message

The transmitter **shall** issue a report reflecting each ADS-B Message transmission and explicitly identify the report as "ownship."

Reports **shall** contain all elements of the transmitted message payload with range, resolution and units of each payload field preserved.

Notes:

1. *This is to aid any application process that uses ADS-B Message propagation time to perform a validity check of received ADS-B Messages by providing a reference point for measured ranges.*

2. *Allows independent monitoring of the transmitted position.*

2.2.7 UAT Transmitter Message Data Characteristics

2.2.7.1 UAT Transmitter Input Requirements

This subparagraph contains requirements for access to the input elements required to compose the ADS-B Messages These input elements either provide data that maps directly into the transmitted ADS-B Message structure, or provide control signals that establish the Message contents.

a. The UAT ADS-B Transmitting Subsystem **shall** accept the input data elements listed in Table 2-64 via an appropriate data input interface and use such data to establish the corresponding ADS-B Message contents.

b. Data elements indicated as "Optional," that have no input interface, **shall** always indicate the "data unavailable" condition, or be processed using the "data unavailable" procedures related to that element.

Table 2-64: UAT ADS-B Transmitter Input Requirements

Element #	Input Data Element	Relevant Paragraph	Data Lifetime (seconds)	Applicable UAT Equipment Class						
				A0, B0	A1L A1S B1S	A1H, B1	A2	A3	B2	B3
1	ICAO 24-bit Address	2.2.4.5.1.3.1	n/a	M	M	M	M	M	M (1)	M (1)
2	Address Selection (ICAO vs Temporary) (3)	2.2.4.5.1.3.1 2.2.4.5.1.3.2	60	Input required only if installation is to have selectable address						
3	Latitude (2)	2.2.4.5.2.1	1.5	M	M	M	M	M	M	M
4	Longitude (2)	2.2.4.5.2.1	1.5	M	M	M	M	M	M	M
5	Altitude Type Selection (Barometric vs Geometric) (3)	2.2.4.5.2.2	60	O	O	O	O	O	n/a	M
6	Barometric Pressure Altitude	2.2.4.5.2.3	2	M	M	M	M	M	n/a	n/a
7	Geometric Altitude	2.2.4.5.2.3	1.5	M	M	M	M	M	n/a	M
8	NIC	2.2.4.5.2.4	2	M	M	M	M	M	M	M
9	Automatic AIRBORNE / ON-GROUND Indication (3)	2.2.4.5.2.5	2	O	O	M	M	M	n/a	n/a
10	North Velocity (2)	2.2.4.5.2.6.1	2	M	M	M	M	M	M	M
11	East Velocity (2)	2.2.4.5.2.6.3	2	M	M	M	M	M	M	M
12	Ground Speed	2.2.4.5.2.6.2	2	O	O	M	M	M	O	n/a
13	Track Angle	2.2.4.5.2.6.4	2	O	O	M	M	M	n/a	n/a
14	Heading	2.2.4.5.2.6.4	2	O	O	M	M	M	n/a	n/a
15	Barometric Vertical Rate	2.2.4.5.2.7.1.1 2.2.4.5.2.7.1.3	2	M	M	M	M	M	n/a	n/a
16	Geometric Vertical Rate (2)	2.2.4.5.2.7.1.1 2.2.4.5.2.7.1.3	2	O	O	O	O	O	n/a	n/a
17	A/V Length and Width, and POA	2.2.4.5.2.7.2	n/a	M	M	M	M	M	M	M
18	UTC 1 PPS Timing (2)	2.2.4.5.2.8	2	M	M	M	M	M	M	M
19	Emitter Category	2.2.4.5.4.1	n/a	M	M	M	M	M	M	M
20	Call Sign	2.2.4.5.4.2	60	M	M	M	M	M	O	O
21	Emergency / Priority Status Selection	2.2.4.5.4.4	60	M	M	M	M	M	O	n/a
22	Source Integrity Level (SIL)	2.2.4.5.4.6	60	M	M	M	M	M	M	M
23	System Design Assurance (SDA)	2.2.4.5.4.8	60	M	M	M	M	M	M	M
24	SIL Supplement	2.2.4.5.4.16	60	M	M	M	M	M	M	M
25	NAC_P (2)	2.2.4.5.4.9	2	M	M	M	M	M	M	M
26	NAC_V (2)	2.2.4.5.4.10	2	M	M	M	M	M	n/a	n/a
27	NIC_{BARO}	2.2.4.5.4.11	2	Can be internally "hard coded"		M	M	M	n/a	n/a
28	Capability Codes	2.2.4.5.4.12	60	M	M	M	M	M	n/a	n/a
29	TCAS Installed and Operational	2.2.4.5.4.12.2	60	M	M	M	M	M	n/a	n/a
30	TCAS/ACAS Resolution Advisory Flag	2.2.4.5.4.13.1	18	Required only if ADS-B Transmitting Subsystem is intended for installation with TCAS/ACAS; otherwise can be "hard coded"						
31	IDENT Switch Active	2.2.4.5.4.13.2	60	M	M	M	M	M	M	n/a
32	Call Sign Identification	2.2.4.5.4.14	2	Require only if CSID logic is Enabled						
33	Geometric Vertical Accuracy (GVA)	2.2.4.5.4.17	60	M	M	M	M	M	M	M
34	Single Antenna Flag	2.2.4.5.4.18	n/a	M	M	M	M	M	M	M
35	Selected Altitude Type	2.2.4.5.6.1	60	n/a	n/a	O	M	M	n/a	n/a
36	Selected Altitude Setting	2.2.4.5.6.2	60	n/a	n/a	O	M	M	n/a	n/a
37	Barometric Pressure Setting	2.2.4.5.6.3	60	n/a	n/a	O	M	M	n/a	n/a
38	Selected Heading	2.2.4.5.6.4	60	n/a	n/a	O	M	M	n/a	n/a
39	Status of MCP/FCU Mode	2.2.4.5.6.5	60	n/a	n/a	O	M	M	n/a	n/a
40	Mode Indicators: Autopilot Engaged	2.2.4.5.6.6	60	n/a	n/a	O	M	M	n/a	n/a
41	Mode Indicators: VNAV Engaged	2.2.4.5.6.7	60	n/a	n/a	O	M	M	n/a	n/a
42	Mode Indicators: Altitude Hold Mode	2.2.4.5.6.8	60	n/a	n/a	O	M	M	n/a	n/a
43	Mode Indicators: Approach Mode	2.2.4.5.6.9	60	n/a	n/a	O	M	M	n/a	n/a
44	Radio Height	2.2.4.5.2.5.1	2	O	O	O	O	O	n/a	n/a
45	Pressure Altitude Disable	2.2.4.5.2.2	n/a	M	M	M	M	M	n/a	n/a
46	Airspeed	2.2.4.5.2.5.1	2	O	O	O	O	O	n/a	n/a
47	Flight Plan ID	2.2.4.5.4.2	60	M	M	M	M	M	n/a	n/a

O = Optional   M = Mandatory (the equipment must have the ability to accept the data element)

Notes:

(1) Non-Aircraft Identifier may be assigned by Regulatory Authority.

(2) If input is not directly accessible, a means to verify the encoding must be demonstrated.

(3) These elements are control inputs and are not themselves directly contained in the transmitted ADS-B Messages.

2.2.7.2 Time Registration and Latency

This subparagraph contains requirements imposed on the ADS-B Transmitting Subsystem relative to two parameters. The first relates to the obligation of the transmitter to ensure position data in each ADS-B Message relates to a standard *Time of Applicability (TOA)*. The second relates to the obligation of the transmitter to reflect new ADS-B Message data available at the transmitter input into the transmitted ADS-B Message itself. This requirement is expressed as a *cutoff time* by which any updated data presented to the UAT transmitter should be reflected in the message output. Rules for Time of Applicability and cutoff time vary depending on the quality of SV data being transmitted and whether the transmitter is in the UTC Coupled state. The *Precision* or *Non-Precision* condition for reporting SV data is determined according to the criteria below:

a. Precision condition is in effect when:

   1. The "NAC_P" value is "10" or "11," or

   2. The "NIC" value is "9," "10" or "11"

b. Otherwise, the Non-Precision condition is in effect.

2.2.7.2.1 Requirements When in Non-Precision Condition and UTC Coupled

When the UAT Transmitting Subsystem is in the Non-Precision Condition, and is UTC Coupled:

a. At the time of the ADS-B Message transmission, position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a Geometric Altitude, **shall** be applicable as of the start of the current 1 second UTC Epoch.

b. All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

<u>Notes:</u>

1. *Specifically, any extrapolation of position performed should be to the start of the 1-second UTC Epoch and not the time of transmission.*

2. *Velocity information cannot be extrapolated and may therefore have additional ADS-B imposed latency (generally no more than one extra second).*

2.2.7.2.2 Requirements When in Precision Condition and UTC Coupled

When the UAT Transmitting Subsystem is in the Precision Condition, and is UTC Coupled:

a. At the time of the ADS-B Message transmission, the position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a Geometric Altitude, **shall** be applicable as of the start of the current 0.2 second UTC Epoch.

b. All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

Notes:

1. *Specifically, any extrapolation of position performed should be to the start of the 0.2 second UTC Epoch and not the time of transmission.*

2. *Operation in this condition assumes a GPS/GNSS sensor output rate of 5 Hz or greater is available to the ADS-B Transmitting Subsystem.*

2.2.7.2.3 Requirements When Non-UTC Coupled

When the UAT Transmitting Subsystem is in the Non-UTC Coupled Condition any change in an ADS-B Message field provided to the transmitter **shall** be reflected in any transmitted message containing that message field that is transmitted more than 1.0 second after the new value is received by the transmitter.

Note: *A UAT Transmitting Subsystem that is capable of meeting the requirements of §2.2.7.2.2 makes no adjustment to the NIC or NAC that it receives as input. It is not expected that a single transmitted message would ever indicate both the Non-UTC Coupled condition and a NIC or* NAC_P *consistent with the Precision condition.*

2.2.7.2.4 Total Latency of Position Measurements

a. When in the non-precision mode, all transmitted messages **shall** reflect position data with a total latency of no more than 1.5 seconds at the time of message transmission.

b. When in the precision mode, all transmitted messages **shall** reflect position data with a total latency of no more than 0.7 seconds at the time of message transmission.

Notes:

1. *Total latency is defined as time of message transmission minus the time of applicability of the sensor measurement.*

2. *The precision mode total latency requirement has been derived from the requirements of RTCA DO-242A, §3.3.3.2.1, RTCA DO-229D, §2.1.2.6.2 and RTCA DO-316, §2.1.2.6.2, allowing 100 milliseconds for an output position to be received by the UAT Transmitting Subsystem.*

2.2.7.2.5 Data Timeout

At the Time of Applicability for the ADS-B Message transmission, any ADS-B Message fields without an update provided to the transmitter within the Data Lifetime parameter (in seconds) of Table 2-64 **shall** be encoded as “data unavailable” in the subsequent transmitted message containing that message field.

2.2.8 Receiver Characteristics

2.2.8.1 Receiving Diversity

"Receiving diversity" refers to an ADS-B Receiving Subsystem's use of signals received from either the Top antenna, or the Bottom antenna, or both antennas. For the purpose of these requirements, several alternate ADS-B Receiving Subsystem architectures that employ receiving antenna "diversity" are illustrated in Figure 2-9.

a. Full receiver and message processing function diversity:

   (see Figure 2-9, part a.)

   There are two receiver input channels, each with its own receiver front end, message synchronization, bit demodulation, and FEC decoding. All Successful Message Receptions from both channels **shall** be provided to the Report Assembly Function. In the event both channels result in Successful Message Reception of identical messages, a single copy of this message may be provided.

b. Other diversity techniques: Other diversity implementations may be used. Any implementation must demonstrate equivalent or better performance to (a) above.

c. Receiving antenna switching:

   (see Figure 2-9, part b.)

   A single receiver input channel, consisting of receiver RF front end, message synchronization, bit demodulation and FEC decoding, is internally connected alternately and periodically, between the Top and Bottom antennas. If this method is implemented, switching when in the AIRBORNE condition **shall** occur such that:

   1. Bottom and Top antennas are alternated for the ADS-B Segments of successive frames, AND

   2. The Bottom antenna is used for the Ground Segment of all frames, AND

   3. No more than a single Long type ADS-B Message arriving at the receiver is lost because of an antenna switch, AND

      Note: *The purpose of this requirement is to place an upper bound on the time to switch antennas.*

   4. Antenna switching is initiated at the UTC Time Mark (±2 ms) and/or at the UTC Time Mark plus 188 milliseconds (±2 ms).

   When an aircraft is determined to be in the ON-GROUND condition (§2.2.4.5.2.5.1), if a single receiver is switched between two antennas, the aircraft **shall** always select the Top antenna for reception.

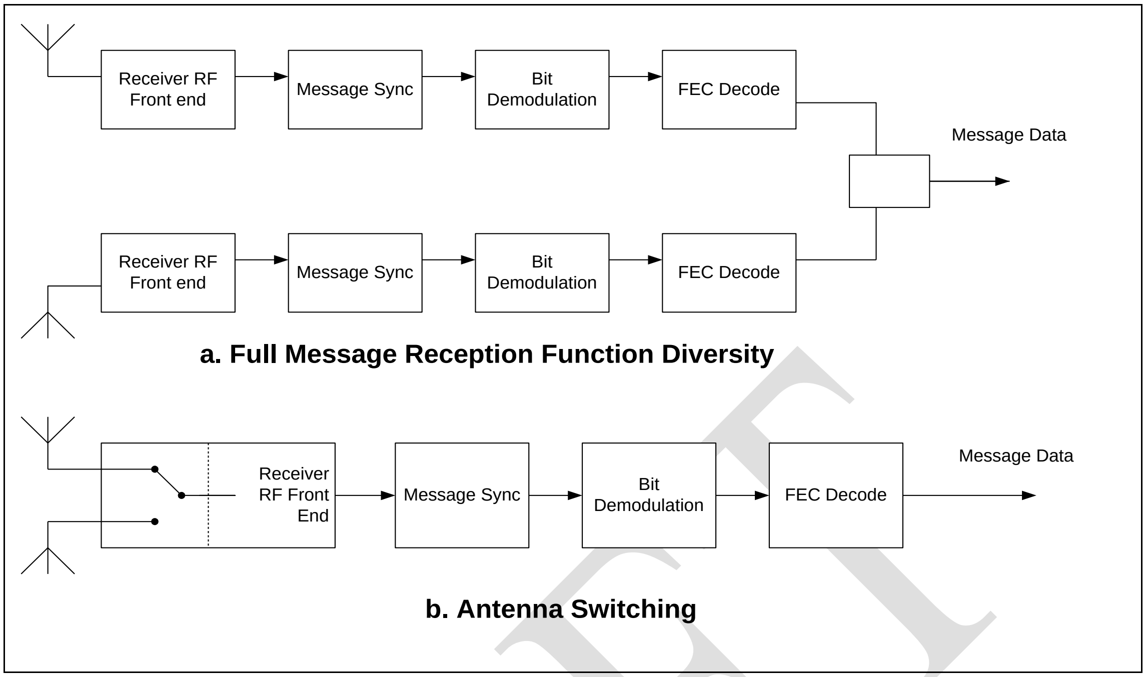


Figure 2-9: **ADS-B Receiving Architectures**

2.2.8.2 Receiver Performance

2.2.8.2.1 Receiver Sensitivity

2.2.8.2.1.1 Long ADS-B Message As Desired Signal

A desired signal level of –93 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offsets, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

Note: *The receiver criteria for Successful Message Reception of UAT ADS-B Messages are provided in §2.2.8.3.1.*

2.2.8.2.1.2 Basic ADS-B Message As Desired Signal

A desired signal level of –94 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offsets, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

Note: *The receiver criteria for Successful Message Reception of UAT ADS-B Messages are provided in §2.2.8.3.1.*

2.2.8.2.1.3 Ground Uplink Message As Desired Signal

A desired signal level of –91 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offsets, and subject to ground-to-air Doppler at 850 knots closure/opening.

Note: *The 850 knot ground station closure rate is derived from a 600 knot true air speed, added to a 250 knot worst-case wind velocity. The 1200 knot air-to-air closure remains valid because both aircraft are assumed to be within the same air mass, so the wind velocity makes no difference to the closure rate.*

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

Note: *This requirement assumes that the baud rate accuracy of the ground transmitter is 2 PPM.*

2.2.8.2.2 Receiver Desired Signal Dynamic Range

The receiver **shall** achieve a Successful Message Reception rate for Long ADS-B Messages of 99% or better when the desired signal level is between –90 dBm and –10 dBm at the antenna in the absence of any interfering signals.

Notes:

1. *The value of –10 dBm represents 120-foot separation from an A3 transmitter at maximum allowed power.*

2. *Certain installations that rely on over-air reception of the ownship transmission to meet the requirements of* §2.2.6.3 *may need to achieve Successful Message Reception at significantly higher levels than –10 dBm.*

2.2.8.2.3 Receiver Selectivity

The receiver **shall** provide the following minimum signal rejection ratios as a function of frequency offset as listed in Table 2-65, for reception of Long ADS-B Messages at a 90% Successful Message Reception rate, applied at a level of –90 dBm. The interference source is an un-modulated carrier applied at the frequency offset.

Table 2-65: Selectivity Rejection Ratios

Frequency Offset from Center	Minimum Rejection Ratio (Undesired/Desired level in dB)	
	Equipment Class A0, A1L, A1S, A1H, A2	Equipment Class A3
-1.0 MHz	10	30
+1.0 MHz	15	40
(±) 2.0 MHz	50	50
(±) 10.0 MHz	60	60

Note: *This requirement establishes the receiver's rejection of off channel energy.*

2.2.8.2.4 Receiver Tolerance to Pulsed Interference

The receiver **shall** be capable of receiving messages in the presence of interference from on channel and off channel sources of pulsed interference, such as DME/TACAN and JTIDS/MIDS. Informative Appendix G indicates, in Table G-2, the levels and pulse density of interference scenarios, against which UAT has been designed to operate effectively, as reported in Appendix K. The UAT receiver must also be tolerant of pulsed interference from other L-Band systems operating and located on the aircraft. These may include 1030 MHz ATCRBS/Mode S interrogation signals from on-board TCAS and 1090 MHz ATCRBS/Mode S reply signals from on-board ATCRBS/Mode S Transponders.

The UAT receiver may experience pulsed interference from DME/TACAN channels operating in the internationally allocated 978 MHz to 1215 MHz frequency range. The receiver **shall** be tolerant to pulsed interference from DME/TACAN. The receiver **shall** meet the reception probability dictated under the following conditions:

a. For all equipment classes:

   The receiver **shall** be capable of achieving 99% reception probability of ADS-B Messages when the desired signal level is between –90 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at either 12 or 30 microseconds pulse spacing at a level of –36 dBm for any 1 MHz channel frequency between 980 MHz and 1215 MHz inclusive.

b. For the A0, A1L, A1S, A1H, and A2 equipment classes:

   1. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –56 dBm and a frequency of 979 MHz.

   2. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when

subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –70 dBm and a frequency of 978 MHz.

c. For the A3 equipment class:

1. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –43 dBm and a frequency of 979 MHz.

2. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –79 dBm and a frequency of 978 MHz.

d. For all equipment classes, following a 21 microsecond pulse at a level of 0 dBm and at a frequency of 1090 MHz, the receiver **shall** return to within 3 dB of normal sensitivity level within 12 microseconds.

Note: *A receiver meeting the requirements of the above paragraphs will perform adequately in the presence of DME/TACAN, JTIDS/MIDS, and co-site interference as reported in Appendix K.*

2.2.8.2.5 Receiver Tolerance to Overlapping ADS-B Messages (Self Interference)

A Successful Message Reception rate of 90% or better, for the stronger of two overlapping desired messages, **shall** result when the level of the stronger message is no weaker than -80 dBm and the stronger message is at least ***X*** dB above the weaker message, when the stronger message and weaker message are aligned in time.

Where the value of ***X*** is:

4 dB for Equipment Classes A0, A1L, A1S, A1H, and A2

9 dB for Equipment Class A3

Notes:

1. *The different values across equipment classes reflect the fact that Class A3 receivers will utilize a narrow filter that degrades demodulation performance slightly in order to gain added rejection from adjacent channel DME ground stations.*

2. *Signal values ensure both the desired and undesired signal levels are above the noise floor.*

2.2.8.2.6 Rate of False "Trigger"

a. With no signal input, the ADS-B Receiver **shall** experience no more than 50 ADS-B Message triggers per second.

b. With no signal input, the ADS-B Receiver **shall** experience no more than 2 Ground Uplink Message triggers per minute.

Note: *Detection of either the ADS-B or Ground Uplink synchronization sequence is referred to as a "trigger."*

2.2.8.2.7 Trigger Processing Rate

Receiver trigger processing rate requirements are as follows:

a. Equipment Classes A3, A2 and A1H receivers **shall** be capable of successfully processing at least 1000 trigger events per second.

b. Equipment Classes A1S, A1L and A0 receivers **shall** be capable of successfully processing at least 900 trigger events per second.

2.2.8.3 Receiver Message Processing

2.2.8.3.1 Criteria for Successful Message Reception

2.2.8.3.1.1 ADS-B Messages

Upon detection of the ADS-B synchronization sequence, the receiver **shall** decode the ADS-B Message according to the procedure specified below:

a. The receiver **shall** attempt to decode the message in the Long format using hard decision decoding with no erasures allowed. The decoder **shall** correct no more than 7 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, then a Successful Message Reception **shall** be declared.
b. Otherwise, the receiver **shall** attempt to decode the message in the Basic format using hard decision decoding with no erasures allowed. The decoder **shall** correct no more than 6 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, AND the first 5 bits of the payload (the "PAYLOAD TYPE CODE" field) are ALL ZEROS, AND the Long decoding process fails, then a Successful Message Reception **shall** be declared.
c. Otherwise, no message reception **shall** be declared.

Notes:

1. *This procedure discriminates the Basic versus Long Message format by using the characteristics of the RS code without an explicit length indicator.*

2. *To avoid misinterpreting the contents of Long Message reception declared to be successful, the receiver should discard any Message that has a "PAYLOAD TYPE CODE" field equal to ZERO. See Appendix M for the probability of such an event occurring (the probability is less than 10^{-9}).*

3. *Appendix M provides the analytic determination of the Undetected Message Error Rate (UMER) achieved through use of the RS coding. Due to the straightforward calculation of the UMER and the fact that the UMER is quite low, no explicit requirement/test is needed for a "False Message Reception Rate" test.*

2.2.8.3.1.2 Ground Uplink Messages

The receiver **shall** determine Successful Message Receipt for a Ground Uplink Message according to the following procedure:

a. Each de-interleaved RS block of the Ground Uplink Message **shall** be individually examined for errors. Each RS block **shall** be declared as valid only if it contains NO uncorrected error after RS decoding. The decoding process **shall** use hard decision decoding with no erasures allowed.

b. Successful Message reception **shall** be declared for a Ground Uplink Message when all six constituent RS blocks are declared valid from (a) above.

Note: *Appendix M provides the analytic determination of the Undetected Message Error Rate achieved though use of the RS coding. Due to the straightforward calculation of the UMER and the fact that the UMER is quite low, no explicit requirement/test is needed for a "False Message Reception Rate" test.*

2.2.8.3.2 Receiver Discrimination Between ADS-B and Ground Uplink Message Types

The receiver **shall** determine the message type by means of the correlation between the received bits, and the synchronization sequences given in §2.2.3.1.1 and §2.2.3.2.1.

Note: *Specifically, the receiver should not attempt to distinguish ADS-B Messages from Ground Uplink Messages by their position in the UAT frame.*

2.2.8.3.3 Receiver Processing of ADS-B Synchronization "Trigger"

Receivers **shall** meet the following message processing requirements:

a. When an initial ADS-B trigger occurs (no message decode in progress), the decode process associated with this trigger **shall** be completed regardless of other trigger activity subsequently detected.

b. The decode process associated with a second, subsequent ADS-B trigger event that occurs during the Message Reception process of an initial ADS-B trigger event **shall** also be completed regardless of other trigger activity subsequently detected.

c. The decode process associated with a third ADS-B trigger event that occurs during the simultaneous decoding of an initial and second ADS-B trigger **shall** also be completed regardless of other trigger activity subsequently detected.

d. The decode process associated with a fourth ADS-B trigger event that occurs during the simultaneous decoding of the second and third ADS-B trigger **shall** also be completed, provided that the fourth trigger event begins not earlier than 28 bit periods after the completion of the reception of the message associated with the initial ADS-B trigger event.

Notes:

1. *Detection of the ADS-B synchronization sequence is referred to as a "trigger."*

2. *These requirements ensure that the receiver "re-trigger" procedure does not abandon the initial trigger when a close match to the sync pattern appears in the*

payload, and that the transmitter need not preclude the sync pattern from occurring in the payload.

3. *From simulation, this three-level decoding depth also assures that — in the highest self interference environments — the receiver will be >99.5% efficient in decoding of all ADS-B Messages that appear at the receiver with an adequate SIR for Successful Message Reception.*

4. *See Appendix H for one potential method to implement a "re-trigger" capability of the synchronization mechanism, and for a recommended synchronization threshold value for ADS-B.*

5. *During decoding of an ADS-B trigger, it is acceptable for the receiver to be "locked out" to Ground Uplink triggers.*

6. *In the case of "full receiver diversity" (*§2.2.8.1 *a.), the requirements of this subparagraph apply to each receiver channel individually.*

2.2.8.3.4 Receiver Processing of Ground Uplink Synchronization "Trigger"

Receivers **shall** meet the following message processing requirements:

a. When an initial Ground Uplink trigger occurs (no message decode in progress), the decode process associated with this trigger **shall** be completed regardless of other trigger activity subsequently detected.

b. A second, subsequent Ground Uplink trigger event that occurs during the decode process of an initial Ground Uplink trigger event **shall** also be completed regardless of other trigger activity subsequently detected.

<u>Notes</u>:

1. *This two-level decoding depth assures that a strong Ground Uplink Message will be decoded when a distant (>200 NM) station on the preceding time slot triggers the receiver. This minimizes planning constraints when assigning slot resources to ground stations.*

2. *See Appendix H for one potential method to implement a "re-trigger" capability of the synchronization mechanism.*

3. *During reception of a Ground Uplink Message, it is acceptable for the receiver to be "locked out" to ADS-B triggers.*

2.2.8.3.5 Receiver Time of Message Receipt

The receiver **shall** declare a Time of Message Receipt (TOMR) and include this as part of the report issued to the on-board application systems. The TOMR value **shall** be reported to within the parameters listed below:

a. Range of at least 25 seconds expressed as seconds since UTC midnight modulo the range.

b. Resolution of 100 nanoseconds or less.

c. Accuracy of ±500 nanoseconds relative to the optimum sample point of the first bit of the synchronization sequence applied at the receiver terminals for UAT equipment using either an internal, or external UTC coupled time source.

d. The reported TOMR will be equal to the following quantity: seconds since the previous UTC midnight modulo the specified TOMR range.

Note: *TOMR is required to support ADS-B Time of Applicability (TOA) and range validation by a receiving application. See Appendix I for a discussion of UAT Timing Considerations. ADS-B applications derive the TOA from the TOMR as follows:*

1. *If the report indicates UTC Coupled, and is in the Non-Precision Condition, the TOA is the TOMR truncated to the start of the UTC second.*

2. *If the report indicates UTC Coupled, and is in the Precision Condition, the TOA is the TOMR truncated to the start of the 0.20 second UTC epoch containing the TOMR.*

3. *If the report indicates Non-UTC Coupled, the TOA is the TOMR minus one (1) second.*

2.2.9 Report Assembly Requirements

Each Applicable Message Reception (§2.2.10.3) **shall** result in report assembly.

Note: *Exemplary report formats are presented in Appendix J.*

2.2.9.1 Report Assembly on Receipt of ADS-B Message

Reports **shall** contain the following information:

a. All elements of the received message payload applicable to the ADS-B report type with range, resolution and units of each payload field preserved.

b. The Time of Message Receipt value measured by the receiver.

Notes:

1. *Time of Applicability may be derived by the receiving application from the TOMR.*

2. *Address uniqueness with UAT ADS-B Messages cannot be guaranteed. However, this need not be a concern for processing of UAT ADS-B Messages by the receiver. This is because each UAT ADS-B Message contains sufficient State Vector information that the surveillance tracking system receiving the reports is able to resolve almost all duplicate address situations.*

2.2.9.2 Report Assembly on Receipt of Ground Uplink Message

Reports **shall** contain the following information:

a. The 432 byte received message payload unaltered.

b. The Time of Message Receipt value measured by the receiver.

Note: *Time of Applicability may be derived by the receiving application from the TOMR.*

2.2.10 Receiver Subsystem Capacity and Throughput Requirements

The ADS-B Receiving Subsystem **shall** process Successful Message Receptions and make them available at the output interface as specified in the subparagraphs below.

2.2.10.1 Fundamental Principals of Report Assembly

Figure 2-10 illustrates the general data flow of ADS-B Messages and Reports for the purposes of establishing the baseline requirements for Report Assembly.

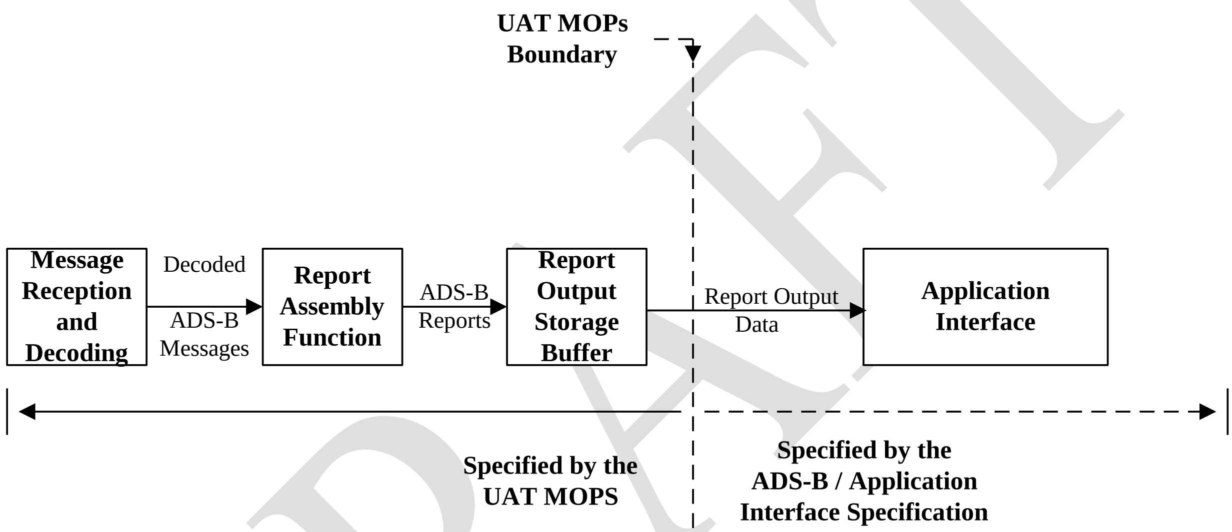


Figure 2-10: ADS-B Message And Report General Data Flow

a. **Message Reception and Decoding** -- The primary function of the Message Reception and Decoding function is to deliver all Successful Message Receptions to the Report Assembly Function.

b. **Report Assembly Function** -- The Report Assembly Function receives all Successful Message Receptions from the Message Reception and Decoding and structures Reports for delivery to the Report Output Storage Buffer.

Note: *It is important to note that the specification of requirements within this document describes the Report Assembly Function to the point where the Reports are structured and delivered to the Report Output Storage Buffer. Specifically, the specification of data delivery via the Application Interface is not addressed in this document.*

c. **Report Output Storage Buffer** -- The primary purpose of the Report Output Storage Buffer is to store and maintain all Reports such that the Reports are available for extraction by the Application Interface upon demand or as needed.

Note: *It is assumed that once the Report is in the Report Output Storage Buffer, no appreciable additional latency is imposed.*

d. **Application Interface** -- The Application Interface is responsible for the extraction of ADS-B reports from the Report Output Storage Buffer via the Report to Application Interface. Requirements for the Application Interface and Report to Application Interface are to be specified in various Application Interface specifications and therefore are not addressed in this document.

2.2.10.2 Capacity for Successful Message Reception

Receiving subsystems **shall** demonstrate the ability to perform Successful Message Reception at the message input rates specified in Table 2-66.

Table 2-66: Message-to-Completed Report Assembly Throughput Requirements

Equipment Class of ADS-B Receiving Subsystem	Measurement Interval	Required Number of Input Messages	
		Ground Uplink	Basic/Long ADS-B
A0, A1L, A1S	1 second	32	600
	10 milliseconds	N/A	20
A1H, A2, A3	1 second	32	700
	10 milliseconds	N/A	20

Note: *A random mix of non-overlapping 20% Basic Messages and 80% Long Messages should be used in the assessment of this requirement.*

2.2.10.3 Applicable Messages

Applicable Messages are defined as those requiring Report Assembly. Successful Messages are deemed to be Applicable Messages according to the criteria below:

a. For Successful Message Reception of ADS-B Messages of PAYLOAD TYPE ZERO (binary 0 0000) through TEN (binary 0 1010), one of the following two criteria **shall** apply:

   1. All Successful Message Receptions are *Applicable Messages*, OR

   2. All Successful Message Receptions are from targets within the “Range Limit” (in NM) **for up to** the “Target Limit” number of targets, where “Range Limit” and “Target Limit” are listed in Table 2-67 by equipment class. If the “Target Limit” number of targets is exceeded within the “Range Limit,” such that ADS-B Messages are discarded, then all such discarded ADS-B Messages **shall** be at greater range than any reported ADS-B Messages.

Table 2-67: Range Criteria for ADS-B Messages

Equipment Class	Range Limit (NM)	Target Limit
A0	15	250
A1L/A1S	30	300
A1H/A2	60	500
A3	150	650

b. For Successful Message Reception of Ground Uplink Messages, one of the following two criteria **shall** apply:

1. All Successful Message Receptions, OR

2. Only those Successful Message Receptions from ground stations within the range criteria from Table 2-68.

Table 2-68: Range Criteria for Ground Uplink Messages

Equipment Class	Minimum Number of Ground Uplink Reports Required (per second)
A0	16 closest to ownship
A1L/A1S	16 closest to ownship
A1H/A2	16 closest to ownship
A3	16 closest to ownship

2.2.10.4 Message Reception-to-Report Completion Time

All ADS-B Applicable Messages **shall** be output from the Report Assembly Function within 200 milliseconds of message input.

All Ground Uplink Applicable Messages **shall** be output from the Report Assembly Function within 500 milliseconds of message input.

2.2.11 Special Requirements for Transceiver Implementations

2.2.11.1 Transmit-Receive Turnaround Time

A transceiver **shall** be capable of switching from transmission to reception within 2 milliseconds.

Note: *Transmit to receive switching time is defined as the time between the optimum sampling point of the last information bit of one transmit message and the optimum sampling point of the first bit of the synchronization sequence of the subsequent receive message.*

2.2.11.2 Receive-Transmit Turnaround Time

A transceiver **shall** be capable of switching from reception to transmission within 2 milliseconds.

Note: *Receive to transmit switching time is defined as the time between the optimum sampling point of the last information bit of one receive message and the optimum sampling point of the first bit of the synchronization sequence of the subsequent transmit message.*

2.2.12 Mutual Suppression Pulses

UAT equipment **shall** provide an output signal suitable for sending suppression signals. The UAT equipment **shall** provide a mutual suppression signal whenever the transmitter output power exceeds –20 dBm. In addition, the suppression signal **shall not** become active prior to 5 microseconds before the start of the ADS-B Message Transmission Interval defined in §2.2.2.5, and the suppression signal **shall not** remain active later than 5 microseconds after the end of the ADS-B Message Transmission Interval defined in §2.2.2.5.

Note: *The tolerance at the beginning and end of the suppression interval ensures that the suppression interval is minimized to prevent excessive receiver blanking of on-board L Band equipment sharing the mutual suppression bus, but adequately protects the SSR Transponder from triggering on UAT transmissions. The UAT equipment must adhere to the electrical characteristics of the on-board mutual suppression bus and is recommended to provide protection circuitry to prevent against UAT equipment failure disabling the mutual suppression.*

UAT equipment **shall not** respond to suppression signals.

Note: *UAT equipment is not to inhibit or delay its transmissions based on suppression signals. There is no need to desensitize the UAT Receiver based on suppression signals.*

2.2.13 Self Test and Monitors

2.2.13.1 Self Test

If the equipment transmits special UAT Messages for self test:

a. The device which radiates test UAT Messages or prevents messages from being broadcast during the test period **shall** be limited to no longer than that required to determine the status of the system.

b. The self-test message signal level at the antenna end of the transmission line **shall** not exceed -40 dBm.

c. If provision is made for automatic periodic self-test procedure, such self-testing **shall** not radiate UAT Messages at a rate exceeding one broadcast every ten seconds.

2.2.13.2 Broadcast Monitoring

A monitor **shall** be provided to verify that UAT Message transmissions are generated per the schedule defined in §2.2.6.1. If any of the UAT Message types for which the equipment is certified is not transmitted, then the equipment **shall** be considered as failed and the appropriate "Fail/Warn" indicators **shall** be set to the "Fail/Warn" state.

2.2.13.3 Address Verification

The UAT transmission device **shall** declare a device failure in the event that its own ICAO 24-bit Address (if required to have a ICAO 24 bit address) is set to all "ZEROs" or all "ONEs."

2.2.13.4 Receiver Self-Test Capability

UAT Receiving Subsystems **shall** be designed to provide sufficient self-test capability to detect a loss of capability to receive UAT Messages, structure appropriate ADS-B reports, and make such reports available to the intended user interface. Should the receiving device detect that any of these basic functions cannot be performed properly, then the receiving device **shall** be considered as failed and the appropriate "Fail/Warn" indicators **shall** be set to the "Fail/Warn" state.

Note: *The above requirements are not intended to require self-test capability when the UAT Transmitting Subsystem is in "stand-by" mode.*

2.2.13.5 Failure Annunciation

Note: *See subparagraphs §2.2.4.5.1.3.1, §2.2.13.2, §2.2.13.3, §2.2.13.4, §4.1.7, §4.1.8, and §4.1.9 for additional failure annunciation requirements.*

2.2.13.5.1 UAT Transmitting Subsystem and ADS-B Function Failure Annunciations

An output **shall** be provided to indicate the status of the UAT Transmitting Subsystem. Failure to generate UAT Messages at a nominal rate, a failure detected by self-test or the monitoring function, or failure of the address verification **shall** cause the UAT Transmitting Subsystem failure annunciation to be asserted. Momentary power interrupts **shall** not cause this failure annunciation to be asserted. The status of the UAT Transmitting Subsystem **shall** be annunciated to the flight crew where applicable.

In addition, if the latitude/longitude information is not available according to Table 2-64, then the ADS-B Function Fail Annunciation **shall** be asserted. The status of the ADS-B Function **shall** be indicated to the flight crew.

2.2.13.5.2 UAT Receiving Subsystem Failure Annunciation

An output **shall** be provided to indicate the validity/non-validity of the UAT Receiving Subsystem. Failure to accept UAT Messages, structure appropriate ADS-B reports, make such reports available to the intended user interface, or failure detected by self-test or monitoring functions **shall** cause the output to assume the invalid state. Momentary power interrupts **shall** not cause the output to assume the invalid state. The status of the UAT Receiving Subsystem **shall** be annunciated to the flight crew where applicable.

2.2.13.5.3 Co-Located UAT Transmitting and Receiving Device Failure Annunciation

In installations where the UAT transmitting and receiving functions are implemented in a common unit, it **shall** be permissible to use a single Fail/Warn output that is used in common to satisfy the requirements of §3.1.9. Otherwise, the Fail/Warn mechanisms for the UAT transmission function and the UAT Receiving Subsystem **shall** be independent.

2.2.14 Antenna System

Antennas meeting the requirements of TSO-C66, TSO-C74, or TSO-C112 are acceptable. Separate antenna for receiving and transmitting are not required.

See Appendix E for further background material on antenna systems.

2.2.14.1 Polarization

If the antenna is being certified as part of the UAT equipment, the antenna **shall** be vertically polarized.

2.2.14.2 Antenna Voltage Standing Wave Ratio (VSWR)

If the antenna is being certified as part of the UAT equipment, the Voltage Standing Wave Ratio (VSWR) produced on the antenna transmission line by the antenna **shall** not exceed 1.7:1 at 978 MHz when the antenna is mounted at the center of a 1.2 meter (4 foot) diameter (or larger) flat circular ground plane. The transmission line impedance **shall** be that as specified by the UAT equipment manufacturer.

2.2.14.3 Requirements for Optional Passive Diplexer

An option to use a passive frequency Diplexer is provided herein to allow sharing of a single antenna between the ATCRBS/Mode S Transponder and the UAT unit. Sharing a common antenna between the two systems may be desirable in aircraft to minimize antenna installation cost and complexity. The Diplexer specified herein is a passive three port component which provides connectivity from the UAT port to the antenna port (UAT Channel) and connectivity from the ATCRBS/Mode S port (Transponder Channel) to the antenna port. The UAT Channel frequency response requirements insure adequate passband bandwidth around the 978 MHz UAT frequency to insure that UAT signal integrity is maintained through the UAT unit, Diplexer and antenna path. Likewise, the Transponder Channel frequency response requirements insure adequate passband bandwidth around the 1030 MHz and 1090 MHz frequencies to insure that interrogation and reply signal integrity is maintained through the transponder, Diplexer and antenna path. The Diplexer characteristics insure that performance of both the UAT and Transponder systems is equivalent to their performance without the Diplexer with the exception of the in-band attenuation and delay of signal through the Diplexer. The insertion loss and delay characteristics of the Diplexer must be taken into consideration when determining cable loss and cable delay budgets between the UAT unit and antenna and the Transponder and the antenna. Other installation issues are discussed in §3.2.1.10 along with further guidance to insure proper installation and operation of the systems. Additional Diplexer information is available in Appendix E. The use of the Diplexer does not preclude the UAT from driving the suppression bus during UAT transmissions. Diplexer installations must include connection and use of the suppression bus driven by the UAT and received by the Transponder as specified in §2.2.12.

2.2.14.3.1 Diplexer RF Requirements

2.2.14.3.1.1 The UAT Channel

The Diplexer **shall** include a UAT Channel that conveys UAT signals without distortion of the waveform. The UAT Channel **shall** convey UAT Basic, Long and Ground Uplink Messages while maintaining the modulation accuracy of the input UAT signals as specified in §2.2.2.4 and produce no more than 0.5 dB amplitude attenuation and no more than 30 nanoseconds in propagation delay. Additionally, the variation in delay **shall** be no more than 10 nanoseconds over the frequency band of 977 MHz to 979 MHz. The UAT Channel **shall** provide a passband from no greater than 977 MHz to no less than 979 MHz (2.0 MHz minimum) and a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband **shall** be different by no greater than 0.20 dB. The UAT port of the Diplexer **shall** be capable of peak power transmissions according to the appropriate aircraft equipage class given by Table 2-1. The VSWR produced by the Diplexer at the UAT port, when the other two ports are terminated in a 50 ohm load, **shall** not exceed 1.3:1 for frequencies within the passband.

2.2.14.3.1.2 The Transponder Channel

The Diplexer **shall** include a Transponder Channel that conveys received 1030 MHz interrogation and 1090 MHz reply signals without distortion of the waveform. The Transponder Channel **shall** convey pulses that are amplitude modulated on either 1030 MHz or 1090 MHz and having rise and fall times of 50 nanoseconds or more and produce no more than 0.5 dB amplitude attenuation and no more than 10 nanoseconds delay while retaining the pulse rise and fall times and pulse width of the input pulses. Additionally, the variation in delay **shall** be no more than 5 nanoseconds over the frequency band of 1015 MHz to 1105 MHz. The Transponder Channel **shall** provide a passband from no greater than 1015 MHz to no less than 1105 MHz (90 MHz minimum) and a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband **shall** be different by no greater than 0.20 dB. The Transponder port **shall** be capable of handling 1000 Watts instantaneous power. The VSWR produced by the Diplexer at the Transponder port, when the other two ports are terminated in a 50 ohm load, **shall** not exceed 1.3:1 for frequencies within the passband. If required by the transponder installation, the Diplexer **shall** support DC coupling from the Transponder port to the antenna port as required by the electrical characteristics of the installed equipment.

2.2.14.3.1.3 Channel to Channel Isolation

The Diplexer **shall** provide RF isolation between the UAT Channel and the Transponder Channel. The Diplexer **shall** provide a minimum of 50 dB of isolation between these ports at 1090 MHz. Additionally, the Diplexer **shall** provide a minimum isolation of 30 dB between the UAT and Transponder ports of the Diplexer at 1030 MHz. The Diplexer **shall** provide a minimum of 20 dB of isolation between the ports at 978 MHz.

Note: *Installations that incorporate the Diplexer must insure that the off frequency power seen by the front end of the UAT equipment and the ATCRBS/Mode S transponders through the Diplexer are within the design tolerances of each unit to insure proper operation. It has been determined that the isolations provided above should insure safe operation for most transponder designs with respect to off frequency effects. The design of the UAT needs to consider the power seen at the input from the transponder and it should be verified that the transponder design can handle the UAT power through the isolation provided.*

2.2.15 Interfaces

2.2.15.1 UAT Transmitting Subsystem Interfaces

2.2.15.1.1 UAT Transmitting Subsystem Input Interfaces

Data delivery mechanisms **shall** ensure that each data parameter is provided to the input function of the UAT Transmitting Subsystem at sufficient update rates to support the UAT Message Update Rates provided in §2.2.6.1.

2.2.15.1.1.1 Discrete Input Interfaces

Appropriate discrete inputs may be used to provide the UAT Transmitting Subsystem with configuration and control information. When implemented, all discrete inputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

2.2.15.1.1.2 Digital Communication Input Interfaces

Approved Avionics Digital Communication interfaces **shall** be used to provide all digital data parameters (including control information) to the UAT Transmitting Subsystem. Such input interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to the UAT Transmitting Subsystem control and message generation functions.

2.2.15.1.1.3 Processing Efficiency

The UAT Transmitting Subsystem input processing function **shall** be capable of efficiently processing all data input interfaces in a manner that ensures that the most recent update received for all required data parameters is made available to the message generation function to support the rates identified in §2.2.6.1.

2.2.15.1.2 UAT Transmitting Subsystem Output Interfaces

2.2.15.1.2.1 Discrete Output Interfaces

Appropriate discrete outputs may be used by the UAT Transmitting Subsystem to provide Mode Status and Failure Monitoring information to other users or monitoring equipment. When implemented, all discrete outputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

2.2.15.1.2.2 Digital Communication Output Interfaces

Appropriate Avionics Digital Communication output interfaces **shall** be implemented by the UAT Transmitting Subsystem to provide status and data communication to other user or monitoring equipment. Such output interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to other user or monitoring equipment.

2.2.15.2 UAT Receiving Subsystem Interfaces

2.2.15.2.1 UAT Receiving Subsystem Input Interfaces

2.2.15.2.1.1 Discrete Input Interfaces

Appropriate discrete inputs may be used to provide the UAT Receiving Subsystem with configuration and control information. When implemented, all discrete inputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

2.2.15.2.1.2 Digital Communication Input Interfaces

Appropriate Avionics Digital Communication interfaces **shall** be used to provide all digital data parameters (including control information) to the UAT Receiving Subsystem. Such input interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to the UAT Receiving Subsystem control and Report Assembly functions.

2.2.15.2.1.3 Processing Efficiency

The UAT Receiving Subsystem input processing function **shall** be capable of efficiently processing all necessary interfaces as required for Receiver Message Processing and Report Assembly, as defined in §2.2.8.3, §2.2.9 and §2.2.10.

2.2.15.2.2 UAT Receiving Subsystem Output Interfaces

2.2.15.2.2.1 Discrete Output Interfaces

Appropriate discrete outputs may be used by the UAT Receiving Subsystem to provide Mode Status and Failure Monitoring information to other users or monitoring equipment. When implemented, all discrete outputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

2.2.15.2.2.2 Digital Communication Output Interfaces

Appropriate Avionics Digital Communication output interfaces **shall** be implemented by the UAT Receiving Subsystem to provide status and data communication to other user or monitoring equipment. Such output interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to other user or monitoring equipment.

2.2.16 Power Interruption

The UAT Transmitting and/or Receiving Subsystems **shall** regain operational capability to within their operational limits within two seconds after the restoration of power following a momentary power interruption.

Note: *The UAT Transmitting Subsystem and/or receiving equipment is not required to continue operation during momentary power interruptions.*

2.2.17 Compatibility with Other Systems

2.2.17.1 EMI Compatibility

The UAT Transmitting and/or Receiving Subsystem **shall** not compromise the operation of any co-located communication or navigation equipment, or ATCRBS and/or Mode-S transponders. Likewise, the UAT antenna **shall** be mounted such that it does not compromise the operation of any other proximate antenna.

2.2.17.2 Compatibility with GPS Receivers

The UAT Transmitting and/or Receiving Subsystem **shall** not compromise the operation of a co-located proximate GPS receiver.

2.2.17.3 Compatibility with Other Navigation Receivers and ATC Transponders

The UAT Transmitting and/or Receiving Subsystem **shall** not compromise the operation of VOR, DME, ADF, LORAN, ATCRBS or Mode-S equipment installed in a proximate location.

In addition, the UAT Receiving Subsystem must be fully operational when located in close proximity of an ATCRBS or Mode-S transponder.

2.3 Equipment Performance – Environmental Conditions

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual aeronautical operation.

Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase "When Required." If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these "when required" tests shall be performed.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are contained in RTCA Document DO-160D, *Environmental Conditions and Test Procedures for Airborne Equipment*. General information on the use of RTCA DO-160D is contained in Sections 1 through 3 of that document. Also, a method of identifying which environmental tests were conducted and other amplifying information on the conduct of the tests is contained in Appendix A of RTCA DO-160D.

Some of the performance requirements in Sections 2.1 and 2.2 are not required to be tested to all of the conditions contained in RTCA DO-160D. Judgment and experience have indicated that these particular parameters are not susceptible to certain environmental conditions and that the level of performance specified in Sections 2.1 and 2.2 will not be measurably degraded by exposure to these environmental conditions.

In addition to the exceptions above, certain environmental tests contained in this subsection are not required for minimum performance equipment unless the manufacturer wishes to qualify the equipment for additional environmental conditions. If the manufacturer wishes to qualify the equipment to these additional conditions, then these tests shall be performed.

The specified performance tests cover all classes of ADS-B Transmitting and Receiving Subsystems. Only those tests that are applicable to the class of equipment being qualified need be performed. Additional tests may have to be performed in order to determine performance of particular design requirements that are not specified in this document. It is the responsibility of the manufacturer to determine appropriate tests for these functions.

Specific ADS-B Transmitting and Receiving Subsystem performance tests have been included in this section for use in conjunction with the environmental procedures of DO-160D (EUROCAE ED-14D). These tests have been chosen as a subset of the ADS-B Transmitting and Receiving Subsystem performance tests provided in subsection 2.4. Normally, a MOPS document does not provide specific equipment performance tests to be used in conjunction with the environmental procedures of RTCA DO-160D (EUROCAE ED-14D). However, there is a sufficiently large number of ADS-B Transmitting and Receiving Subsystem performance tests in subsection 2.4 that it would be impractical to repeat all of those tests in conjunction with all of the appropriate environmental procedures.

2.3.1 Environmental Test Conditions

Table 2-69 lists all of the environmental conditions and test procedures (hereafter referred to as environmental procedures) that are documented in RTCA DO-160D (EUROCAE ED-14D). Table 2-70 lists the sets of ADS-B Transmitting and Receiving Subsystem performance tests that are specified in detail in this subsection and which are intended to be performed subject to the various environmental procedures of RTCA DO-160D (EUROCAE ED-14D). In order to simplify the process of relating the environmental procedures to the ADS-B equipment performance tests, Table 2-69 divides the environmental procedures into groups. All of the procedures in a given group are carried out in conjunction with the same set of ADS-B Transmitting and Receiving Subsystem performance tests. Using this approach, the environmental procedures fall into five groups. The environmental procedures that apply to all of the sets of ADS-B Transmitting and Receiving Subsystem tests fall into group 1. Group 2 procedures apply to 10 of the sets of ADS-B Transmitting and Receiving Subsystem performance tests. Group 3 procedures apply to 8 of the sets of ADS-B Transmitting and Receiving Subsystem performance tests. Group 4 procedures apply to one set of the performance tests. Group 5, which applies to none of the ADS-B Transmitting and Receiving Subsystem performance tests, includes only environmental procedures that are intended to determine the effect of the ADS-B Transmitting and/or Receiving Subsystem on rack mounting hardware, compass needles, explosive gases, and other RF hardware.

Table 2-70 indicates which of the groups of environmental procedures is related to each set of ADS-B Transmitting and/or Receiving Subsystem performance tests. Each ADS-B Transmitting and/or Receiving Subsystem performance test shall be validated under all of the environmental procedures in the groups required for that test as indicated in Table 2-70.

Table 2-69: Environmental Test Group Applicability

ENVIRONMENTAL TEST GROUP APPLICABILITY					
RTCA DO-160D TEST #	**ENVIRONMENTAL CONDITION**	**RTCA DO-160D Paragraph**	**EUROCAE ED-14D Paragraph**	**TEST GROUPS**	**REMARKS**
4a	Temperature	4.5	4.5	1	
4b	Altitude	4.6.1	4.6.1	3	
4c	Decompression and Overpressure	4.6.2	4.6.2	3	
4d	Overpressure	4.6.3	4.6.3	3	
5	Temperature Variation	5.0	5.0	3	
6	Humidity	6.0	6.0	2	
7a	Operational Shock	7.2	7.2	2	
7b	Crash Safety	7.3	7.3	5	NO TESTS
8	Vibration	8.0	8.0	3 -and- 1	3 during: 1 after
9	Explosion *(When Required)*	9.0	9.0	5	NO TESTS
10	Waterproofness *(When Required)*	10.0	10.0	2	
11	Fluids Susceptibility *(When Required)*	11.0	11.0	2	
12	Sand and Dust *(When Required)*	12.0	12.0	2	
13	Fungus Resistance *(When Required)*	13.0	13.0	2	
14	Salt Spray *(When Required)*	14.0	14.0	2	
15	Magnetic Effect	15.0	15.0	5	NO TESTS
16	Power Input Momentary Interruptions and All Others	16.0	16.0	4 3 -and- 2	3 during: 2 after
17	Voltage Spike	17.0	17.0	2	
18	Audio Frequency Conducted Susceptibility	18.0	18.0	1	
19	Induced Signal Susceptibility	19.0	19.0	1	
20	RF Susceptibility	20.0	20.0	1	
21	Emission of RF Energy	21.1	21.1	5	
22	Lightning Induced Transient Susceptibility	22.0	22.0	3	
23	Lightning Direct Effects	23.0	23.0	3	
24	Icing *(When Required)*	24.0	24.0	2	
25	Electrostatic Discharge	25.0	25.0	5	NO TESTS

Note: *Tests in Group 5 determine the effects of the ADS-B equipment on other equipment (mounts, compass needles, explosive gases, and other RF equipment) and therefore do not involve the ADS-B equipment performance requirements of this document, with the exception of the "Requirements for Optional Passive Diplexer."*

Table 2-70: Performance Test Requirements During Environmental Testing

PERFORMANCE TEST REQUIREMENTS DURING ENVIRONMENTAL TESTING						
Test Procedure Paragraph	**TEST PROCEDURE DESCRIPTION**	**Required Environmental Test Groups (See Table 2-69)**				
	TEST GROUPS	**1**	**2**	**3**	**4**	**5**
2.3.2.1	Transmission Frequency (§2.2.2.1)	**Y**	**Y**	**Y**		
2.3.2.2	Modulation Type (§2.2.2.3)	**Y**				
2.3.2.3	Modulation Rate and Distortion (§2.2.2.2 & §2.2.2.4)	**Y**				
2.3.2.4	Transmitter Power Output (§2.2.2.5)	**Y**	**Y**	**Y**		
2.3.2.5	In Band Transmission Spectrum (§2.2.2.6)	**Y**	**Y**			
2.3.2.6	Message Transmission Cycle (Transmitter Diversity) (§2.2.6.1.3)	**Y**				
2.3.2.7	Message Start Opportunity (MSO) (§2.2.6.2.1)	**Y**				
2.3.2.8	Relationship of the MSO to the Modulated Data (§2.2.6.2.2)	**Y**				
2.3.2.9	Report Assembly on Transmission of Ownship ADS-B Message (§2.2.6.3 & §2.2.7.1)	**Y**	**Y**	**Y**		
2.3.2.10	Receiving Diversity (§2.2.8.1)	**Y**				**NO TESTS**
2.3.2.11	Long ADS-B Message As Desired Signal (§2.2.8.2.1.1)	**Y**	**Y**			
2.3.2.12	Basic ADS-B Message As Desired Signal (§2.2.8.2.1.2)	**Y**	**Y**			
2.3.2.13	Ground Uplink Message As Desired Signal (§2.2.8.2.1.3)	**Y**	**Y**			
2.3.2.14	Receiver Desired Signal Dynamic Range (§2.2.8.2.2)	**Y**	**Y**			
2.3.2.15	Receiver Selectivity (§2.2.8.2.3)	**Y**	**Y**			
2.3.2.16	Report Assembly on Receipt of ADS-B Message (§2.2.9.1)	**Y**	**Y**	**Y**		
2.3.2.17	Report Assembly on Receipt of Ground Uplink Message (§2.2.9.2)	**Y**	**Y**	**Y**		
2.3.2.18	Address Verification (§2.2.13.3, §2.2.13.5.1, and §2.2.13.5.3)	**Y**	**Y**	**Y**	**Y**	
2.3.2.19	Receiver Self Test Capability (§2.2.13.4, §2.2.13.5.2, §2.2.13.5.3)	**Y**	**Y**	**Y**	**Y**	
2.3.2.20	Transmission Device Failure Annunciation (§2.2.13.5.1)	**Y**	**Y**	**Y**	**Y**	
2.3.2.21	Requirements for Optional Passive Diplexer (§2.2.14.3)	**Y**	**Y**	**Y**		**Y**
2.3.2.22.1	Power Interruption for ADS-B Transmitting Subsystem (§2.2.16)	**Y**			**Y**	**NO TESTS**
2.3.2.22.2	Power Interruption for ADS-B Receiving Subsystem (§2.2.16)	**Y**			**Y**	

Note: *"**Y**" in the above table denotes that the test procedure identified in the far left column is required to be performed when performing the group of tests indicated by the column under which "**Y**" is indicated.*

2.3.2 Detailed Environmental Test Procedures

The test procedures set forth below are considered satisfactory for use in determining equipment performance under environmental conditions. Although specific test procedures are cited, it is recognized that other methods may be preferred. These alternative procedures may be used if the manufacturer can show that such procedures provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternative procedures. The ADS-B Transmitting and Receiving Subsystem performance tests do not include specific pass/fail criteria. It is intended that such criteria be obtained from the ADS-B Transmitting and Receiving performance requirements provided in Sections 2.1 and 2.2 for the applicable class of equipment being subjected to the environmental testing.

2.3.2.1 Transmission Frequency (§2.2.2.1)

Perform the entire procedure provided in §2.4.2.1.

2.3.2.2 Modulation Type (§2.2.2.3)

Perform the entire procedure provided in §2.4.2.3.

2.3.2.3 Modulation Rate and Distortion (§2.2.2.2 and §2.2.2.4)

Perform the entire procedure provided in §2.4.2.4.

2.3.2.4 Transmitter Power Output (§2.2.2.5)

Perform the entire procedure provided in §2.4.2.5.

2.3.2.5 In-Band Transmission Spectrum (§2.2.2.6)

Perform the entire procedure provided in §2.4.2.6.

2.3.2.6 Message Transmission Cycle (Transmitter Diversity) (§2.2.6.1.3)

Perform the entire procedure provided in §2.4.6.1.3.

2.3.2.7 Message Start Opportunity (MSO) (§2.2.6.2.1)

Perform the entire procedure provided in §2.4.6.2.1.

2.3.2.8 Relationship of the MSO to the Modulated Data (§2.2.6.2.2)

Perform the entire procedure provided in §2.4.6.2.2.

2.3.2.9 Report Assembly on Transmission of Ownship ADS-B Message (§2.2.6.3 and §2.2.7.1)

Purpose/Introduction:

The transmitter shall issue a report reflecting each ADS-B Message transmission and explicitly identify the report as "ownship."

Reports shall contain all elements of the transmitted message payload with range and accuracy of each payload field preserved.

This subparagraph also contains requirements for access to the input elements required to compose the ADS-B Messages such that the input bits can be verified for appropriate mapping into the structure of the transmitted message.

a. The UAT ADS-B Transmitting Subsystem shall accept the input data elements listed in Table 2-64 via an appropriate data input interface and use such data to establish the corresponding ADS-B Message contents.

> ***Note:*** *Table 2-64 indicates what data is applicable for each type of transmitting equipment. When "Optional" ("O") is indicated in the table, then the applicable data need not be provided to the UUT.*

b. Data elements indicated as "Optional" in Table 2-64, that have no appropriate input interface, shall always indicate the "data unavailable" condition.

Equipment Required:

Supply the UUT with data interfaces appropriate for the equipment class and intended application.

Provide one UAT test receiver that provides data logging of all received messages.

Measurement Procedure:

Step 1: Basic Type "0" Message Payload Transmission Setup

Review the data input requirements indicated in Table 2-64 and determine the data necessary for the Class of Transmitting equipment being tested.

Then, review Appendix C, Table C-1, and establish the exact data necessary to structure each parameter selected from Table 2-64 in the previous paragraph.

Step 2: Basic Type "0" Message Payload Transmission and Report Verification

Verify that the ADS-B Transmitting Subsystem properly provides ADS-B transmissions of Basic Type "0" messages and that the UUT properly provides an "Ownship" report via the report interface.

Step 3: Basic Type "0" Message Payload Transmission Contents

Compare the data received by the UAT Test Receiver with the contents of the UUT ownship reports.

Verify that the each field of the received transmission is equivalent to its respective field in the ownship reports and that the data is equivalent to the input data provided in Step 1.

Step 4: Long Type "1" Message Payload Transmission Setup

Review the data input requirements indicated in Table 2-64 and determine the data necessary for the Class of Transmitting equipment being tested.

Then, review Appendix C, Table C-1, and establish the exact data necessary to structure each parameter selected from Table 2-64 in the previous paragraph.

Step 5: Long Type "1" Message Payload Transmission and Report Verification

Verify that the ADS-B Transmitting Subsystem properly provides ADS-B transmissions of Type "1" messages and that the UUT properly provides an "Ownship" report via the report interface.

Step 6: Long Type "1" Message Payload Transmission Contents

Compare the data received by the UAT Test Receiver with the contents of the UUT ownship reports.

Verify that the each field of the received transmission is equivalent to its respective field in the ownship reports and that the data is equivalent to the input data provided in Step 1.

2.3.2.10 Receiving Diversity (§2.2.8.1)

2.3.2.10.1 Full Diversity (§2.2.8.1.a and §2.2.8.1.b)

Perform the entire procedure provided in §2.4.8.1.1.

2.3.2.10.2 Antenna Switching (§2.2.8.1.c)

Purpose/Introduction:

The purpose of this test procedure is to verify that antenna switching is accomplished.

Measurement Procedure:

This test procedure only applies if receiver diversity is implemented using a switching technique as specified in §2.2.8.1.c.

Input signal levels for the following test procedures will be –85 dBm.

Step 1: Antenna Switching Verification – AIRBORNE Condition

Place the UUT into the AIRBORNE condition. Input a valid Time Mark to the ADS-B Transceiver but do not enable the Transmitter so that reception will not be inhibited. Separate messages are required as input to the two antenna ports. Input Message "A," a valid Long ADS-B Message, to the Top antenna port of the receiver. Input Message "B," a valid Long ADS-B Message with a different data content than Message "A," to the Bottom antenna port. Input Message "A" and Message "B" at exactly the same time. Timing of the generated ADS-B Message in the one-second epoch is relative to the leading edge of the UTC Time Mark, measured from the optimum sampling point of the first bit of the synchronization pattern input. Generate Message "A" and Message "B" with timing of 500 milliseconds from the leading edge of the UTC Time Mark. Monitor and record the output of the receiver. Verify that Message "A" and Message "B" are both received 50 times, but in alternating seconds.

Step 2: Antenna Switching Verification – ON-GROUND Condition

This procedure is required for only those systems capable of reporting the ON-GROUND condition. Set up the ADS-B Receiving Subsystem to ON-GROUND condition. Terminate the bottom antenna port. Input a valid Long ADS-B Message to the Top antenna port, once per second for 100 seconds, with a time relative to the UTC Time Mark that varies from 5 milliseconds to 905 milliseconds in 10 millisecond increments. Monitor and record the output of the receiver over the 100 second time interval. Verify that the ADS-B Message is received exactly 100 times over the 100 second interval.

2.3.2.11 Long ADS-B Message As Desired Signal (§2.2.8.2.1.1)

Perform the entire procedure provided in §2.4.8.2.1.1.

2.3.2.12 Basic ADS-B Message As Desired Signal (§2.2.8.2.1.2)

Perform the entire procedure provided in §2.4.8.2.1.2.

2.3.2.13 Ground Uplink Message As Desired Signal (§2.2.8.2.1.3)

Perform the entire procedure provided in §2.4.8.2.1.3.

2.3.2.14 Receiver Desired Signal Dynamic Range (§2.2.8.2.2)

Perform the entire procedure provided in §2.4.8.2.2.

2.3.2.15 Receiver Selectivity (§2.2.8.2.3)

Perform the entire procedure provided in §2.4.8.2.3.

2.3.2.16 Report Assembly on Receipt of ADS-B Message (§2.2.9.1)

Perform the entire procedure provided in §2.4.9.1.

2.3.2.17 Report Assembly on Receipt of Ground Uplink Message (§2.2.9.2)

Perform the entire procedure provided in §2.4.9.2.

2.3.2.18 Address Verification (§2.2.13.3)

Note: *This procedure applies only to ADS-B Transmitting Subsystems.*

Perform the entire procedure provided in §2.4.13.3.

2.3.2.19 Receiver Self Test Capability (§2.2.13.4)

Note: *This procedure applies only to ADS-B Receiving Subsystems.*

Perform the entire procedure provided in §2.4.13.4.

2.3.2.20 Transmission Device Failure Annunciation (§2.2.13.5.1)

Note: *This procedure applies only to ADS-B Transmitting Subsystems.*

Perform the entire procedure provided in §2.4.13.5.1.

2.3.2.21 Requirements for Optional Passive Diplexer (§2.2.14.3)

Perform the entire procedure provided in §2.4.14.3, inclusive of its subsections.

2.3.2.22 Power Interruption (§2.2.16)

2.3.2.22.1 Power Interruption for ADS-B Transmitting Subsystems (§2.2.16)

Perform the entire procedure provided in §2.4.16.1.

2.3.2.22.2 Power Interruption for ADS-B Receiving Subsystems (§2.2.16)

Perform the entire procedure provided in §2.4.16.2.

2.4 Equipment Test Procedures

The test procedures set forth in the following subparagraphs are considered satisfactory for use in determining required performance under standard and stressed conditions. Although specific test procedures are cited, it is recognized that other methods may be preferred by the testing facility. These alternate procedures may be used if the equipment manufacturer can show that they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

2.4.1 Definition of Standard Conditions of Test

The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein commencing at §2.4.2:

a. <u>Power Input Voltage</u> – Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage ±2 percent. The input voltage shall be measured at the input terminals of the equipment under test.

b. <u>Power Input Frequency</u>

   (1). In the case of equipment designed for operation from an AC source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency ±2 percent.

   (2). If the equipment is designed for operation from an AC source of variable frequency (e.g., 300 to 1000 Hz), tests shall be conducted with the input frequency adjusted to within five percent of a selected frequency and, unless otherwise specified, within the range for which the equipment is designed.

c. <u>Accuracy of Test Equipment</u> – Throughout this section, the accuracy of the test equipment is not addressed in detail, but rather is left to the calibration process prescribed by the agency that certifies the testing facility.

d. <u>Adjustment of Equipment</u> – The circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests. Unless otherwise specified, adjustments may not be made once the test procedures have started.

e. Test Instrument Precautions – During the tests, precautions shall be taken to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes and other test instruments, across the input and output terminals of the equipment under test.

f. Ambient Conditions – Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure and humidity. However, the room temperature shall not be lower than 10 degrees C.

g. Connected Loads – Unless otherwise specified, all tests shall be performed with the equipment connected to loads having the impedance values for which it is designed.

h. Standard ADS-B Broadcast Message Test Signals

The ADS-B Broadcast Message general signal conventions **shall** be as specified in §2.2.1 and §2.2.2.

General Characteristics

(1). Radio Frequency: The carrier frequency of the signal generator for ADS-B Broadcast Messages shall be 978 MHz ±19.56 kHz.

(2). CW Output: The CW output between transmissions shall be a maximum level of –98 dBm.

(3). Amplitude Variation: The instantaneous amplitude during a message shall not fall more than 1 dB below the maximum value.

(4). Signal Level: Unless otherwise noted in the measurement procedure, the signal level shall be -60 ±3 dBm.

(5). ICAO 24-Bit Discrete Address: Unless otherwise noted in the measurement procedure, the ADS-B Transmitting Subsystem address used for all broadcast messages shall be: Hexadecimal – AA AA AA, (i.e., binary – 1010 1010 1010 1010 1010 1010).

2.4.1.1 Verification of Signal Levels (§2.2.1.1)

No specific test procedure is required to validate §2.2.1.1.

2.4.1.2 Verification of Desired Signals (§2.2.1.2)

No specific test procedure is required to validate §2.2.1.2.

2.4.1.3 Verification of Data Quantization (§2.2.1.3)

Appropriate test procedures required to validate the requirements of §2.2.1.3 are included in numerous sections of this document, in particular in §2.4.4.

2.4.2 Verification of ADS-B Transmitter Characteristics (§2.2.2)

No specific test procedure is required to validate §2.2.2.

2.4.2.1 Verification of Transmission Frequency (§2.2.2.1)

Purpose/Introduction:

The transmission frequency f_0 **shall** be 978 MHz, ±20 PPM.

Note: *All transmissions from ground stations will operate at the same transmission frequency and frequency tolerance.*

Equipment Required:

The tests performed in this subparagraph require a Vector Signal Analyzer (VSA), or an equivalent Signal Analyzer, with the following characteristics:

A minimum capability of displaying a standard "Eye Diagram" as described in Appendix A, as well as providing a computed measurements summary which includes a computed Center Frequency, or Carrier Offset from Center Frequency, and a Modulation Frequency Deviation. Examples: HP89441A, or the HP89600 series.

For §2.4.2.1 through §2.4.2.4, configure the Vector Signal Analyzer equipment for Digital Demodulation Mode according to Table 2-71.

Notes:

1. *Equipment parameter labels, menus, setup options, and units may vary from one manufacturer to another, and parameter labels are usually abbreviated. In Table 2-71, text enclosed in brackets is not displayed on the HP89441A display. The bracketed text is added to clarify the functional terms and setting values for those not using the HP89441A.*

2. *The use of the word "symbol," when directly associated with the HP89441A, means a single data bit, instead of an 8-bit byte.*

Table 2-71: Digital Demodulation Mode Configuration

VECTOR SIGNAL ANALYZER PARAMETER SETTINGS	
Parameter Item/Function	**Parameter Setting Value**
Preset	(press to Preset Equipment)
Instrument Mode	Digital Demodulation
Instrument Mode / demodulation setup / demod[ulation] format	[2 FSK]
Instrument Mode / demodulation setup / symbol rate	1.041667 MHz
Instrument Mode / demodulation setup / result [message] length	420 sym[bols]
Instrument Mode / demodulation setup / meas[urement] filter	off
Instrument Mode / demodulation setup / ref[erence] filter	raised cosine
Instrument Mode / demodulation setup / [filter] alpha	0.5
Instrument Mode / demodulation setup / normalize	off
Frequency / center frequency	978 MHz
Frequency / frequency span	[preferably] 3.255 MHz
Range / ch[annel] 1 [signal] range	–50 dBm
Time / result [message] length	420 sym[bols]
Time / sync search	on
Time / sync pattern	"EACDDA4E2" Hexidecimal (per §2.2.3.1.1)
Time / points/symbol	4
Average / average	on
Average / num[ber of] averages	10
Average / average type	rms expo[nential]
Trigger / trigger type	IF ch[annel]1
Trigger / IF level	0.0001 V[olts]
Trace A – Measurement Data	FSK measured time
Trace A – Data Format	part real (I)
Trace A – RefLvl/Scale / Y per div[ision]	78.125 kHz
Trace C – Measurement Data	FSK measured time
Trace C – Data Format	eye diagram I
Trace C – Data Format / more format setup / eye length	1
Trace C – RefLvl/Scale / Y per div[ision]	70 kHz
Trace D – Measurement Data	symbol table/error summary

Note: *The "Frequency / frequency span" in Table 2-71, listed as the preferred value for the Vector Signal Analyzer, while it is optimum for the Agilent 89441A, may be changed above or below the value listed [3.255 MHz] in order to produce the cleanest presentation; the one with the largest "EYE" opening. Analyzer equipment other than the Agilent 89441A, or 89600 series, may require a different bandwidth, or frequency span, setting in order to produce the optimum (largest) "EYE" opening.*

Measurement Procedures:

Step 1: Equipment Setup (§2.2.2.1)

For the tests in this subparagraph, configure the Vector Signal Analyzer according to the Digital Demodulation Mode setup listed in Table 2-71. See Appendix N for the state file "UAT-DMD.STA" to automatically setup the HP89441A Vector Signal Analyzer. If the Trace A – RefLvl/Scale / Y per div[ision] setting does not equal 78.125 kHz, manually enter the value.

Step 2: Transmission Frequency Pre-Test Setup (§2.2.2.1)

Connect the ADS-B Transmitting Equipment to the Vector Signal Analyzer through enough attenuation to present a signal at the Vector Signal Analyzer input of –60 ± 5 dBm, and initiate a series of Long ADS-B fixed pattern test messages each having the following message elements: the 36 bit SYNCH, followed by a 272 bit Payload having a repeating bit pattern of alternating ONEs and ZEROs, and a 112 bit FEC as generated by the Reed-Solomon algorithm. Trace A Ch1 2FSK Meas Time should show a somewhat noisy SYNCH element (34.56 microseconds), followed by a less noisy Payload element (261.12 microseconds), and finishing with a somewhat noisy FEC element (107.52 microseconds), similar to Figure 2-11.

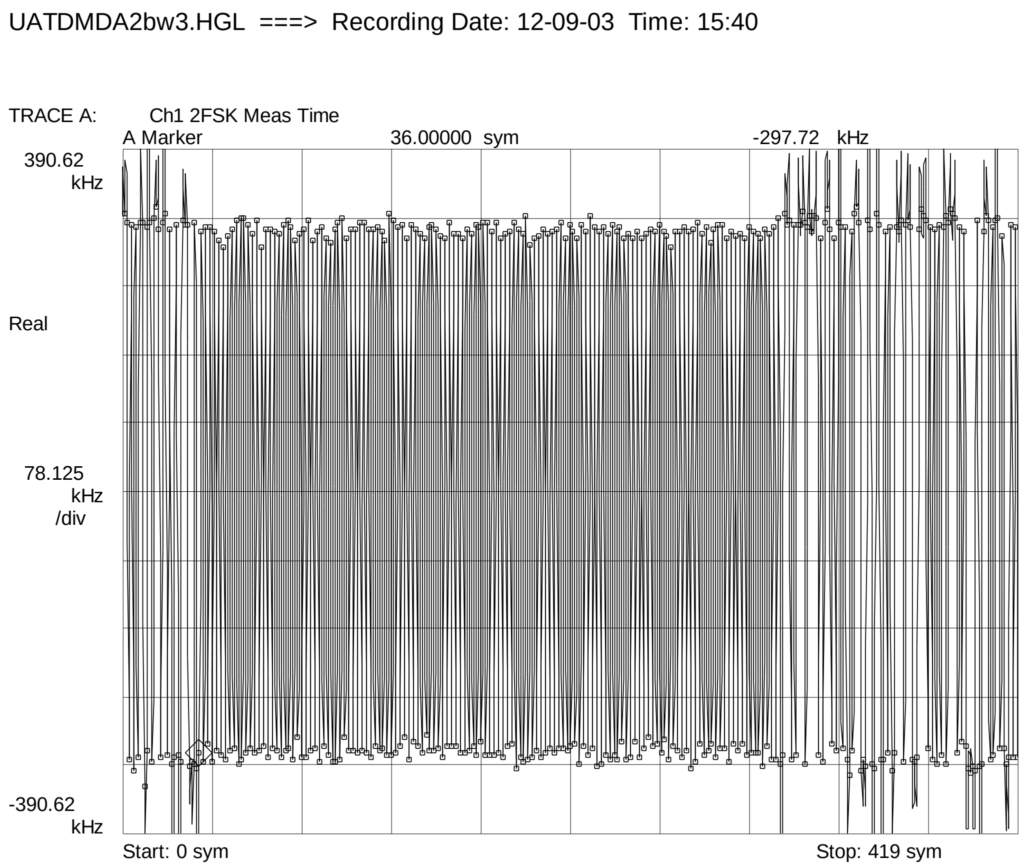


Figure 2-11: Digital Demodulation Mode – Trace A: Ch1 2FSK Meas Time

Step 3: Transmission Frequency Test (§2.2.2.1)

The maximum carrier frequency offset is:

$$f_{off} = \pm 20 * f_0 \text{ (in MHz)} = \pm 19560 \text{ Hz}$$

Verify that the Carrier Offset f_{off}, as shown in the Trace D Error Summary from the Vector Signal Analyzer display, is in the following range:

$$-19560 \text{ Hz} <= f_{off} <= +19560 \text{ Hz}$$

2.4.2.2 Verification of Modulation Rate (§2.2.2.2)

Purpose/Introduction:

The nominal modulation rate is 1.041667 megabits per second.

Measurement Procedure:

The test in §2.4.2.4 includes the verification of Modulation Rate.

2.4.2.3 Verification of Modulation Type (§2.2.2.3)

Purpose/Introduction:

These test procedures will verify that data **shall** be modulated onto the carrier using binary Continuous Phase Frequency Shift Keying. The modulation index, *h*, **shall** be 0.6; this implies that if the data rate is R_b, then the nominal frequency separation between "mark" (binary 1) and "space" (binary 0) is $\Delta f = h \bullet R_b$. A binary 1 **shall** be indicated by a shift up in frequency from the nominal carrier frequency of $\Delta f/2$ (+312.5 kHz) and a binary 0 by a shift of $-\Delta f/2$ (-312.5 kHz). These frequency deviations apply at the optimum sampling points for the bit interval.

Equipment Required:

The test performed in this subparagraph requires equipment described in §2.4.2.1.

Measurement Procedures:

Step 1: Equipment Setup (§2.2.2.3)

For the test in this subparagraph, configure the Vector Signal Analyzer according to the Digital Demodulation Mode setup listed in Table 2-71. See Appendix N for the state file "UAT-DMD.STA" to automatically setup the HP89441A Vector Signal Analyzer. If the Trace A – RefLvl/Scale / Y per div[ision] setting does not equal 70 kHz, manually enter the value. On a display of 10 vertical divisions, deviations of ±280 kHz will occur at ±4 vertical divisions, respectively, from the display center.

Step 2: Transmission Frequency Modulation CPFSK, Index, and Shift Test (§2.2.2.3)

Connect the ADS-B Transmitting Equipment to the Vector Signal Analyzer through enough attenuation to present a signal at the Vector Signal Analyzer input of –60 ± 5 dBm, and initiate a series of Long ADS-B fixed pattern test messages each having the following message elements: the 36 bit SYNCH, followed by a 272 bit Payload having a repeating bit pattern of alternating ONEs and ZEROs, and a 112 bit FEC as generated by the Reed-Solomon algorithm. In Trace A Ch1 2FSK Meas Time, verify that the FSK modulation measured by the display marker, positioned at each of the whole numbered bits, is greater than +280 kHz for evenly numbered bits, and less than –280 kHz for oddly numbered bits. In the Trace D Error Summary, verify that the Deviation is a minimum of 280 kHz (rms).

2.4.2.4 Verification of Modulation Distortion (§2.2.2.4)

Purpose/Introduction:

The minimum vertical opening of the eye diagram of the transmitted signal (measured at the optimum sampling points) **shall** be no less than 560 kHz when measured over an entire Long ADS-B Message containing pseudorandom payload data.

The minimum horizontal opening of the eye diagram of the transmitted signal (measured at 978 MHz) **shall** be no less than 0.624 microseconds (0.65 symbol periods) when measured over an entire Long ADS-B Message containing pseudorandom payload data.

This test procedure also verifies the Modulation Rate specified in §2.2.2.2, by measurement of the Eye Diagram.

Equipment Required:

The test performed in this subparagraph requires equipment described in §2.4.2.1.

Measurement Procedures:

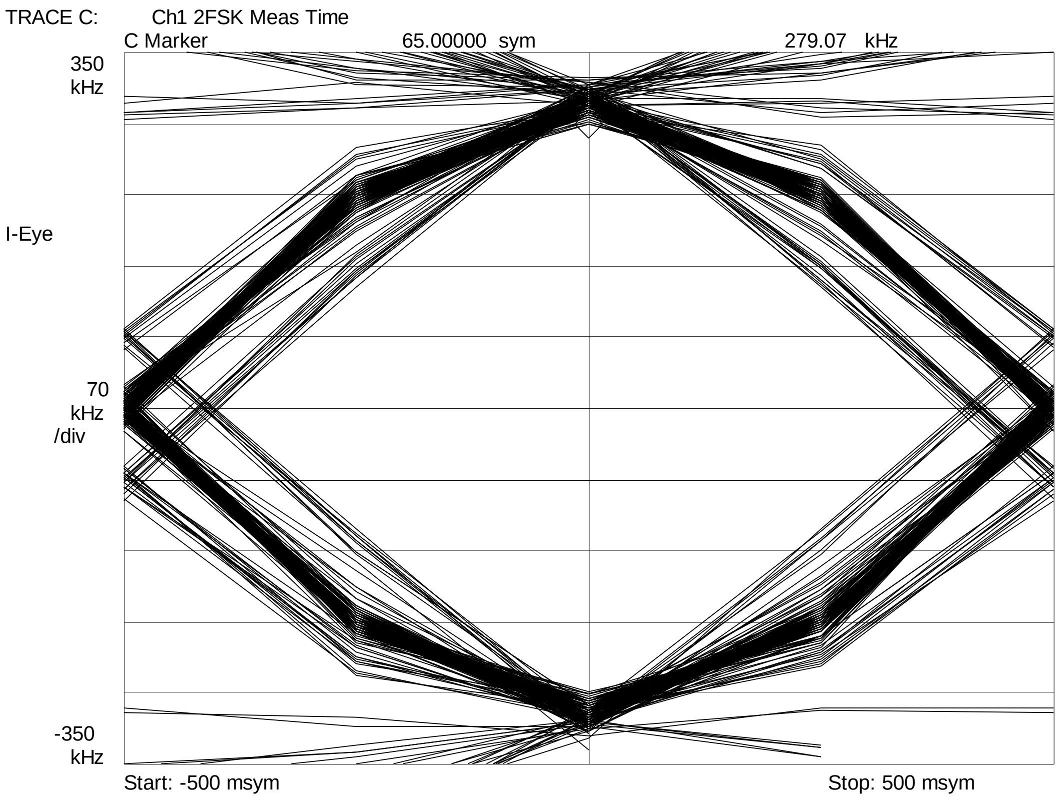
Step 1: Equipment Setup (§2.2.2.4)

For the test in this subparagraph, configure the Vector Signal Analyzer according to the Digital Demodulation Mode setup listed in Table 2-71. See Appendix N for the state file "UAT-DMD.STA" to automatically setup the HP89441A Vector Signal Analyzer. If the Trace C – RefLvl/Scale / Y per div[ision] setting does not equal 70 kHz, manually enter the value. On a display of 10 vertical divisions, deviations of ±280 kHz will occur at ±4 vertical divisions, respectively, from the display center.

Step 2: Vertical Modulation Distortion (§2.2.2.2 and §2.2.2.4)

Connect the ADS-B Transmitting Equipment to the Vector Signal Analyzer through enough attenuation to present a signal at the Vector Signal Analyzer input of –60 ± 5 dBm, and initiate a series of Long ADS-B test messages each having the following message elements: the 36 bit SYNCH, followed by a 272 bit Payload having a pseudo-random series of bits which changes for each successive payload, and a 112 bit FEC as generated by the Reed-Solomon algorithm. On the Trace C "Eye Diagram," find the minimum upper crossing, and the maximum lower crossing, at the horizontal center of the display, and verify that the upper crossing minus the lower crossing is no less than 560 kHz (8 vertical divisions). Trace C should resemble Figure 2-12.

UATDMDC2bw3.HGL ===> Recording Date: 12-09-03 Time: 15:40



<u>Figure 2-12:</u> Digital Demodulation Mode – Trace C: "Eye Diagram"

<u>Step 3</u> <u>Horizontal Modulation Distortion (§2.2.2.2) and (§2.2.2.4)</u>

On the Trace C "Eye Diagram," at the vertical center of the display, locate the innermost left crossing, and locate the innermost right crossing, and verify that the spacing between the right crossing and the left crossing is no less than 0.65 symbols in width.

2.4.2.5 Verification of Transmitter Power Output (§2.2.2.5)

<u>Purpose/Introduction:</u>

The Time/Amplitude profile of an ADS-B Message Transmission **shall** fall within the following limits relative to a *reference time* defined as 0.48 microseconds prior to the center of the first bit of the synchronization sequence (§2.2.3.1.1) appearing at the output port of the equipment.

All power measurements for subparagraphs "**a**" through "**f**" below apply to the selected antenna port for installations that support transmitter diversity (§2.2.6.1.3). The RF power output on the non-selected antenna port **shall** be at least 20 dB below the level on the selected port.

All power measurements for subparagraphs "**a**" and "**f**" assume a 300 kHz bandwidth. All power measurements for subparagraphs "**b**," "**c**," "**d**" and "**e**" assume a 2 MHz bandwidth.

a. Prior to 8 bit periods before the reference time, the average RF output power **shall** not exceed –80 dBm.

  Note: *This unwanted power requirement is necessary to ensure that the ADS-B Transmitting Subsystem does not prevent closely located UAT receiving equipment from meeting its requirements. It assumes that the isolation between transmitter and receiver equipment exceeds 20 dB.*

b. Between 8 and 6 bit periods prior to the reference time, the RF output power **shall** remain at least 20 dB below the minimum power requirement for the appropriate equipment class per Table 2-1.

c. During the Active state, defined as beginning at the reference time and continuing for the duration of the message (276 bit periods for the Basic Message and 420 bit periods for the Long Message), the RF output power **shall** comply with Table 2-2.

d. The RF output power **shall** not exceed the maximum limits of Table 2-2 at any time during the ADS-B Message Transmission Interval, as shown in Figure 2-1.

e. Within 6 bit periods after the end of the Active state, the RF output power **shall** be at a level at least 20 dB below the minimum power requirement for the appropriate equipment class per Table 2-1.

f. Within 8 bit periods after the end of the Active state, the average RF output power **shall** fall to a level not to exceed –80 dBm.

  Note: *This unwanted power requirement is necessary to ensure that the ADS-B Transmitting Subsystem does not prevent closely located UAT receiving equipment from meeting its requirements. It assumes that the isolation between transmitter and receiver equipment exceeds 20 dB.*

This test procedure verifies that the UAT Transmitter outputs the required power for the appropriate equipment class as stipulated in §2.2.2.5. The transmitter power requirements are verified for the Active state, the Inactive state and the defined intervals prior to and subsequent to the transmitted message.

Equipment Required:

The test configuration requires that data sources be provided to the appropriate UAT Transmitter interfaces to enable generation of Long ADS-B Messages. This could also be accomplished by the use of an internally generated Long ADS-B test message with randomly generated data content. Measure the power at the RF antenna port, or with attenuators, as appropriate, for the RF power measuring equipment being sure to account for the resulting loss. The RF power measurement system must be capable of measuring the average RF power of the modulated signal sampled over a defined interval indicated for each of the measurements below.

Measurement Procedures:

In all of the power measurements below, the power output measurement must be adjusted to take into account the loss allocated for cabling to the antenna of the aircraft. In the case of diversity transmitters, both top and bottom channel measurements must be performed. Unless specified otherwise, for the following power measurements, use a 2 MHz bandwidth filter setting.

Step 1: Measure Active State RF Power Output

Set up the UAT equipment to transmit a Long ADS-B Message. Measure the average RF power, over 1 microsecond intervals, of the transmitted signal during the message transmission interval, i.e., from the first bit of the synchronization pattern to the last bit of the message. Verify that the output power is at least the corresponding value in Table 2-2 for the equipment class under test. Verify that the power measurement does not exceed the maximum allowable and does not fall below the minimum allowable power level for the equipment class. Verify that the minimum and maximum power values specified in Table 2-2 for the equipment class are satisfied over the entire message by measuring the power at the 1 microsecond interval yielding the maximum power measurement and the interval yielding the minimum power.

Step 2: Verify RF Transmitter Power Prior to the Active State

a) Set up the UAT equipment to transmit a Long ADS-B Message. Measure the average RF power of the transmitted signal using 1 microsecond intervals over the interval which commences 8 bit periods (7.68 microseconds) prior to the active state, i.e., the start of the first bit of the synchronization pattern and ends 6 bits (5.76 microseconds) prior to the active state. The measured power level must be a minimum 20 dB below the corresponding minimum power value in Table 2-2 for the equipment class under test. The maximum allowed power values are: Low Power = 18.5 dBm, Medium Power = 22.0 dBm, High Power = 30.0 dBm. Verify that the power measurement does not exceed the corresponding allowable power level for the equipment class.

b) Measure the average RF power of the transmitted signal using 1 microsecond intervals over the interval which commences 6 bit periods prior to the active state. The measured power level must be at or below the corresponding maximum power value in Table 2-2 for the equipment class under test. The maximum allowed power values are: Low Power = 42.5 dBm, Medium Power = 46.0 dBm, High Power = 54.0 dBm. Verify that the power measurement does not exceed the corresponding allowable power level for the equipment class.

Step 3: Verify RF Transmitter Power Post Active State

a) Measure the average RF power of the transmitted signal using 1 microsecond intervals over the time interval which begins at the end of the Active state and ends 6 bit periods later. The measured power level must be at or below the corresponding maximum power value in Table 2-

2 for the equipment class under test. The maximum allowed power values are: Low Power = 42.5 dBm, Medium Power = 46.0 dBm, High Power = 54.0 dBm. Verify that the power measurement does not exceed the corresponding allowable power level for the equipment class.

b) Measure the average RF power of the transmitted signal using 1 microsecond intervals over the interval which commences 6 bit periods from the end of the message Active state and ends 2 bit periods later. The measured power level must be a minimum 20 dB below the corresponding minimum power value in Table 2-2 for the equipment class under test. The maximum allowed power values are: Low Power = 18.5 dBm, Medium Power = 22.0 dBm, High Power = 30.0 dBm. Verify that the power measurement does not exceed the corresponding allowable power level for the equipment class.

Step 4: Measure Inactive State RF Power Output

Set up the UAT equipment to transmit a Long ADS-B Message. For the following power measurement, use a 300 kHz bandwidth filter setting. Measure the average RF power over a 1 microsecond interval ending 10 bit periods prior to the start of the active state. Verify that the output power is –80 dBm or lower. Measure the peak RF power 10 bit periods after the end of the last transmitted message bit. Verify that the output power is –80 dBm or lower. Verify that the output power remains under –80 dBm for the 100 microsecond interval following the last transmitted bit. Repeat power measurement with no message transmission and verify that the output power when measured with a 300 kHz bandwidth is –80 dBm or lower.

Step 5: Measure Power at the Non Selected Antenna Port

The following step is required for those systems implementing transmitter diversity. Set up the UAT Transmitting Subsystem to transmit a Long ADS-B Message. Measure the ADS-B Message power at the Top antenna port and Bottom antenna port simultaneously on a UTC epoch that has selected to transmit on the Top antenna port. Verify that the power measured at the Bottom antenna port is 20 dB or more below the power measured on the Top antenna port.

Repeat on a UTC epoch that has selected to transmit on the Bottom antenna port. Verify that the power measured at the Top antenna port is 20 dB or more below the power measured on the Bottom antenna port.

2.4.2.6 Verification of In Band Transmission Spectrum (§2.2.2.6)

Purpose/Introduction:

The average spectrum of a UAT message transmission modulated with pseudo-random payload data **shall** fall within the limits specified in Table 2-3 and Figure 2-2 when measured in a 100 kHz bandwidth.

This test procedure verifies that the UAT Transmitter output conforms to the required transmission spectrum as stipulated in §2.2.2.6. The transmitter in band spectrum is specified for 250% of the occupied bandwidth or 3.25 MHz.

Equipment Required:

The test configuration requires data sources be provided to the appropriate UAT Transmitter interfaces to enable generation of Long ADS-B Messages. This could also be accomplished by the use of an internally generated Long ADS-B test message with randomly generated data content. Measure the power at the RF antenna port, or with attenuators, as appropriate, for the RF power measuring equipment being sure to account for the resulting loss. The RF power measurement system must be capable of measuring average RF power of the modulated signal sampled over a defined interval indicated for each of the measurements below. In all of the power measurements below, the power output measurement must be adjusted to take into account the loss allocated for cabling to the antenna of the aircraft.

Measurement Procedures:

In the case of diversity transmitters, perform all measurements for both top and bottom channels.

Step 1: Measure RF Power Output At Center Frequency

Set up the UAT equipment to transmit a Long ADS-B Message. Measure the peak RF power of the transmitted signal during the message transmission interval (including the ramp-up and ramp-down period) with a 100 kHz bandwidth over the range from 977.5 to 978.5 MHz. Record the maximum power measured.

Step 2: Measure RF Power Output Over Frequency Spectrum

Set up the UAT equipment to transmit a Long ADS-B Message. Measure the peak RF power of the transmitted signal with a 100 kHz bandwidth over the frequency range from 974.75 MHz to 981.25 MHz (±3.25 MHz) (including the ramp-up and ramp-down period). Verify that the levels relative to the power level recorded in Step 1 above are at, or below, the UAT Spectral Mask depicted in Figure 2.2.

2.4.2.7 Verification of Out-of-Band Emissions (§2.2.2.7)

Appropriate test procedures required to validate the requirements of §2.2.2.7 are provided in 47 CFR Part 87.

2.4.3 Verification of Broadcast Message Characteristics (§2.2.3)

No specific test procedure is required to validate §2.2.3.

2.4.3.1 Verification of ADS-B Message Format (§2.2.3.1)

No specific test procedure is required to validate §2.2.3.1.

2.4.3.1.1 Verification of Synchronization (§2.2.3.1.1)

Purpose/Introduction:

Following ramp up, the message **shall** include a 36-bit synchronization sequence. For the ADS-B Messages the sequence **shall** be:

111010101100110111011010010011100010

with the left-most bit transmitted first.

This test procedure verifies that the UAT Transmitter equipment correctly outputs the 36-bit synchronization sequence that is transmitted with each UAT Message.

Equipment Required:

The test configuration requires data sources be provided to the appropriate UAT Transmitter interfaces to enable generation of ADS-B Messages. Connect the RF antenna port through appropriate attenuation so that the output message can be received by measurement equipment that can detect and decode the modulated bit pattern to verify the 36 bits of the synchronization sequence.

Measurement Procedures:

Set up the UAT equipment to transmit a Long ADS-B Message. Verify that the first 36 bits transmitted contain the synchronization sequence:

111010101100110111011010010011100010.

2.4.3.1.2 Verification of Payload (§2.2.3.1.2)

No specific test procedure is required to validate §2.2.3.1.2.

2.4.3.1.3 Verification of FEC Parity (§2.2.3.1.3)

Appropriate test procedures required to validate the requirements of §2.2.3.1.3 are included in §2.4.3.1.3.1.

2.4.3.1.3.1 Verification of Code Type (§2.2.3.1.3.1)

Purpose/Introduction:

The FEC Parity generation **shall** be based on a systematic Reed-Solomon (RS) 256-ary code with 8 bit code word symbols. FEC Parity generation **shall** be per the following code:

a. Basic ADS-B Message: Parity **shall** be per a RS (30, 18) code

Note: *This results in 12 bytes (code symbols) of parity capable of correcting up to 6 symbol errors per block.*

b. Long ADS-B Message: This **shall** be per a RS (48, 34) code

Note: *This results in 14 bytes (code symbols) of parity capable of correcting up to 7 symbol errors per block.*

For either message length the primitive polynomial of the code **shall** be as follows:

$$p(x) = x^8 + x^7 + x^2 + x + 1.$$

The generator polynomial **shall** be as follows:

$$\prod_{i=120}^{P} (x - \alpha^i).$$

P = 131 for RS (30,18) code and P = 133 for RS (48,34) code

α is a primitive element of a Galois field of size 256 (i.e., GF(256)).

Note: *See Appendix C for more information on the implementation of the Reed Solomon code.*

The "FEC Parity" field is a 96-bit field (bit 1 of byte 19 through bit 8 of byte 30) for Basic ADS-B Messages, and a 112-bit field (bit 1 of byte 35, through bit 8 of byte 48) for Long ADS-B Messages. The "FEC Parity" symbols sequence is generated based on systematic encoding of Reed-Solomon (RS) 256-ary code with 8-bit code word symbols.

The following test procedure verifies that an ADS-B Transmitting Subsystem correctly generates the proper FEC for both Basic and Long ADS-B Messages.

This test procedure also verifies that an ADS-B Transmitting Subsystem correctly outputs the properly generated FEC in the transmitted Basic and Long ADS-B Messages.

Equipment Required:

a. Provide a method to supply controlled ADS-B Messages containing the payloads stipulated in the following tests. The message contents are input prior to the RS Encoding to verify proper RS parity encoding.

b. Provide a method to monitor the transmitted ADS-B Message sequences and associated FEC Parity resulting from the RS Encoding.

Measurement Procedures:

Step 1: Establish the Initial Conditions

Configure the ADS-B UAT Transmitting system to transmit Basic and Long ADS-B Messages and verify that the equipment under test is transmitting both messages.

Step 2: Verify FEC Parity for Basic Message (§2.2.3.1.3.1)

Load the set of Basic test messages given in Table 2-73 into the equipment under test. For each case of provided stimulus given in Table 2-73, verify that the ADS-B UAT Transmitting System properly generates the associated FEC Parity sequence as given in column 3 of Table 2-73.

Verify that all the FEC symbol sequences generated in column 3 of Table 2-73 follow the trailing end of the associated transmitted messages in left to right order as given in the following example message:

ADS-B Basic Message Payload (input to the RS encoder)

`913D23BB0C59DFACFCD7209492DFEEEDF381`

Transmitted ADS-B Basic Massage (output from the RS encoder)

`913D23BB0C59DFACFCD7209492DFEEEDF381`**E00B381341E499399 E8B62BF**

***Note**: Underlined data in the above transmitted ADS-B Basic Message is the FEC Parity sequence of that Basic ADS-B Message Payload.*

Step 3: Verify FEC Parity for Long Message (§2.2.3.1.3.1)

Load the set of Long test messages given in Table 2-74 into the equipment under test. For each case of provided stimulus given in Table 2-74, verify that the ADS-B UAT Transmitting System properly generates the associated FEC Parity sequence as given in column 3 of Table 2-74.

Verify that all of the FEC symbol sequences generated in column 3 of Table 2-74 follow the trailing end of the associated transmitted messages in left to right order as shown in the following example message:

ADS-B Long Message Payload (input to RS encoder)

`88C14FE677A75B489603580CAA606FD81EE91B64CBABA0563FC0C E1C2DA3016B2BA3`

Transmitted ADS-B Long Message (output from the RS encoder)

`88C14FE677A75B489603580CAA606FD81EE91B64CBABA0563FC0C E1C2DA3016B2BA3`**A078D3F21607140B4B6CB3E6EE2C**

***Note**: Underlined data in the above transmitted Long ADS-B Message is the FEC Parity sequence of that Long ADS-B Message Payload.*

Table 2-73: FEC Parity Encoding for Basic ADS-B Messages

No.	Basic Message	FEC Parity
1	913D23BB0C59DFACFCD7209492DFEEEDF381	E00B381341E499399E8B62BF
2	CDB4DB1F9A0CCDEA489D8E6633517082B58C	A1B8F183C8E609566F658B4A
3	17E2DCA2CCD5CBB109093A79330A9FFCDE97	CF7B4C67EEB1ADA4A75C757C
4	E5F871DECAF67B1EBD90BCC6E12883A283A9	26856284FF1846544E806833
5	F88BB215044741EB4503DB45EB0E088F5954	238909EF489ECCFA9C517103
6	2DDED1237D3CB84FDFD08DB934FA2F509288	B7E88C2AAC53B4FA680BDD63
7	1BFC58B922B425BF58082B5B2F6557D186FA	F53ACB6EB8CC7F09630B6D7C
8	CDD81CE4BAAB269060F3157CFCBA9ED06777	F389A23D7325C965A417DB8D
9	3DE973832F4D0B8A11AC04B0C06E228E0F56	42F4FE5F593C439ACD2E59B4
10	D5BF734F90953E6FD73D0EAEE96079F20F8C	0B7E1F709281212459963B78
11	B06978700FCCC13DDB8A7F2A32F3E2FB4DE4	D8B0D03BB104BD8092E4FF9A
12	5D06390EDA86A0C5F0532EA31837CDADD985	E12FD9632FB81081BA93453F
13	AE6A7620E7A0801B1594EBAF3F04770F043B	970F50A979D8312E1644C627
14	94EEBF889F502A52FF492DADA564682CD6E4	4168AF9AC449F62A2E32C22E
15	A84753F740104D900BA1A19B12E468B4092F	32A5FF94A0D4082083E22F55
16	2E802B5B8EE72A40EB4C2B3F707D1654B876	5EDC4A263D142BCEBAB36405
17	AC46B6B6A5F833BEC977877BCC33682DE61E	19D387B6C981C1E0198D0E98
18	DC1DD3024B21D65522BA5CE608744997AC20	B2DC6A2236A84CF530B3E273
19	B78696AE86E5FE4613D4AD4404FE595A6C54	B7C9E95FA0D7D7CA6AD7F3AA
20	F969C1A21E56D8602AF07769092D9D0E4AC2	33F36D4A513F133C8CB0850E
21	19A7AB011597F35820E3C770EB5A4051B3DE	662C2B69418B4927F2DDF7A4
22	6EEBA1E49C120EA576226715E2F9C2373D79	E6671F503C6AD08457F6B933
23	BE41419F4C3A3D96F97C7BA7EA486CF97E5E	719637E7650F9348F0355659
24	739E56B97628DA6585F33B123B5FB3DD3274	F29E2577F1C3A580AC28792B
25	897124E7F8661C5F979EC7E6E8F9D3041097	AE6352F2F849AA7C7BEE6FC1
26	DD4C708CEDF7ADBAFD4BC9BBF6D6D27B3CE2	F462D294648FAF59BBDA9F6A
27	F808A811E0A5057892A7F552EB3453FED45D	AAE09B6BF747200DDEACAC1F
28	6B6EBA3A33B5886E536693D118EAC116B7F6	CF23176AAD1781DCA56995F3
29	5E267BDADF9CA9BD120A559568EEDFE4F418	2120E3658F1F4CC802F7C486
30	DC7CAFCC1F6A2C6E1C464E09F7711DEDD49E	5EBFA9BFD7EB0D675A3A944B

Table 2-74: FEC Parity Encoding for Long ADS-B Messages

No.	Long Message	FEC Parity
1	88C14FE677A75B489603580CAA606FD81EE91B64CBABA0563FC0CE1C2DA3016B2BA3	A078D3F21607140B4B6CB3E6EE2C
2	739F75B1744FE00C87AA9F7EF0878830D23419434CEEC8B8391CEC5D1614C3381BAE	7AB075D35A6813030823D0B86148
3	F7B2895F117D54FB38EB0995CEB8B876A1FE2B1F4ADF316A8A01D924A9795A3F2450	71446A127F22DC38CCF6AA942818
4	7BF8B323408D048D38D81BF61F7DBC5F407063B8BBFF098CAC3BD5D6C64E84E56C30	7C4D68B1A532B310E1F4C0AAC2AC
5	FCB5D44275F7C1B8B55460F026954F7F593AE4A8CCB0360CE5B37BAD077FC22D4167	BE8964B29C12D09551ED3294F9E1
6	1C4FE476AD33112F584C7D8B61FF934D37069DD15FDD19E797027DE02CAAFC5B2741	E04F254E947E2C1C277C764ABEF3
7	8B8848D93ED768DF48DBC3B7A050478B2A88578A563E3CC41D7D94FA4D2A09F409DF	FF6029E7BFDF3E2D8DC1E2A25D33
8	22D0F51374CDEB578780AD17A70201A28F8127F591C3FF7FB17FF3E0589D5F630ED1	60748ED1FF0578140C3D9C91823B
9	939B650F35FF024810E5F486999F3E46B741C022A445F7B159FE32C1F6ADA528959C	22B6F9BB18DAAC43F24A0690D630
10	A6EDD48FCC8F42F74B094AB3DD6FDBC8F851EBE0251D06F8B4BA1A8EC4361FB92B89	D76929F61929FF6A963971FDBBDD
11	5DEFC36EDD7A4BCCD1C8AB288528ED9E9C96376129B5843976878A707806E4D64842	8B353AB2A7E79DDD650BECA9A646
12	090E24911DEB507BAAAE516C54265F62EFB39493C83D20D05B608C8BCE1CEED9802C	47431D8E69AFA71CC5F5C67AD845
13	7AD1E6D34A9CA0D7799A675843EE58DA3FE12D9E8C53E023EAC764F5143D549B6846	BB47BB5EAE83C13D3D8228CE9C48
14	D84229B09708E1A966FBB9A03B33C263E187182E0469462C2552D92A71C019ECA4CC	233FCB722101B928780F6847C43D
15	B9EE5CBB0F8393AA978C27ACDED299F501B478F6769C97F5488E8896DEB7FEDC2CC6	B98EC747D02F064510C784CD4094
16	03812A8935D098FA6F4B735A8C3E6B6DAFA57773C2F64A0F8FACAD8CA12D95D761FC	C0C28F63377126FB49EC9AF92ACF
17	7F0D163159EAAAA6091C75845B1362E2677EB5C23104BE221DC6C8CF6F7690E38256	B03A848FBD41F3028294787502C8
18	85DF5C0EB4EBC9AA1444BD938DAF897C7D17B077932D693438A9962B6F8347A054C6	F7A24606BA6C64E6D59E44AAABB2
19	86CAAC59028EAD4C6093F09F47253108602ACE1AF3163570CAB29F38071ADAA32239	F4C149C242B2EC2222192A020FA3
20	F444274488BEF7E710DD29A1E87DBB0FF5C4BF248833317D87F420E6F2085DA73413	9162AAEED525C53F29EC69D105AB
21	4C3C6F11981C3325E00DC1B2244F519FF587FF51D3325143921E7BD9CA98D644AEDA	C29E4A0F06E1F9EBF26F7CAF4517
22	3310BEEE66C7C07AD937DAC5EEB1E25EECFF1EA8EABB85CA56D0DDBF0CE42BF7A758	ED2B84F52713986644AB601BCAA3
23	C9D17AAA3F6FD86D09821F14F63CA5C6E16B868F40EC6BFCF10AC51CC3DE23DCFB6E	AE480E7E9C7B642C90E504E172ED
24	82C67962E58DBBC8787447250382D23E99FEB0F5A3BDC592BB1F9F510264FA1C5728	5A01A378DD239B679973E95B0E3B
25	ADC32EA3DF10D1150A16E2638B935EE2E9CEEEC8F8AB693A0983A30853EB1570BFF2	2DBB1FE1563CB0F472688639441F
26	610FCC04C9CB9C7AA7EE871654259E52BEA714DB0C4F6E9B6CB8731F1BD4B646B382	4FFCF3041CD1819FC386DCF7BEE0
27	3706C10380B636FB28A13CC52ACE0B39FD5B2950613842B6AD2E8D1E3D0560853DA7	A9319228174413D125E1F867FBBE
28	5DB8599FF7B8B1C51CD608884E2D0799864719699299394 1D529246FA1735CB1077E	F338358C9E2266FFB5C01EF1492B
29	6E015A24CD483EFFDB378589DE3730CDEEB04C4B303A1EE75D3438FC7BA0EBF92D16	5235F0CC8F97FA043B1E96AD3A5E
30	4F1488A232FBE98335A89D8973156389620B9229D8DC027969A460A2FBE626144C30	5D6647DEF9E73CBFAE6D605A1707
31	D280C7991A8F6237BB1CE460955F4CE9C2D5B7234B58FD42B79BEB900CA04B740242	AF644F247F765B9A5A823F28A985
32	95BBFB6C98B6972B5B89CD9008CF073BB36719DDC18090A4B6DA39544932CEFD775A	721B2D4CC23D7EBEA0F2783C4301
33	4023E5FB7228717AF6F291770B86896A708B0560DE08983A293F488D557B097EBB2E	FC3C3E45783264E555B46718F5C3
34	5DB1F23A86B39DCEEFEDDC1D39FF76D61EB37B4692BAFB63CE7F9837AEC8E7FB16D4	0163745136488B0A9C031CA751BB

<u>Table 2-74:</u> FEC Parity Encoding for Long ADS-B Messages (Continued)

No	Long Message	FEC Parity
35	22B83EC9766028157193069378286323A0126978763564D37AE20DEB62EF29B6EDB4	48EC70F7392515B4BE76663A7721
36	7FE4D4D5C6261CB4789FE3DD34A96FD4A6268021982B45620EADEB62357DA8EC7440	A31F0994ECDB931F3F008AE6DF10
37	B556DB291BFF5CB64D48EE956BA8970AA705FA7AA6CEE06BEA1E5E2188D80D2B36F8	F5968F9911568FC113113468CB66
38	7A7D8A28C27D6C2CF70C7DDE4DFD9AB02389ADF477916861CAF02621FB8A18C93AD5	B623395367CF47B8754206001FE1
39	6F94FDAC9AC43905EEF91CEF2E6D2AF35154072411E0250DFFA439D643C8B5B8AEDD	E52D541A8095AF2AA5E4395C2490
40	2890593C9F4A71B19C61DBF3ACACE8240BBA36C21A6B7873FD1B41E98FFF94549C8B	A45AFF6327F998395AEF39F8A9DD
41	4B371AFA1971AEE8BDF24CF6314A3F7F4E235FD454D44BF7C096685ACF7AFA9137C7	D9D838E28B4E13754B8693F133B5
42	9E0DDBDA7030968CAF6ACA652831718F29E7BE4264A0132A68C9F287272C09F9A4C6	0A40F4600B88244B68F8745D0AB6
43	183F49F3C85680F33CC58B24DD0DB29544684E5DAFF43C2674E3CA7850C8A9420CA7	A7C75E04043159891F506EB40CC1
44	5F885E5AEAD4EC6FF1BDF491BB23D62AD40AB0BB1219AFB0CF26C0272DEF5C5023D2	A3A7B3455C440B5175616B22745F
45	819822A12A1C2A79BA0A84AA4D1D8997D4B59F2163C068FBAFF7B5140FA7C34C0502	72BC9F3E5E3698B9D7BA8CCADA60
46	D9C0A438C6E5D9D35619E0893B89FC8F1A10321987D19996CAC412D136835C7DCD71	89CDB99711192AE95ED9A77108EF
47	71E41EA79FC27830AFEE057730E8BD0EA27664941E50F7EEB427341A9F633B420AF4	FB93C7DBF32B423DB4E9A6DC6C94
48	C8F3FC9E3D843BFE408C1AD7CB93A045FCC58164CED02A323BC68A04E19849F2A696	C9F02B36C8171AF59AE4087BC7B3
49	07A1F480699D0B0A86E285EFFAA811792989657E0BB38B527E21882C711CD86E77FB	A26A29143A37629BFEC8681DCF2D
50	76618366C9C36A873446E2F823D9A1E9D05FD21F2B1CFEEFF98AA75EC56EAB4F9C39	A07DE4E95FCD470D812220635C19
51	B826A3215AB4238BEFC0FC239A20B1AE611B6194351C8192F361979DA435C6EC995F	781CE9C5A6DA28D43305EEFF82E2
52	031E91CEA08B9EBCA9A6653FA57C7B063DC26C42F2F9C3FBBB160837D5B49DC617CB	812C8A0200CF06D5508C21A43E0D
53	6E2E81654BE17AC87BCBD12BC66C103F16F621C8E63C64091FD432A09C4654CCF120	2CF9A1B6141D59DBDB1D7891B2A0
54	9D89BAD4818277405FF2D094EC3AC63EE8DB936289B65802C410557BEFD944634FBE	3BCA615E5E9855DFE5C2484EC6B6
55	13F2986219087B5F89742EF33592A5636162E1F64225FCB96A3965BEAEACF7215E48	C80533045488FABF82B63A156461
56	5C07C205555043387044BFE339644E656FB5951A4D25DF04745A2025789D8C98AA27	B1C57A12030650463F913ACCFD5E
57	7B0DA278B7C0941364918A36BAC8F0F1A8AE2DB2A1169F232AE7BBF770DA280BF0E7	6B6B181A0477B99072291D08BA26
58	1BDE012041DEC9F401856B1D6D3DFAA79691FB5DAE1F8384AAC540B93F1070D4FB5F	C9DDAE407B765F6EC354B11F5F44
59	211F5E3936550C5389A6303F2CBB074821FAAC6A0781B57197931926ED03852AF939	8E2780D213F6C92CBD998270E451
60	18C918731D74215EC6338316033027C4E7B53355D0B8F3FB28D380997C42541E61C8	777E1834F68AE8C02902AA0C4E55

2.4.3.1.3.2 Verification of Generation and Transmission Order of FEC Parity (§2.2.3.1.3.2)

Appropriate test procedures required to validate the generation and transmission order of FEC Parity are included in §2.4.3.1.3.1.

2.4.3.2 Verification of Ground Uplink Message Format (§2.2.3.2)

No specific test procedure is required to validate §2.2.3.2.

2.4.3.2.1 Verification of Synchronization (§2.2.3.2.1)

No specific test procedure is required to validate §2.2.3.2.1.

2.4.3.2.2 Verification of Payload (Before Interleaving and After De-interleaving) (§2.2.3.2.2)

No specific test procedure is required to validate §2.2.3.2.2.

2.4.3.2.2.1 Verification of UAT-Specific Header (§2.2.3.2.2.1)

No specific test procedure is required to validate §2.2.3.2.2.1.

2.4.3.2.2.1.1 Verification of "GROUND STATION LATITUDE" Field Encoding (§2.2.3.2.2.1.1)

No specific test procedure is required to validate §2.2.3.2.2.1.1.

2.4.3.2.2.1.2 Verification of "GROUND STATION LONGITUDE" Field Encoding (§2.2.3.2.2.1.2)

No specific test procedure is required to validate §2.2.3.2.2.1.2.

2.4.3.2.2.1.3 Verification of "POSITION VALID" Field Encoding (§2.2.3.2.2.1.3)

No specific test procedure is required to validate §2.2.3.2.2.1.3.

2.4.3.2.2.1.4 Verification of "UTC Coupled" Field Encoding (§2.2.3.2.2.1.4)

No specific test procedure is required to validate §2.2.3.2.2.1.4.

2.4.3.2.2.1.5 Verification of Reserved Bits (§2.2.3.2.2.1.5)

No specific test procedure is required to validate §2.2.3.2.2.1.5.

2.4.3.2.2.1.6 Verification of "APPLICATION DATA VALID" Field Encoding (§2.2.3.2.2.1.6)

No specific test procedure is required to validate §2.2.3.2.2.1.6.

2.4.3.2.2.1.7 Verification of "SLOT ID" Field Encoding (§2.2.3.2.2.1.7)

No specific test procedure is required to validate §2.2.3.2.2.1.7.

2.4.3.2.2.1.8 Verification of "TIS-B SITE ID" Field Encoding (§2.2.3.2.2.1.8)

No specific test procedure is required to validate §2.2.3.2.2.1.8.

2.4.3.2.2.1.9 Verification of Reserved Bits (§2.2.3.2.2.1.9)

No specific test procedure is required to validate §2.2.3.2.2.1.9.

2.4.3.2.2.2 Verification of Ground Uplink Application Data (§2.2.3.2.2.2)

No specific test procedure is required to validate §2.2.3.2.2.2.

2.4.3.2.2.2.1 Verification of The Length Subfield Encoding (§2.2.3.2.2.2.1)

No specific test procedure is required to validate §2.2.3.2.2.2.1.

2.4.3.2.2.2.2 Verification of The Reserved Subfield Encoding (§2.2.3.2.2.2.2)

No specific test procedure is required to validate §2.2.3.2.2.2.2.

2.4.3.2.2.2.3 Verification of The Frame Type Subfield Encoding (§2.2.3.2.2.2.3)

No specific test procedure is required to validate §2.2.3.2.2.2.3.

2.4.3.2.2.2.4 Verification of The Frame Data Content (§2.2.3.2.2.2.4)

No specific test procedure is required to validate §2.2.3.2.2.2.4.

2.4.3.2.2.2.4.1 Verification of FIS-B APDU (§2.2.3.2.2.2.4.1)

No specific test procedure is required to validate §2.2.3.2.2.2.4.1.

2.4.3.2.2.2.4.2 Verification of Other Potential Future Frame Data Content (§2.2.3.2.2.2.4.2)

No specific test procedure is required to validate §2.2.3.2.2.2.4.2.

2.4.3.2.3 Verification of FEC Parity (Before Interleaving and After De-interleaving) (§2.2.3.2.3)

No specific test procedure is required to validate §2.2.3.2.3.

2.4.3.2.3.1 Verification of Code Type (§2.2.3.2.3.1)

No specific test procedure is required to validate §2.2.3.2.3.1.

2.4.3.2.3.2 Verification of Generation and Transmission Order of FEC Parity (§2.2.3.2.3.2)

No specific test procedure is required to validate §2.2.3.2.3.2.

2.4.3.2.4 Verification of Interleaved Payload and FEC Parity (§2.2.3.2.4)

No specific test procedure is required to validate §2.2.3.2.4.

2.4.4 Verification of The ADS-B Message Payload (§2.2.4)

No specific test procedure is required to validate §2.2.4.

2.4.4.1 Verification of Payload Type (§2.2.4.1)

No specific test procedure is required to validate §2.2.4.1.

2.4.4.2 Verification of Payload Elements (§2.2.4.2)

No specific test procedure is required to validate §2.2.4.2.

2.4.4.3 Verification of ADS-B Payload Composition by Payload Type Code (§2.2.4.3)

No specific test procedure is required to validate §2.2.4.3.

2.4.4.4 Verification of Payload Transmission Order (§2.2.4.4)

Appropriate test procedures are provided in §2.4.4.5 through §2.4.4.5.8.

2.4.4.5 Verification of Payload Contents (§2.2.4.5)

No specific test procedure is required to validate §2.2.4.5.

2.4.4.5.1 Verification of HEADER Element (§2.2.4.5.1)

Appropriate test procedures required to validate the requirements in §2.2.4.5.1 are included in §2.4.4.5.1.1 through §2.4.4.5.1.3.6.

2.4.4.5.1.1 Verification of "PAYLOAD TYPE CODE" Field Encoding (§2.2.4.5.1.1)

<u>Purpose/Introduction:</u>

The "PAYLOAD TYPE CODE" field is a 5-bit (bit 1 of byte 1 through bit 5 of byte 1) field used to identify the payload for decoding by the receiver. Definition of the "PAYLOAD TYPE CODE" field encoding that **shall** be used for all ADS-B Messages is provided in Table 2-10.

<u>Measurement Procedure:</u>

<u>Step 1:</u> <u>Establish Initial Conditions</u>

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing Payload Type Code information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Verify the following test procedures for each Message Type according to the capability of the UAT equipage classes.

<u>Step 2:</u> <u>Verify Payload Type Code Encoding for UAT Messages</u>

Set the ADS-B Transmitting Subsystem to transmit ADS-B Messages according to the capability of UAT equipage classes.

Verify that for each of the UAT equipage classes, the transmitted ADS-B Message Type is encoded according to Table 2-10.

2.4.4.5.1.2 Verification of "ADDRESS QUALIFIER" Field Encoding (§2.2.4.5.1.2)

Purpose/Introduction:

The "ADDRESS QUALIFIER" field is a 3-bit (bit 6 of byte 1 through bit 8 of byte 1) field used to indicate what the 24-bit "ADDRESS" field represents. Definition of the "ADDRESS QUALIFIER" field encoding that **shall** be used for all ADS-B Messages is provided in Table 2-12.

If the Address Selection Input (ICAO versus Temporary) is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "ADDRESS QUALIFIER" **shall** default to a value of ALL ZEROs (binary 000).

Measurement Procedure:

Step 1: Verification of Ownship ICAO 24-bit Aircraft Address

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide a valid ICAO Address to the ADS-B Transmitting Subsystem. Set the Address Selection (ICAO versus Temporary) input (see Table 2-98) to ICAO. Verify that the "ADDRESS QUALIFIER" field is set to ZERO (binary 000).

Step 2: Verification of Ownship Self-Assigned Temporary Address

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide a valid ICAO Address to the ADS-B Transmitting Subsystem. Set the Address Selection (ICAO versus Temporary) input (see Table 2-98) to Temporary. Verify that the "ADDRESS QUALIFIER" field is set to ONE (binary 001).

Step 3: Verification of Data Lifetime (§2.2.7.1)

Provide a valid ICAO Address to the ADS-B Transmitting Subsystem. Disable the Address Selection input and verify that, after 60 seconds, the "ADDRESS QUALIFIER" field in the next transmitted message is set to ZERO (binary 000).

2.4.4.5.1.3 Verification of "ADDRESS" Field Encoding (§2.2.4.5.1.3)

No specific test procedure is required to validate §2.2.4.5.1.3.

2.4.4.5.1.3.1 Verification of ICAO 24-bit Aircraft Address of Transmitting Aircraft (§2.2.4.5.1.3.1)

Purpose/Introduction:

An "ADDRESS QUALIFIER" value of ZERO (binary 000) **shall** indicate that the message is an ADS-B Message from an aircraft, and that the "ADDRESS" field holds the ICAO 24-bit address that has been assigned to that particular aircraft. The ICAO Aircraft Address **shall** be stored (or "latched") in the UAT Transmitting System upon Power Up.

If the Address Selection Input is set to the "ICAO" value, then the ADS-B Transmitting Subsystem **shall** declare a device failure in the event that it's own ICAO 24-bit Address (i.e., the Mode-S Address) is invalid, unavailable, or set to all "ZEROs" or all "ONEs."

Note: *The world-wide method for allocating and assigning the 24-bit ICAO aircraft addresses is described in Annex 10 to the Convention on International Civil Aviation, Volume III, Chapter 9. [ICAO Annex 10, Vol. III, Ch. 9].*

Equipment Required:

A method of loading valid data for ADS-B broadcast messages into the ADS-B equipment under test. A method of detecting and monitoring ADS-B broadcast messages. A method of modifying the ICAO 24-Bit Address provided to the Unit Under Test.

Measurement Procedure:

Step 1: Verification of ICAO 24-bit Aircraft Address of Transmitting Aircraft

Set up the ADS-B Transmitting Subsystem to transmit UAT messages. Set the Address Selection input to the ICAO value. Input each address in Table 2-75.

Verify that the "ADDRESS" field holds the input value of the input address and that the "ADDRESS QUALIFIER" field has a value of ZERO (binary 000).

Table 2-75: ICAO 24-bit Aircraft Address Encoding

"AA" [HEX]
AA AA AA
55 55 55
77 77 77
BB BB BB
DD DD DD
EE EE EE
FE DC BA
AB CD EF

The following Steps are used to verify that the ADS-B Transmitting monitoring function properly annunciates a "Fail Warn" condition in the event that the ICAO 24-Bit Address provided to the ADS-B Transmitting Subsystem is set to ALL ZEROs or ALL ONEs.

Step 2: Initial Conditions

Establish any state where the ADS-B Transmitting Subsystem is operational and indicating no Fail Warn conditions.

Step 3: Address set to ALL ZEROs

Remove power from the UUT. Set the ICAO 24-Bit Address provided to the UUT to ALL ZEROs. Apply power to the UUT. Verify that the ADS-B transmission function properly annunciates the "Fail Warn" state within no more than 2.0 seconds.

Step 4: New Initial Conditions

Repeat Step 2.

Step 5: Address set to ALL ONE's

Remove power from the UUT. Set the ICAO 24-Bit Address provided to the UUT to ALL ONE's. Apply power to the UUT. Verify that the ADS-B transmission function properly annunciates the "Fail Warn" state within no more than 2.0 seconds.

Step 6: Restore Normal Operations

Establish any state where the ADS-B Transmitting Subsystem is operational and indicating no Fail Warn conditions prior to continuing with further testing.

2.4.4.5.1.3.2 Verification of Self-Assigned Temporary Address of Transmitting Aircraft (§2.2.4.5.1.3.2)

Purpose/Introduction:

An "ADDRESS QUALIFIER" value of ONE (binary 001) **shall** indicate that the message is an ADS-B Message from an aircraft that is not receiving ATC services, and that the "ADDRESS" field holds the transmitting aircraft's self-assigned ownship temporary address. An "ADDRESS QUALIFIER" value of ONE **shall not** be used when the "Receiving ATC Services Flag" (§2.2.4.5.4.13.3) is set to ONE, indicating that the Participant is receiving ATC services.

The self-assigned temporary address **shall** be generated as follows:

Let: $ADDR_P$ = the ICAO 24-bit address that has been assigned to the aircraft;

$ADDR_T$ = the temporary address that is to be generated;

M(1) = the 12 least significant bits (LSBs) of the ownship “LATITUDE” field (per §2.2.4.5.2.1) the first time the temporary address option is selected;

M(2) = the 12 least significant bits (LSBs) of the ownship “LONGITUDE” field (per §2.2.4.5.2.1) the first time the temporary address option is selected;

M(3) = $4096 \times M(1) + M(2)$; and

TIME = the number of seconds that have elapsed since UTC midnight the first time the temporary address option is selected, represented as a 24-bit number.

Also, let “⊕” denote the modulo 2 bit-by-bit addition (or “exclusive OR”) operation.

a. If the transmitting aircraft’s ICAO 24-bit address $ADDR_P$ is available, then the temporary address $ADDR_T$ **shall** be the modulo 2, bit-by-bit summation of the permanent address and M(3), that is:

$$ADDR_T = ADDR_P \oplus M(3).$$

b. If the aircraft’s 24-bit ICAO address $ADDR_P$ is <u>not</u> available, then time of day **shall** be used as an additional randomizer. In that case, the temporary address $ADDR_T$ **shall** be the modulo 2, bit-by-bit summation of TIME and M(3), that is,

$$ADDR_T = TIME \oplus M(3).$$

<u>Measurement Procedure:</u>

<u>Step 1:</u> <u>Establish Initial Conditions</u>

Set up the ADS-B Transmitting Subsystem to transmit UAT messages.

<u>Step 2:</u> <u>Verify the Encoded Data when the ICAO 24-bit Address is Available</u>

Via the appropriate interface, provide the UUT with the exact Latitude, Longitude and $ADDR_P$ data provided in Table 2-76 and set the Address Selection (ICAO vs Temporary) to Temporary.

For each input Latitude and Longitude, verify the output “ADDRESS” field holds the exact 24-bit value in the $ADDR_T$ column in Table 2-76.

Table 2-76: Temporary Addresses with ICAO 24-bit Address

Latitude	Longitude	M(1)	M(2)	M(3)	$ADDR_P$	$ADDR_T$
234567	155555	567	555	567555	123456	444103
0AF3C4	097DB0	3C4	DB0	3C4DB0	030562	3F48D2
378536	214C37	536	C37	536C37	155555	463962
14C208	1553CA	208	3CA	2083CA	391122	1992E8
295AF6	047D5B	AF6	D5B	AF6D5B	E1E1E1	4E8CBA
0C3B98	22C97A	B98	97A	B9897A	FAA123	432859
123099	304532	099	532	099532	2E6A53	27FF61
3FFFFF	000001	FFF	001	FFF001	9F2BA6	60DBA7
044C64	211853	C64	853	C64853	B2C5A0	748DF3
1379A4	23F786	9A4	786	9A4786	D3C975	498EF3
11AE25	079F6C	E25	F6C	E25F6C	C47A3C	262550
247F01	395888	F01	888	F01888	A77130	5769B8
33A042	2FC9FB	042	9FB	0429FB	6431A6	60185D
006FAB	123543	FAB	543	FAB543	40AE48	BA1B0B
197605	0FF41F	605	41F	60541F	59562E	390231

Step 3: Verify the Encoded Data when the ICAO 24-bit Address is **not** Available

Via the appropriate interface, provide the UUT with the exact Latitude and Longitude data provided in Table 2-77 and set the Address Selection (ICAO versus Temporary) to Temporary.

For each input Latitude and Longitude, verify the output "ADDRESS" field holds the exact 24-bit value in the $ADDR_T$ column in Table 2-77.

Table 2-77: Temporary Addresses without ICAO 24-bit Address

Latitude	Longitude	M(1)	M(2)	M(3)	Time	$ADDR_T$
234567	155555	567	555	567555	007E90	560BC5
0AF3C4	097DB0	3C4	DB0	3C4DB0	00E880	3CA530
378536	214C37	536	C37	536C37	014370	522F47
14C208	1553CA	208	3CA	2083CA	010A47	21898D
295AF6	047D5B	AF6	D5B	AF6D5B	00A1ED	AFCCB6
0C3B98	22C97A	B98	97A	B9897A	00301F	B9B965
123099	304532	099	532	099532	002D5A	09B868
3FFFFF	000001	FFF	001	FFF001	012A65	FEDA64
044C64	211853	C64	853	C64853	010101	C74952
1379A4	23F786	9A4	786	9A4786	0015E6	9A5260
11AE25	079F6C	E25	F6C	E25F6C	0109EA	E35686
247F01	395888	F01	888	F01888	00FACE	F0E246
33A042	2FC9FB	042	9FB	0429FB	000158	0428A3
006FAB	123543	FAB	543	FAB543	0019E6	FAACA5
197605	0FF41F	605	41F	60541F	00E430	60B02F

Step 4: Verify Self-Assigned Address only when Not Receiving ATC Services

Via the appropriate interface, set the "Receiving ATC Services Flag (§2.2.4.5.4.13.3) to ONE (1) and set the Address Selection Input to Temporary. Verify that the resultant ADDRESS QUALIFIER value is still set to ZERO (binary 000).

2.4.4.5.1.3.3 Verification of ICAO 24-bit Aircraft Address of TIS-B or ADS-R Target Aircraft (§2.2.4.5.1.3.3)

No specific test procedure is required to validate §2.2.4.5.1.3.3.

2.4.4.5.1.3.4 Verification of TIS-B Track File Identifier (§2.2.4.5.1.3.4)

No specific test procedure is required to validate §2.2.4.5.1.3.4.

2.4.4.5.1.3.5 Verification of Surface Vehicle Address (§2.2.4.5.1.3.5)

No specific test procedure is required to validate §2.2.4.5.1.3.5.

2.4.4.5.1.3.6 Verification of Fixed ADS-D Beacon Address (§2.2.4.5.1.3.6)

No specific test procedure is required to validate §2.2.4.5.1.3.6.

2.4.4.5.1.3.7 Verification of ADS-R Target with Non-ICAO Address (§2.2.4.5.1.3.7)

No specific test procedure is required to validate §2.2.4.5.1.3.7.

2.4.4.5.2 Verification of STATE VECTOR Element (§2.2.4.5.2)

Purpose/Introduction:

Format for the STATE VECTOR element is defined in Table 2-13. This encoding applies to ADS-B Messages with PAYLOAD TYPE CODES of "0" through "10," when the ADDRESS QUALIFIER value is "0," "1," "4" or "5." Each of the fields shown is defined in §2.2.4.5.2.1 through §2.2.4.5.2.10.

When more than one position source is provided to the ADS-B Transmitting Subsystem, the transmitter will select a single source to provide horizontal position, horizontal velocity, and their associated quality metrics. Heading used to populate the Track Angle/Heading Field on the surface may be supplied by a different source than that which supplies horizontal position and ground speed.

Measurement Procedure:

This test procedure verifies that the source selection logic chooses the best source based on the quality of the available integrity. It also verifies that all horizontal position, velocity, and quality metrics are used from a single selected source. This test procedure is written assuming that two position sources are available to the ADS-B transmitter. If more than two sources are available in an installation, this test should be expanded to encompass the available sources.

Step 1: Select Source with Smallest Radius of Containment, Airborne

Configure the ADS-B Transmitter as Airborne. Provide position information on Interface A with: Latitude=35.0 North, Longitude=90.0 West, N/S Velocity=100 Knots North, E/W Velocity=100 Knots East, Horizontal Accuracy=35 meters, Horizontal Integrity = 80 meters, SIL=3.

Provide position information on Interface B with: Latitude=23.0 South, Longitude=70.0 East, N/S Velocity=50 Knots South, E/W Velocity=50 Knots

West, Horizontal Accuracy=20 meters, Horizontal Integrity=190 meters, SIL=3.

Verify that the transmitted UAT Message fields are populated with data from Interface A. Specifically the Latitude=35.0 North, the Longitude=90.0 West, N/S Velocity=100 Knots North, E/W Velocity=100 Knots East, NAC_P=8, and SIL=3.

Step 2: Switch Sources when Integrity of the Alternate Source is Consistently Better, Airborne

Change the Horizontal Integrity on Interface B to 60 meters. Wait for the source selection logic to re-evaluate the selection criteria. Verify that the transmitted UAT Message fields are populated with data from Interface B. Specifically the Latitude=23.0 South, the Longitude=70.0 East, N/S Velocity=50 Knots South, E/W Velocity=50 Knots West, NAC_P=9, and SIL=3.

Step 3: Select Source with Smallest Radius of Containment, Surface

Configure the ADS-B Transmitter as On-Ground. Provide position information as in Step 1. If heading is available to the system, invalidate it so the system reverts to using Track Angle.

Verify that the transmitted UAT Message fields are populated with data from Interface A. Specifically, the Latitude=35.0 North, the Longitude=90.0 West, Ground Track=45 Degrees, NAC_P = 8, and SIL=3.

Step 4: Switch Sources when Integrity of the Alternate Source is Consistently Better, Surface

Change the Horizontal Integrity on Interface B to 60 meters. Wait for the source selection logic to re-evaluate the selection criteria. Verify that the transmitted UAT Message fields are populated with data from Interface B. Specifically the Latitude=23.0 South, the Longitude=70.0 East, Ground Track=225 Degrees, NAC_P=9, and SIL=3.

Appropriate test procedures required to validate all other requirements in §2.2.4.5.2 are included in §2.4.4.5.2.1 through §2.4.4.5.2.10.

2.4.4.5.2.1 Verification of "LATITUDE" and "LONGITUDE" Field Encoding (§2.2.4.5.2.1)

a. The "LATITUDE" field is a 23-bit (bit 1 of byte 5 through bit 7 of byte 7) field used to encode the latitude of the ADS-B Transmitting Subsystem in WGS-84. The encoding of this field **shall** be as indicated in Table 2-14. Also see Figure 2-6.

b. The "LONGITUDE" field is a 24-bit (bit 8 of byte 7 through bit 7 of byte 10) field used to encode the latitude of the ADS-B Transmitting Subsystem in WGS-84. The encoding of this field **shall** be as indicated in Table 2-14. Also see Figure 2-6.

c. The encoding of ALL ZEROs in the "LATITUDE" and "LONGITUDE" and "NIC" (§2.2.4.5.2.4) fields **shall** indicate that Latitude/Longitude information is "unavailable."

Note: *Since the encoding of ALL ZEROs is a valid location on the earth, ADS-B Receiving Subsystems will interpret this as Latitude/Longitude information "unavailable" only if the NIC field is also set to ZERO.*

If either the Latitude Input or the Longitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the LATITUDE, LONGITUDE and NIC fields **shall** default to a value of ALL ZEROs.

2.4.4.5.2.1.1 Verification of Latitude and Longitude for NAC_P < 10 (§2.2.4.5.2.1and §2.2.7.2.1)

Purpose/Introduction:

The following test procedure verifies the UAT Transmitting equipment meets the latitude and longitude encoding requirements of §2.2.4.5.2.1 for NAC_P values less than TEN (10).

The following test procedures verify that ADS-B Transmitting Subsystems correctly receive Latitude and Longitude position data from the Navigation source and output encoded Latitude and Longitude data in the Basic ADS-B Message. Latitude and Longitude data are encoded according to Angular Weighted Binary Encoding Method with a resolution of 2^{-24} circles. This test is required for all equipment.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B Transmitting Subsystem to transmit ADS-B Messages and verify that the equipment under test is transmitting the messages.

Step 2: Verify the Encoded Latitude and Longitude – Data Lifetime

Set up the ADS-B Transmitting Subsystem as above and provide the valid non-zero Latitude and Longitude values in degrees at the nominal rate of the navigation data source.

Discontinue providing Latitude and/or Longitude data to the ADS-B transmission device. After 2 seconds, verify that for each UNAVAILABLE Longitude and/or Longitude input entry in columns 2 and 3 of Table 2-80, that the resultant "LATITUDE," "LONGITUDE" and "NIC" fields yield binary coding values of ALL ZEROs as described in Table 2-80.

The test shall be considered to have failed if the "LATITUDE" or "LONGITUDE" or "NIC" field is NOT encoded as ALL ZEROs. Otherwise, the test shall be considered to have passed.

Step 3: Verify the Encoded Latitude and Longitude – Data Equal ZERO

Set up the ADS-B Transmitting Subsystem as above and provide ZERO DEGREE Latitude and/or Longitude values at the nominal rate of the navigation data source.

Verify that each ZERO DEGREE Longitude and/or Longitude input value in degrees in Table 2-80 (Cases 6 through 8) matches the corresponding binary coding value in the "LATITUDE" and "LONGITUDE" fields, and the binary coding values of NOT ALL ZEROs in the "NIC" field, as described in Table 2-80.

The test shall be considered to have failed if the "NIC" field is encoded as ALL ZEROs. Otherwise, the test shall be considered to have passed.

Step 4: Verify the Encoded Latitude and Longitude Data - Discrete Values

Via the appropriate Navigation Data Source interface, provide the ADS-B Transmitting Subsystem with the exact Latitude and Longitude data provided in the Latitude and Longitude values columns for each line item given in Table 2-78, Table 2-79 and Table 2-80 respectively.

Provide the Latitude and Longitude data via the interface at the nominal rate of the navigation data source.

Allow the system to stabilize after applying the data prior to continuing with following steps.

For each Basic ADS-B Message that is broadcast by the ADS-B Transmitting Subsystem:

1. Verify that each Latitude input value in degrees in Table 2-78 correctly matches the corresponding binary coding value in Table 2-78.

   If the encoded value differs from the binary value in Table 2-78, then the test shall be considered to have failed. Otherwise, the test is considered to have passed.

2. Verify that for each Longitude input value in degrees in Table 2-79 correctly matches the corresponding binary coding value in Table 2-79.

   If the encoded value differs from the binary value in Table 2-79, then the test shall be considered to have failed. Otherwise, the test is considered to have passed.

Step 5: Verify Latitude and Longitude Data Encoding – Input Resolution (Part 1)

If the input data used to establish the LATITUDE and LONGITUDE subfields have more resolution than that required by the LATITUDE and LONGITUDE subfields (i.e., more than 24 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the LATITUDE and LONGITUDE subfield.

If the input data fields that are used to determine the output value of the LATITUDE and LONGITUDE subfields do not have finer resolution than that required by the LATITUDE and LONGITUDE subfields, skip Step 5 and stop.

Enter an input value corresponding to Latitude of 45 + ($360/2^{25}$) degrees North.

Verify that the value of the Latitude subfield in the output message is either "2097152" (binary 0010 0000 0000 0000 0000 0000, representing 45 degrees) or “2097153” (binary 0010 0000 0000 0000 0000 0001, representing 45 +($360/2^{24}$) degrees).

If the input field used to establish the Latitude subfield does not have resolution finer than ($360/2^{25}$) degree, skip the rest of Step 5 and stop. Otherwise (Latitude input resolution is finer than [$360/2^{25}$] degree), let **Z** be equal to the smallest possible value that can be represented by the number of bits in the input field (i.e., **Z** is the value of the least significant bit of the input field). Set the value of the input field to correspond to Latitude of (45 + [$360/2^{25}$] – **Z** degrees).

Verify that the value of Latitude subfield in the output UAT message is “2097152” (binary 0010 0000 0000 0000 0000 0000, representing 45 degrees). Set the value of input field to correspond to Latitude of (45+[$360/2^{25}$] + **Z** degrees).

Verify that the value of secondary Latitude subfield in the output UAT message is “2097153” (binary 0010 0000 0000 0000 0000 0001, representing 45+($360/2^{24}$) degrees).

Note: *If the resolution of the Latitude/Longitude input is such that a Latitude of 45+($360/2^{25}$) degrees can be represented (but still finer than ($360/2^{25}$) degrees, e.g., a resolution of 0.00001 degree increments), then values corresponding to Latitude/Longitude must be tested, and the output examined for each value to confirm that output is within ±($360/2^{25}$) degrees (inclusive) of the input value.*

Step 6: Verify Latitude and Longitude Data Encoding – Input Resolution (Part 2)

Repeat Step 4 with an input value corresponding to Longitude of 45+($360/2^{25}$) degrees East.

<u>Table 2-78:</u> Latitude Encoding Values

Latitude (degrees)	Latitude Coding (binary)
0.000000000	000 0000 0000 0000 0000 0000
0.000026822	000 0000 0000 0000 0000 0001
0.000048280	000 0000 0000 0000 0000 0010
0.000112653	000 0000 0000 0000 0000 0101
0.000219941	000 0000 0000 0000 0000 1010
0.000434518	000 0000 0000 0000 0001 0100
0.000885129	000 0000 0000 0000 0010 1001
0.001764894	000 0000 0000 0000 0101 0010
0.003545880	000 0000 0000 0000 1010 0101
0.007086396	000 0000 0000 0001 0100 1010
0.014167428	000 0000 0000 0010 1001 0100
0.028329492	000 0000 0000 0101 0010 1000
0.056653619	000 0000 0000 1010 0101 0000
0.113301873	000 0000 0001 0100 1010 0000
0.226598382	000 0000 0010 1001 0100 0000
0.453191400	000 0000 0101 0010 1000 0000
0.906377435	000 0000 1010 0101 0000 0000
1.812749505	000 0001 0100 1010 0000 0000
3.625493646	000 0010 1001 0100 0000 0000
7.250981927	000 0101 0010 1000 0000 0000
14.501958489	000 1010 0101 0000 0000 0000
29.003911614	001 0100 1010 0000 0000 0000
58.007817864	010 1001 0100 0000 0000 0000
90.000000	100 0000 0000 0000 0000 0000
-66.093739	101 0001 0000 0000 0000 0000
-60.468739	101 0101 0000 0000 0000 0000
-90.000000	100 0000 0000 0000 0000 0000

Table 2-79: Longitude Encoding Values

Longitude (degrees)	Longitude Coding (binary)
0.000018	0000 0000 0000 0000 0000 0000
0.000037	0000 0000 0000 0000 0000 0001
0.000073	0000 0000 0000 0000 0000 0011
0.000147	0000 0000 0000 0000 0000 0110
0.000294	0000 0000 0000 0000 0000 1101
0.000587	0000 0000 0000 0000 0001 1011
0.001175	0000 0000 0000 0000 0011 0110
0.002350	0000 0000 0000 0000 0110 1101
0.004699	0000 0000 0000 0000 1101 1011
0.009398	0000 0000 0000 0001 1011 0110
0.018797	0000 0000 0000 0011 0110 1100
0.037594	0000 0000 0000 0110 1101 1000
0.075188	0000 0000 0000 1101 1011 0000
0.150375	0000 0000 0001 1011 0110 0000
0.300751	0000 0000 0011 0110 1100 0000
0.601501	0000 0000 0110 1101 1000 0000
1.203003	0000 0000 1101 1011 0000 0000
2.406006	0000 0001 1011 0110 0000 0000
4.812012	0000 0011 0110 1100 0000 0000
9.624023	0000 0110 1101 1000 0000 0000
19.248047	0000 1101 1011 0000 0000 0000
38.496094	0001 1011 0110 0000 0000 0000
76.992188	0011 0110 1100 0000 0000 0000
153.984375	0110 1101 1000 0000 0000 0000
-52.031250	1101 1011 0000 0000 0000 0000
-104.062500	1011 0110 0000 0000 0000 0000
151.875000	0110 1100 0000 0000 0000 0000
-56.250000	1101 1000 0000 0000 0000 0000
-112.500000	1011 0000 0000 0000 0000 0000
135.000000	0110 0000 0000 0000 0000 0000
-90.000000	1100 0000 0000 0000 0000 0000
180.000000	1000 0000 0000 0000 0000 0000

Table 2-80: Latitude and Longitude Encoding Values for Data Unavailable and Data Equals ZERO Cases

Case	Input Latitude (degrees)	Input Longitude (degrees)	Latitude Coding (binary)	Longitude Coding (binary)	NIC Coding (binary)
1	Unavailable	0.000018	ALL ZEROs	ALL ZEROs	ALL ZEROs
2	0.000055	Unavailable	ALL ZEROs	ALL ZEROs	ALL ZEROs
3	Unavailable	0.000000	ALL ZEROs	ALL ZEROs	ALL ZEROs
4	0.000000	Unavailable	ALL ZEROs	ALL ZEROs	ALL ZEROs
5	Unavailable	Unavailable	ALL ZEROs	ALL ZEROs	ALL ZEROs
6	0.000000	0.000000	ALL ZEROs	ALL ZEROs	*NOT ALL ZEROs*
7	14.501958489	0.000000	0x0A5000	ALL ZEROs	*NOT ALL ZEROs*
8	0.000000	-56.250000	ALL ZEROs	0xD80000	*NOT ALL ZEROs*

2.4.4.5.2.1.2 Verification of Latitude and Longitude for $NAC_P \geq 10$ (§2.2.4.5.2.1 and §2.2.7.2.2)

Appropriate test procedures required to validate the requirements in §2.2.4.5.2.1 are included in §2.4.7.2.2.1 and §2.4.7.2.2.2.

2.4.4.5.2.2 Verification of "ALTITUDE TYPE" Field Encoding (§2.2.4.5.2.2)

Purpose/Introduction:

The "ALTITUDE TYPE" field is a 1-bit (bit 8 of byte 10) field used to identify the source of information in the "ALTITUDE" and "SECONDARY ALTITUDE" fields. The encoding of this field is reflected in Table 2-15.

If the Altitude Type Selection Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "ALTITUDE TYPE" **shall** default to a value of ZERO if Pressure Altitude is available.

A means **shall** be provided to operationally inhibit the broadcast of Pressure Altitude information, making it unavailable for transmission. If an Altitude Type Selection Input is available, it **shall** be used to operationally select the preferred ALTITUDE TYPE that is reported if more than one ALTITUDE TYPE is available. If only one altitude source is available, then the use of that Altitude **shall** be refelected in both the "ALTITUDE TYPE" and "ALTITUDE" fields.

If the Altitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then that Altitude **shall** be deemed unavailable for the purposes of encoding the "ALTITUDE TYPE" field.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing valid altitude information.

Step 2: Verify Altitude Type Encoding

Set the ADS-B Transmitting Subsystem to transmit ADS-B Messages.

Operationally select Barometric Pressure Altitude as the Primary Altitude information. Verify that the “ALTITUDE TYPE” field in SV (bit 8 of byte 10) is set to ZERO.

Operationally select Geometric Altitude as the Primary Altitude information. Verify that the “ALTITUDE TYPE” field in SV (bit 8 of byte 10) is set to ONE.

Step 3: Verify Altitude Type Encoding – Selected Altitude Type Information is Not Available

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide valid Barometric Pressure Altitude and Geometric Altitude to the UUT.

Operationally select Barometric Pressure Altitude as the Primary Altitude information. Verify that if the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is set to ZERO (0).

Discontinue the input of Barometric Pressure Altitude data to the ADS-B system. Verify that after 2 seconds, Geometric Altitude is reported in “ALTITUDE” subfield of transmitted message and that it is set to the corresponding binary coding value in Table 2-16. Verify that the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is now set to ONE (1).

Reconnect the Barometric Pressure Altitude data input and operationally select Geometric Altitude as the Primary Altitude information. Verify that the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is set to ONE (1).

Discontinue the input of Geometric Altitude data to the ADS-B system and resume the input of Barometric Pressure Altitude. Verify that after 2 seconds, that the Barometric Pressure Altitude is reported in the “ALTITUDE” subfield of transmitted messages and that it is set to the corresponding binary coding value as described in Table 2-16. Verify that the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is now set to ZERO (0).

Step 4: Verification of Altitude Type Encoding – Altitude Type Data Lifetime

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide valid Barometric Pressure Altitude and Geometric Altitude to the UUT.

Disable the input that tells the UUT which Altitude Type was operationally selected. Verify that, after 60 seconds, the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is now set to ZERO (0).

Repeat this step and also discontinue the Barometric Pressure Altitude data when you disable the input that tells the UUT which Altitude Type was operationally selected. Verify that, after 60 seconds, the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is now set to ONE (1).

Step 5: Verify Altitude Type Selection – Altitude Broadcast Inhibit Selection

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide valid Barometric Pressure Altitude and Geometric Altitude to the UUT.

Operationally inhibit the broadcast of pressure altitude information.

Operationally select the Barometric Pressure Altitude as the Primary Altitude information. Verify the following:

1. The “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is set to ONE (1).

2. The Geometric Altitude is reported in the “ALTITUDE” field.

3. The Barometric Pressure Altitude is reported in the “SECONDARY ALTITUDE” subfield of transmitted messages, and that it is set to ZERO (binary 0000 0000 0000) indicating that data is not available.

Do not operationally inhibit the broadcast of pressure altitude information.

Operationally select the Barometric Pressure Altitude as the Primary Altitude information. Verify that the “ALTITUDE TYPE” field in the State Vector (bit 8 of byte 10) is set to ZERO (0). Verify that the Barometric Pressure Altitude is reported in the “ALTITUDE” subfield of transmitted messages and that it is set to the corresponding binary coding value as described in Table 2-16.

2.4.4.5.2.3 Verification of “ALTITUDE” Field Encoding (§2.2.4.5.2.3)

Purpose/Introduction:

The “ALTITUDE” field is a 12-bit (bit 1 of byte 11 through bit 4 of byte 12) field used to encode the altitude of the ADS-B Transmitting Subsystem. The encoding of this field **shall** be as indicated in Table 2-16.

If the Altitude Input is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-98, then that Altitude **shall** be deemed unavailable for the purposes of encoding the “ALTITUDE” field.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing Altitude information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Selection of Primary Altitude Information

Operationally select Barometric Pressure Altitude as the Primary Altitude information for the following steps (step 3 through step 7) and verify that the “ALTITUDE TYPE” field in (bit 8 of byte 10) is set to ZERO.

Step 3: Verify Altitude Field Encoding – Data Lifetime

Set up the system to enable broadcast of UAT Messages. Provide valid non-zero Altitude data and valid non-zero velocity data to the ADS-B system.

Discontinue the input of Altitude data to the ADS-B system. Verify that after the Altitude data has not been provided to the ADS-B Transmitting Subsystem for 2 seconds, that the "ALTITUDE" field is set to a value of "0" (binary 0000 0000 0000).

Resume Altitude data input with a value of –775 feet and verify that the ADS-B Message contains an "ALTITUDE" field that is set to a value of "10" (binary 0000 0000 1010).

Step 4: Verify Altitude Field Encoding – Altitude Equal ZERO

Set the Altitude input data to represent an altitude of ZERO feet. Verify that the "ALTITUDE" field is set to a value of "41" (binary 0000 0010 1001).

Step 5: Verify Altitude Field Encoding – Discrete Values

Verify that for each integer Altitude input values in feet in Table 2-81 that the system generates UAT Messages that Altitude subfield in each such message is set to the corresponding binary coding value in Table 2-81.

Verify that the Altitude subfield in the transmitted message is not incremented until the input value reaches a number corresponding to a multiple of 25 feet.

Table 2-81: Altitude Field Encoding

Altitude Data		
Meaning (Altitude in feet)	**Coding (decimal)**	**Coding (binary)**
-1000	1	0000 0000 0001
-900	5	0000 0000 0101
-775	10	0000 0000 1010
-500	21	0000 0001 0101
25	42	0000 0010 1010
1100	85	0000 0101 0101
3225	170	0000 1010 1010
7500	341	0001 0101 0101
16025	682	0010 1010 1010
33100	1365	0101 0101 0101
67225	2730	1010 1010 1010
86425	3498	1101 1010 1010
92825	3754	1110 1010 1010
99225	4010	1111 1010 1010
100425	4058	1111 1101 1010
100825	4074	1111 1110 1010
101225	4090	1111 1111 1010
101300	4093	1111 1111 1101
101325	4094	1111 1111 1110

Step 6: Verify Altitude Field Encoding – Maximum Values

Continue to increase the Altitude value.

Verify that if the resolution of the input value is the same as the output resolution (i.e, 25 feet), verify that for an input corresponding to an altitude of 101,350 feet, the altitude field is set to “4095” (binary 1111 1111 1111).

If the resolution of input value is greater than output resolution, verify that for an input corresponding to an altitude of greater than 101,325 feet but less than or equal to 101,337.5 feet, the altitude field continue to be set to “4094” (binary 1111 1111 1110).

If the resolution of the input data makes it possible to enter an input value that corresponds to exactly 101,337.5 feet, then this value shall be input and it shall verify that the Altitude subfield for all such messages is set to either “4094” (binary 1111 1111 1110, representing 101,325 feet) or “4095” (binary 1111 1111 1111, representing 101,337.5 feet).

Step 7: Verify Altitude Field Encoding – Input Resolution

If the input data used to establish the ALTITUDE subfield has more resolution than that required by the ALTITUDE subfield (i.e., more than 12 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the ALTITUDE subfield.

If the input data field that is used to determine the output value of the ALTITUDE subfield does not have finer resolution than that required by the ALTITUDE subfield, then skip Step 7 and stop.

Enter an input value corresponding to an altitude of 37.5 feet.

Verify that the value of the ALTITUDE subfield in the output message is either “42” (binary 0000 0010 1010, representing 25 feet) or “43” (binary 0000 0010 1011, representing 50 feet).

If the input field used to establish the Altitude subfield does not have resolution finer than 12.5 feet, skip the rest of Step 7 and stop. Otherwise (Altitude input resolution is finer than 12.5 feet), let **Z** be equal to the smallest possible value that can be represented by the number of bits in the input field (i.e., **Z** is the value of the least significant bit of the input field). Set the value of the input field to correspond to an altitude of (37.5 –**Z** feet).

Verify that the value of the altitude subfield in the output UAT message is “42” (binary 0000 0010 1010, representing 25 feet). Set the value of input field to correspond to an altitude of (37.5+**Z** feet).

Verify that the value of the altitude subfield in the output UAT message is “43” (binary 0000 0010 1011, representing 50 feet).

Note: *If the resolution of the Altitude input is such that an altitude of 37.5 feet can be represented (but still finer than 12.5 feet, e.g., a resolution of 10* *feet increments), then values corresponding to altitude must be tested, and the output examined for each value to confirm that output is within ±12.5 feet (inclusive) of the input value.*

Step 8: Reselection of Primary Altitude Information

Operationally select Geometric Pressure Altitude as the Primary Altitude information for Steps 3 through 7 and verify that the "ALTITUDE TYPE" field in bit 8 of byte 10 is set to ONE.

Repeat Steps 3 through 7 with Geometric Pressure Altitude as the Primary Altitude data and verify the encoding.

2.4.4.5.2.4 Verification of "NIC" Field Encoding (§2.2.4.5.2.4)

Purpose/Introduction:

The Navigation Integrity Categories ("NIC") field is a 4-bit (bits 5, through 8, of byte 12) field used to allow surveillance applications to determine whether the reported geometric position has an acceptable integrity containment region for the intended use. The value of the NIC parameter specifies an integrity containment region. The NIC integrity containment region is described horizontally using the R_C parameter. The encoding of this field **shall** be as indicated in Table 2-17. The value of the NIC parameter **shall** be the highest value in Table 2-17 consistent with the NIC Input with the exception that if the NIC Input is consistent with a value of "9," "10" or "11" and the ADS-B equipment does not support the timing requirements for the Precision condition (§2.2.7.2.2), a NIC value of "8" **shall** be transmitted.

If the NIC Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "NIC" **shall** default to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages. Provide NIC data at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Verify "NIC" Field Encoding for UAT Messages

Set the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Verify that with each of the NIC parameter input values that specifies an integrity containment radius, R_C in Table 2-17, the system generates UAT Messages such that "NIC" subfield in each such message set to the corresponding binary coding value in Table 2-17. If the ADS-B equipment does not support the timing requirements for the precision condition (§2.2.7.2.2), then verify that the NIC subfield in the transmitted UAT Messages is equal to "8," when the test cases are being run with R_C data that is provided to the ADS-B Transmitting Subsystem that is consistent with NIC values of "9," "10" or "11."

Step 3: “NIC” Field Encoding – Data Lifetime

Discontinue providing update of NIC data. After 2 seconds, verify that the “NIC” subfield in the ADS-B Message is set to ZERO (binary 0000).

Resume providing NIC data and verify that the ADS-B Message contains a “NIC” subfield set equal to the corresponding binary coding value shown in the Table 2-17.

2.4.4.5.2.5 Verification of “A/G STATE” Field Encoding (§2.2.4.5.2.5)

Purpose/Introduction:

The Air/Ground State (“A/G STATE”) field is a 2-bit (bits 1 and 2 of byte 13) field that indicates the format used for representing horizontal velocity. The value of this field determines the encoding of the “HORIZONTAL VELOCITY” field. The “A/G STATE” field is composed of two (2) 1-bit fields used as follows:

1. The Vertical Status bit (bit 1 of byte 13) is used to reflect the AIRBORNE or ON-GROUND condition as determined in §2.2.4.5.2.5.1.

2. The Subsonic/Supersonic bit (bit 2 of byte 13) is used to indicate the scale factor for the velocity information. The Subsonic/Supersonic bit (bit 2 of byte 13) **shall** be set to ONE (1) if either the East – West Velocity OR the North – South Velocity, exceeds 1022 knots. The Subsonic/Supersonic bit (bit 2 of byte 13) **shall** be reset to ZERO (0) if the East - West and the North - South Velocities, drop below 1000 knots.

The encoding of “A/G STATE” field **shall** be as indicated in Table 2-18.

Measurement Procedure:

Step 1: Verification of the “Subsonic/Supersonic” bit for Subsonic Velocities

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Ensure the ADS-B Transmitting Subsystem has any inputs necessary to establish the AIRBORNE condition. Provide velocity information in the form of Velocity Over Ground (i.e., Ground Speed) with a valid value that is greater than zero but non-supersonic (i.e., both North/South AND East/West velocity inputs are less than 1000 knots).

Verify that ADS-B Messages are generated with the “Subsonic/Supersonic” bit (bit 2 of byte 13) set to ZERO (0), indicating the “Subsonic” setting.

Raise the East/West Velocity input to a value of 1021 knots, and verify that ADS-B Messages are continuing to be generated with the ”Subsonic/Supersonic” bit (bit 2 of byte 13) set to ZERO (0). Lower the East/West Velocity input to a value below 1000 knots, and raise the North/South Velocity input to a value of 1021 knots.

Verify that ADS-B Messages are continuing to be generated with the "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ZERO (0).

Lower the North/South Velocity input to a value below 1000 knots, then raise both the East/West and North/South Velocity inputs to values of 1021 knots.

Verify that ADS-B Messages are continuing to be generated with the Subsonic/Supersonic bit (bit 2 of byte 13) set to ZERO (0).

Note: *During the execution of the previous step, care must be taken to ensure that neither the East/West nor the North/South Velocity inputs are raised to a value greater than 1021 knots.*

Step 2: Verification of the "Subsonic/Supersonic" Bit Transition

This step verifies that the ADS-B Transmitting Subsystem correctly transitions between the Subsonic and Supersonic scale.

Set up the system to enable broadcast of UAT Messages as indicated in Step 1. Provide velocity information in the form of Velocity Over Ground (i.e., Ground Speed). Initially, both the East/West Velocity input and the North/South velocity input shall be greater than 0 knots but less than 1000 knots, as in Step 1. Raise the East/West velocity to a value of 1023 knots.

Verify that ADS-B Messages are generated with Subsonic/Supersonic Flag (bit 2 of byte 13) set to ONE (1), indicating the "Supersonic" scale.

Decrease the East/West velocity input to a value of 999 knots. Verify that ADS-B Messages are generated with "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ZERO (0). Raise the North/South velocity to a value of 1023 knots.

Verify that ADS-B Messages are generated with the "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ONE (1).

Decrease the North/South velocity input to a value of 999 knots.

Verify that ADS-B Messages are generated with the "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ZERO (0).

Raise both North/South and East/West input values to 1023 knots, and verify that ADS-B Messages are generated with "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ONE (1).

Decrease both North/South and East/West input values to 999 knots, and verify that ADS-B Messages are generated with "Subsonic/Supersonic" bit (bit 2 of byte 13) set to ZERO (0).

2.4.4.5.2.5.1 Verification of Determination of Vertical Status (§2.2.4.5.2.5.1)

Purpose/Introduction:

The UAT ADS-B Transmitting Subsystem **shall** determine its Vertical Status (i.e., AIRBORNE or ON-GROUND condition) using the procedures described in §2.2.4.5.2.5.1.

Measurement Procedure:

Step 1 Verify Vertical Status (with automatic means)

Provide input to the UUT to the Automatic AIRBORNE/ON-GROUND Indication data input to indicate ON-GROUND condition. Set up the UUT to broadcast ADS-B Messages by providing data from the navigation source. Provide no radio altitude data, or speed data to the UUT. Verify that the ADS-B Messages broadcasted properly contain Vertical Status (bit 1 of byte 13) equal to ONE.

Provide input to the UUT to the Automatic AIRBORNE/ON-GROUND Indication data input to indicate AIRBORNE condition. Set up the UUT to broadcast ADS-B Messages by providing data from the navigation source. Provide no radio altitude data, or speed data to the UUT. Provide both East/West Velocity input and the North/South Velocity input data less than 1000 knots. Verify that the ADS-B Messages broadcasted properly contain Vertical Status (bit 1 of byte 13) equal to ZERO.

Step 2 Verify Vertical Status (without automatic means)

Set up the ADS-B Transmitting Subsystem to broadcast messages by providing data from the navigation source. Provide Emitter Category, radio altitude data, airspeed data and ground speed to the UUT according to the values defined in Table 2-82 or in the case of no data, do not provide the data as indicated. In the cases of "no data," discontinue the input for the "data lifetime" value in Table 2-98 to verify that the input is no longer used to determine the "ON-GROUND" condition. Conversely, prior to the timeout, verify that the value is used to determine the "ON-GROUND" condition. Ensure that NO input is applied to the Automatic AIRBORNE/ON GROUND indication data input. Verify that the UUT broadcasts ADS-B Messages that contain the proper Vertical Status (bit 1 of byte 13) as indicated for each row of Table 2-82.

Table 2-82: Vertical Status Determination when no Automatic AIRBORNE/ON-GROUND Indication is Available

Vertical Status Determination					
Test	**Emitter Category Base-40 Digit (§2.2.4.5.4.1)**	**Ground Speed (knots)**	**Airspeed (knots)**	**Radio Altitude (feet)**	**Resulting Vertical Status (Bit 1 of Byte 13)**
1	2 – 6, 15	100	100	50	AIRBORNE
2	2 – 6, 15	100	50	25	AIRBORNE
3	2 – 6, 15	50	100	25	AIRBORNE
4	2 – 6, 15	50	50	50	AIRBORNE
5	2 – 6, 15	99	99	49	ON-GROUND
6	2 – 6, 15	50	25	No Data	AIRBORNE
7	2 – 6, 15	25	50	No Data	AIRBORNE
8	2 – 6, 15	49	49	No Data	ON-GROUND
9	2 – 6, 15	No Data	25	No Data	AIRBORNE
10	2 – 6, 15	25	No Data	No Data	AIRBORNE
11	2 – 6, 15	100	No Data	25	AIRBORNE
12	2 – 6, 15	No Data	100	25	AIRBORNE
13	2 – 6, 15	99	No Data	49	ON-GROUND
14	2 – 6, 15	No Data	99	49	ON-GROUND
15	2 – 6, 15	25	No Data	50	AIRBORNE
16	2 – 6, 15	No Data	25	50	AIRBORNE
17	2 – 6, 15	No Data	No Data	25	AIRBORNE
18	2 – 6, 15	No Data	No Data	No Data	AIRBORNE

Note: *The Air/Ground State bit for other Emitter Categories shall be in accordance with the determination of vertical status defined in §2.2.4.5.2.5.1.*

2.4.4.5.2.5.2 Verification of Validation of Vertical Status (§2.2.4.5.2.5.2)

Purpose/Introduction:

When an automatic means of determining Vertical Status indicates the “ON-GROUND,” condition, then the following additional tests **shall** be performed to validate the “ON-GROUND” condition:

If one or more of the following parameters is available to the UAT ADS-B Transmitting Subsystem participant:

Ground Speed (GS), or
Airspeed (AS), or
Radio Height (RH) from radio altimeter

And, of the following parameters that are available:

GS > 100 knots, or
AS > 100 knots, or
RH > 50 feet

Then, the participant **shall** set its Vertical Status to the “AIRBORNE” condition.

Otherwise, the participant **shall** set its Vertical Status to the “ON-GROUND” condition.

If any of the inputs used to derive the override of the “ON-GROUND” condition as specified above are “unavailable” for the “Data Lifetime” timeout duration listed in Table 2-98, then the input **shall** no longer be used for the purposes of overriding the “ON-GROUND” condition.

Note: *The Vertical Status can be used by ADS-B Transmitting Subsystems to select only the TOP antenna when in the ON-GROUND condition. A false indication of the automatic means could therefore impact signal availability. To minimize this possibility, this validation procedure has been established.*

Measurement Procedure:

Step 1 ON-GROUND Override Verification - input data variation

For ADS-B Transmitting Subsystems with automatic means of determining on the ground status, provide input external to the UUT to indicate ON-GROUND condition. Set up the UUT to broadcast ADS-B Messages by providing data from the navigation source. Provide Emitter Category, radio altitude data, and ground speed to the UUT according to the values defined in Table 2-83 or in the case of no data, do not provide the data or discontinue providing the data as indicated. In the cases of “no data,” discontinue the input for the “data lifetime” timeout value in Table 2-98 to verify that the input is no longer used to determine the “ON-GROUND” override condition. Conversely, prior to the timeout, verify that the value is used to determine the “ON-GROUND” override condition. Verify that the UUT transmits ADS-B Messages with the Vertical Status bit as indicated in Table 2-83 for each run.

Table 2-83: ON-GROUND Override Verification

ON-GROUND Override					
Test	**Emitter Category Base-40 Digit (§2.2.4.5.4.1)**	**Ground Speed (knots)**	**Airspeed (knots)**	**Radio Altitude (feet)**	**Resulting Vertical Status (Bit 1 of byte 13)**
1	2 – 6, 15	100	100	50	ON-GROUND
2	2 – 6, 15	100	100	51	AIRBORNE
3	2 – 6, 15	100	101	50	AIRBORNE
4	2 – 6, 15	101	100	50	AIRBORNE
5	2 – 6, 15	No Data	100	50	ON-GROUND
6	2 – 6, 15	No Data	100	51	AIRBORNE
7	2 – 6, 15	No Data	101	50	AIRBORNE
8	2 – 6, 15	No Data	No Data	50	ON-GROUND
9	2 – 6, 15	No Data	No Data	51	AIRBORNE
10	2 – 6, 15	100	No Data	50	ON-GROUND
11	2 – 6, 15	101	No Data	50	AIRBORNE
12	2 – 6, 15	100	No Data	51	AIRBORNE
13	2 – 6, 15	100	No Data	No Data	ON-GROUND
14	2 – 6, 15	101	No Data	No Data	AIRBORNE
15	2 – 6, 15	No Data	100	No Data	ON-GROUND
16	2 – 6, 15	No Data	101	No Data	AIRBORNE
17	2 – 6, 15	100	101	No Data	AIRBORNE
18	2 – 6, 15	101	100	No Data	AIRBORNE
19	2 – 6, 15	100	100	No Data	ON-GROUND
20	2 – 6, 15	No Data	No Data	No Data	ON-GROUND

Note: *The Air/Ground State bit for other Emitter Categories shall be in accordance with the determination of vertical status defined in §2.2.4.5.2.5.1.*

Step 2 ON-GROUND Override Verification – Velocity Input Data Variation

For ADS-B Transmitting Subsystems with automatic means of determining on the ground status, provide input external to the UUT to indicate ON-GROUND condition. Set up the UUT to broadcast ADS-B Messages by providing data from the navigation source. Provide position data and North/South Velocity and East/West Velocity initially to 1000 knots. Provide Heading input value of 45 Degrees. Provide Emitter Category and radio altitude data to the UUT according to the values defined in Table 2-83 or in the case of no data, do not provide the data or discontinue providing the data as indicated. Verify that the UUT transmits ADS-B Messages with the Vertical Status State bit as indicated in Table 2-83 for each run. For each run that results in Airborne state, verify that the "A/G STATE" Field equals ZERO (binary 00) and that the correct Horizontal Velocity subfield value (North/South Velocity and East/West Velocity) is contained in the ADS-B Transmitted Message. For each run that results in ON-GROUND state, verify that the "A/G STATE" Field equals TWO (binary 10) and that the correct Horizontal Velocity subfield value (Ground Speed and Heading) is contained in the ADS-B Transmitted Message.

Repeat above except provide North/South Velocity and East/West Velocity data equal to 1200 knots. For each run that results in Airborne state, verify that the "A/G STATE" Field equals ONE (binary 01).

2.4.4.5.2.6 Verification of "HORIZONTAL VELOCITY" Subfields (§2.2.4.5.2.6)

No specific test procedure is required to validate §2.2.4.5.2.6.

2.4.4.5.2.6.1 Verification of Encoding as "North Velocity" Form (§2.2.4.5.2.6.1)

Appropriate test procedures required to validate the requirements of §2.2.4.5.2.6.1 are included in §2.4.4.5.2.6.1.1, §2.4.4.5.2.6.1.2 and §2.4.4.5.2.6.1.3.

2.4.4.5.2.6.1.1 Verification of the "North/South Velocity" Sign Flag (§2.2.4.5.2.6.1.a)

Purpose/Introduction:

The "N/S Sign" subfield (bit 4 of byte 13) **shall** be used to indicate the direction of the North/South velocity vector as shown in Table 2-20.

This test procedure verifies that the "N/S Sign" bit in UAT Messages is correctly set to "0" for travel in a northward direction, and "1" for travel in a southward direction.

These test procedures are intended for use for UAT Messages where the "A/G STATE" field is set to "0" or "1." The values of the input Velocity data should be set so as to ensure that the "A/G STATE" is set to either "0" or "1."

Measurement Procedure:

Step 1: North / South Sign Bit Verification – Velocity Data Not Available

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity data at the nominal update rate. Ensure the ADS-B Transmitting Subsystem has the inputs necessary to be in the AIRBORNE condition. Provide valid non-zero barometric pressure altitude data and valid non-zero velocity data to the ADS-B System.

Verify that when the North/South Velocity is not provided to the ADS-B Transmitting Subsystem for a period of 2 seconds, that the North/South Velocity Sign Bit is set to ZERO (0) as specified in Table 2-20.

Step 2: North / South Direction Bit Verification – Directional Components

The method for testing this field depends largely upon the nature of the input for North/South Velocity Data.

CASE 1:

If the directional component of the input is a single bit or a "flag" type (i.e., a single discrete value is used to represent "NORTH," and another discrete value is used to represent "SOUTH"), then the procedure for this step shall be as follows:

Set this input to the value that indicates travel in a northward direction, and check that ADS-B UAT Messages are generated with "A/G STATE" set to either “0” or “1,” and that all such messages contain a “N/S Sign” bit subfield with a value of “0.”

Next, set the input to the value that indicates travel in a southward direction, and verify that ADS-B UAT Messages are generated with “A/G STATE” set to either “0” or “1,” and that all such messages contain a “N/S Sign” bit subfield with a value of “1.”

CASE 2:

If the directional component of the input is variable (e.g., a heading expressed in degrees or other similar manner, so that the input value must be evaluated by the ADS-B transmission device in order to determine the proper value for the “N/S Sign” bit), then the test procedure shall be as follows.

In this case, the input variable must be made to assume values corresponding to movement in a northward direction, and it must be verified, for each such value, that UAT Messages are generated with “A/G STATE set to either “0” or “1,” and that all such messages contain a “N/S Sign” bit subfield with a value of “0.”

The input must then be made to assume values corresponding to movement in a southward direction, and it must be verified, for each such value, that the transmitter generates UAT Messages with “A/G STATE set to either “0” or “1,” and that all such messages contain a “N/S Sign” bit subfield with a value of “1.”

2.4.4.5.2.6.1.2 Verification of the “North Velocity Magnitude” Subfield - Subsonic (§2.2.4.5.2.6.1.b)

Purpose/Introduction:

When the “A/G STATE” field is set to “0” or “1,” the “North Velocity or Ground Speed” component **shall** assume the “North Velocity” format indicated in Table 2-19.

The “North Velocity Magnitude” subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) field that **shall** be used to report the magnitude of the North/South Velocity of the ADS-B Transmitting Subsystem. The Range, Resolution and Not Available encoding of the “North Velocity Magnitude” subfield **shall** be as shown in Table 2-21.

This test procedure verifies that the North/South Velocity subfield in UAT Messages is correctly set for the subsonic condition where the “A/G STATE” field is set to ZERO (0).

Measurement Procedure:

Step 1: North / South Velocity Verification – Velocity Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set up the UUT to enable broadcast of UAT Messages such that the “A/G STATE” field is “0.” Provide valid non-zero velocity data to the ADS-B System.

Discontinue North/South Velocity data for a period of 2 seconds and verify that when North/South Velocity Data is not provided to the ADS-B transmission device, the North/South Velocity subfield is set to ALL ZEROs (binary 00 0000 0000).

Step 2: North / South Velocity Verification – Velocity Equal ZERO

Set up the ADS-B Transmitting Subsystem as above and set the North/South Velocity input to represent a velocity of ZERO knots.

Verify that the North/South Velocity subfield is set to ONE (binary 00 0000 0001).

Step 3: North / South Velocity Verification – Discrete Values

Verify that for each integer North/South Velocity input value in knots in Table 2-84 that the system generates UAT Messages with the "A/G STATE" set to "0," and that the North/South Velocity subfield in each such message is set equal to the corresponding binary coding value in Table 2-84.

Table 2-84: Discrete Values for Subsonic North/South Velocity

North/South Velocity (Subsonic)		
Coding (binary)	**Coding** (decimal)	**Meaning** (N/S Velocity in knots)
00 0000 0010	2	N/S Velocity = 1 knot
00 0000 0101	5	N/S Velocity = 4 knots
00 0000 1010	10	N/S Velocity = 9 knots
00 0000 1111	15	N/S Velocity = 14 knots
00 0101 0000	80	N/S Velocity = 79 knots
00 0101 1010	90	N/S Velocity = 89 knots
00 1010 0101	165	N/S Velocity = 164 knots
00 1010 1010	170	N/S Velocity = 169 knots
01 0101 0101	341	N/S Velocity = 340 knots
10 0101 0101	597	N/S Velocity = 596 knots
10 1010 1010	682	N/S Velocity = 681 knots
11 0101 0101	853	N/S Velocity = 852 knots
11 1010 1010	938	N/S Velocity = 937 knots
11 1111 1110	1022	N/S Velocity = 1021 knots

Step 4: North / South Velocity Verification – Maximum Values

If the resolution of the input value is the same as the output resolution (i.e., 1 knot), verify that for an input corresponding to a northward velocity of 1022 knots, UAT Messages are generated with "A/G STATE" set to "0," and all such messages contain a North/South Velocity subfield with a value of 1023 (binary 11 1111 1111).

If the resolution of the input value is greater than the output resolution, verify that for input value corresponding to the largest possible northward velocity that is less than 1021.5 knots, UAT Messages are generated with "A/G STATE" of "0," and all such messages contain a North/South Velocity subfield with a value of 1022 (binary 11 1111 1110).

If the resolution of the input data makes it possible to enter an input value that corresponds to exactly 1021.5 knots, then this value shall be input and it shall be verified that the resultant North/South Velocity output field is equal to either 1022 (binary 11 1111 1110, representing 1021 knots) or 1023 (binary 11 1111 1111, representing > 1021.5 knots).

Step 5: North / South Velocity Verification – Data Accuracy

If the input data used to establish the North/South Velocity subfield has more resolution than that required by the North/South Velocity subfield (i.e., more than 10 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the North/South Velocity subfield. If the input data field that is used to determine the output value of the North/South Velocity subfield consists of 10 bits or less, proceed to Step 6.

Enter an input value corresponding to a northward velocity of 1.5 knots.

Verify that the value of the North/South Velocity subfield in the output message is either "2" (binary 00 0000 0010, representing 1 knot) or "3" (binary 00 0000 0011, representing 2 knots).

If the input field used to establish the North/South Velocity subfield has exactly 11 bits, skip to step 6. Otherwise (indicating that more than 11 bits are used to establish North/South Velocity subfield), let ***Z*** be equal to the smallest possible fraction that can be represented by the number of bits in the input field (i.e., ***Z*** is the value of the least significant bit of the input field). Set the value of the input field to correspond to a northward velocity of (1.5 – ***Z*** knots).

Verify that the value of the North/South Velocity subfield in the output UAT Message is "2" (binary 00 0000 0010, representing 1 knot).

Set the value of the input field to correspond to a northward velocity of (1.5 + ***Z*** knots).

Verify that the value of the North/South Velocity subfield in the output UAT Message is "3" (binary 00 0000 0011, representing 2 knots).

Note: *If the resolution of the North/South Velocity input is such that a northward velocity of 1.5 knots cannot be represented (but is still greater than 1 knot, e.g., a resolution of 0.2 knot increments), then values corresponding to northward velocity must be tested, and the output examined for each value to confirm that the output is within ±0.5 knots (inclusive) of the input value.*

Step 6: North / South Velocity Verification - Part 6

Note: *If the nature of the inputs is such that a separate bit or "flag" type field is input to the transmitter to indicate "North" or "South," the following step is not necessary. However, if the transmitter must perform some interpretation of its inputs in order to determine the correct output value of the N/S Sign Bit, the following step must be performed.*

Repeat Steps 3, 4 and 5 so that each step is performed with North/South Velocity input data indicating travel in both NORTH and SOUTH directions, i.e., replace the word "northward" with "southward" in steps 3, 4 and 5.

2.4.4.5.2.6.1.3 Verification of the "North Velocity Magnitude" Subfield - Supersonic (§2.2.4.5.2.6.1.b)

Purpose/Introduction:

When the "A/G STATE" field is set to "0" or "1," the "North Velocity or Ground Speed" component **shall** assume the "North Velocity" format indicated in Table 2-19.

The "North Velocity Magnitude" subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) field that **shall** be used to report the magnitude of the North/South Velocity of the ADS-B Transmitting Subsystem. The Range, Resolution and Not Available encoding of the "North Velocity Magnitude" subfield **shall** be as shown in Table 2-21.

If the North Velocity Magnitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "North Velocity Magnitude" subfield **shall** default to a value of ALL ZEROs.

This test procedure verifies that the North/South Velocity subfield in UAT Messages is correctly set for the supersonic condition where the "A/G STATE" field is set to ONE (1).

Measurement Procedure:

Step 1: North / South Velocity Verification – Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages with A/G STATE set to "1" by providing North/South Velocity input data with a value greater than 1022 knots.

Set the ADS-B Transmitting Subsystem to Airborne status. Discontinue North/South Velocity data for a period of 2 seconds and verify that when North/South Velocity Data is not provided to the ADS-B Transmitting Subsystem, that the North/South Velocity subfield in output UAT Messages is set to ZERO (binary 00 0000 0000).

Step 2: North / South Velocity Verification – Velocity Equal ZERO

Set up the ADS-B Transmitting Subsystem as above and set the North/South Velocity input to represent a velocity of ZERO knots.

Verify that the North/South Velocity subfield in subsequent UAT Messages is set to ONE "1" (binary 00 0000 0001).

Step 3: North / South Velocity Verification – Discrete Values

Verify that for each integer North/South Velocity input value in knots identified in Table 2-85 that the system generates UAT Messages with the North/South

Velocity Subfield set equal to the corresponding binary coding value in the table.

Table 2-85: Discrete Values for Supersonic North/South Velocity

North/South Velocity (Supersonic)		
Coding (binary)	**Coding** (decimal)	**Meaning** (N/S Velocity in knots)
00 0000 0010	2	N/S Velocity = 4 knots
00 0000 0101	5	N/S Velocity = 16 knots
00 0000 1010	10	N/S Velocity = 36 knots
00 0000 1111	15	N/S Velocity = 56 knots
00 0101 0000	80	N/S Velocity = 316 knots
00 0101 1010	90	N/S Velocity = 356 knots
00 1010 0101	165	N/S Velocity = 656 knots
00 1010 1010	170	N/S Velocity = 676 knots
01 0101 0101	341	N/S Velocity = 1,360 knots
10 0101 0101	597	N/S Velocity = 2,384 knots
10 1010 1010	682	N/S Velocity = 2,724 knots
11 0101 0101	853	N/S Velocity = 3,408 knots
11 1010 1010	938	N/S Velocity = 3,748 knots
11 1111 1110	1022	N/S Velocity = 4,084 knots

Verify that for 4 knot increases in the input value, the North/South Velocity subfield in subsequent UAT Messages of A/G STATE equal "1" is incremented by one from the previous value (i.e., that the value of the North/South Velocity subfield corresponds to the values given in the table in the above referenced section).

Verify that the North/South Velocity subfield in the output message is not incremented until the input value reaches a number corresponding to an even multiple of 4 knots.

Step 4: North / South Velocity Verification – Maximum Velocity

Continue to increase the value of the North/South Velocity Data input.

Verify that, for discrete values greater than or equal to 4084 knots but less than or equal to 4086 knots, the North/South Velocity subfield continues to be set to "1022" (binary 11 1111 1110).

Continue to increase the value of the North/South Velocity input.

Verify that for discrete input values representing a North/South Velocity greater than 4086 knots, up to the maximum possible input value, that the transmitter continues to generate UAT Messages with a A/G STATE subfield equal to "1," and that the North/South Velocity subfield for all such messages is set to "1023" (binary 11 1111 1111).

Step 5: North / South Velocity Verification – Input Resolution

If the input data used to establish the North/South Velocity subfield has finer resolution than that required by the North/South Velocity subfield, then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the North/South Velocity subfield. If the input data field that is used to determine the output value of the North/South Velocity subfield does not have finer resolution than that required by the North/South Velocity subfield, proceed to Step 6.

Enter an input value corresponding to a northward velocity of 6 knots.

Verify that the value of the North/South Velocity subfield in the output message is either "2" (binary 00 0000 0010, representing 4 knots) or "3" (binary 00 0000 0011, representing 8 knots).

If the input field used to establish the North/South Velocity subfield does not have resolution finer than 2 knots, skip to step 6. Otherwise (North/South Velocity input resolution is finer than 2 knots), let ***Z*** be equal to the smallest possible value that can be represented by the number of bits in the input field (i.e., ***Z*** is the value of the least significant bit of the input field). Set the value of the input field to correspond to a northward velocity of (6 – ***Z*** knots).

Verify that the value of the North/South Velocity subfield in the output UAT Message is "2" (binary 00 0000 0010, representing 4 knots). Set the value of the input field to correspond to a northward velocity of (6 + ***Z*** *k*nots).

Verify that the value of the North/South Velocity subfield in the output UAT Message is "3" (binary 00 0000 0011, representing 8 knots).

Note: *If the resolution of the North/South Velocity input is such that a northward velocity of 6 knots cannot be represented (but is still finer than 4 knots, e.g., a resolution of 1.75 knot increments), then values corresponding to northward velocity must be tested, and the output examined for each value to confirm that the output is within ±2 knots (inclusive) of the input value.*

Step 6: North / South Velocity Verification - Part 6

Note: *If the nature of the inputs is such that a separate bit or "flag" type field is input to the transmitter to indicate "North" or "South," the following step is not necessary. However, if the transmitter must perform some interpretation of its inputs in order to determine the correct output value of the N/S Sign bit, the following step must be performed.*

Repeat Steps 3, 4 and 5 so that each step is performed with North/South Velocity input data indicating travel in both NORTH and SOUTH directions, i.e., replace the word "northward" with "southward" in steps 3, 4 and 5.

2.4.4.5.2.6.2 Verification of Encoding as "Ground Speed" Form (§2.2.4.5.2.6.2)

Appropriate test procedures required to validate the requirements of §2.2.4.5.2.6.2 are included in §2.4.4.5.2.6.2.1 and §2.4.4.5.2.6.2.2.

2.4.4.5.2.6.2.1 Verification of Reserved Bit (§2.2.4.5.2.6.2.a)

Purpose/Introduction:

The 1-bit subfield (bit 4 of byte 13) **shall** be "Reserved" and set to ZERO (0).

Measurement Procedure:

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages. Set the ADS-B Transmitting Subsystem to transmit ADS-B Messages according to the capability of the UAT equipage classes. Verify that bit 4 of byte 13 is set to ZERO.

2.4.4.5.2.6.2.2 Verification of the Encoding of the Ground Speed Magnitude – Subsonic (§2.2.4.5.2.6.2.b)

Purpose/Introduction:

When the "A/G STATE" field is set to "2" the "North Velocity or Ground Speed" component **shall** assume the "Ground Speed" format, if Ground Speed is available, as indicated in Table 2-22.

The "Ground Speed" subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) field that **shall** be used to report the Ground Speed of the ADS-B Transmitting Subsystem (in knots). The Range, Resolution and Not Available encoding of the "Ground Speed" subfield **shall** be as shown in Table 2-23.

If the Ground Speed Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "Ground Speed" subfield **shall** default to a value of ALL ZEROs.

This test procedure will verify that the "Ground Speed" subfield in these messages is correctly encoded by the ADS-B Transmitting Subsystem.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B Transmitting Subsystem such that messages are transmitted with the "A/G STATE" field set to "2." Specifically, ensure that ground speed is available, and less than 1022 knots, heading is available, and the automatic AIRBORNE/ON GROUND indication (if used) is indicating "ON-GROUND."

Step 2: Ground Speed Verification – Data Lifetime

Provide valid non-zero, subsonic ground speed and heading data to the ADS-B System.

Discontinue ground speed data for a period of 2 seconds and verify that when ground speed data is not provided to the ADS-B Transmitting Subsystem, the "Ground Speed" subfield in subsequent UAT output messages is set to ZERO (binary 00 0000 0000).

Step 3: Ground Speed Verification – Data Equal to ZERO

Setup the ADS-B Transmitting Subsystem as above and set the Ground Speed input to represent a velocity of ZERO knots.

Verify that the "A/G STATE" field is set to "2" and that the "Ground Speed" subfield in subsequent UAT output messages is set to ONE (binary 00 0000 0001).

Step 4: Ground Speed Verification – Discrete Values

Verify for each integer Ground Speed (expressed in knots) in Table 2-86, that the system generates UAT Messages with "A/G STATE" set to "2," and that the Ground Speed subfield coding in each such message is set equal to the corresponding binary coding value in the table.

Table 2-86: Discrete Values for Subsonic Ground Speed

Ground Speed (Subsonic)		
Coding (binary)	**Coding** (decimal)	**Meaning** (Speed in knots)
00 0000 0010	2	Speed = 1 knot
00 0000 0101	5	Speed = 4 knots
00 0000 1010	10	Speed = 9 knots
00 0000 1111	15	Speed = 14 knots
00 0101 0000	80	Speed = 79 knots
00 0101 1010	90	Speed = 89 knots
00 1010 0101	165	Speed = 164 knots
00 1010 1010	170	Speed = 169 knots
01 0101 0101	341	Speed = 340 knots
10 0101 0101	597	Speed = 596 knots
10 1010 1010	682	Speed = 681 knots
11 0101 0101	853	Speed = 852 knots
11 1010 1010	938	Speed = 937 knots
11 1111 1110	1022	Speed = 1021 knots

Step 5: Ground Speed Verification – Maximum Values

If the resolution of the input value is the same as the output resolution (i.e., 1 knot), verify that for an input corresponding to an Ground Speed of 1022 knots, UAT Messages are generated with "A/G STATE" set to "2," and all such messages contain a Ground Speed subfield with a value of 1023 (binary 11 1111 1111).

If the resolution of the input value is greater than the output resolution, verify that for input value corresponding to the largest possible Ground Speed that is less than 1021.5 knots, UAT Messages are generated with "A/G STATE" of "2," and all such messages contain a Ground Speed subfield with a value of 1022 (binary 11 1111 1110).

If the resolution of the input data makes it possible to enter an input value that corresponds to exactly 1021.5 knots, then this value shall be input and it shall be verified that the resultant Ground Speed output field is equal to either 1022 (binary 11 1111 1110, representing 1021 knots) or 1023 (binary 11 1111 1111, representing > 1021.5 knots).

Step 6: Ground Speed Verification – Data Accuracy

If the input data used to establish the Ground Speed subfield has more resolution than that required by the Ground Speed subfield (i.e., more than 10 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the Ground Speed subfield. If the input data field that is used to determine the output value of the Ground Speed subfield consists of 10 bits or less, proceed to Step 6.

Enter an input value corresponding to an Ground Speed of 1.5 knots.

Verify that the value of the Ground Speed subfield in the output message is either “2” (binary 00 0000 0010, representing 1 knot) or “3” (binary 00 0000 0011, representing 2 knots).

If the input field used to establish the Ground Speed subfield has exactly 11 bits, skip to Step 7. Otherwise (indicating that more than 11 bits are used to establish Ground Speed subfield), let ***Z*** be equal to the smallest possible fraction that can be represented by the number of bits in the input field (i.e., ***Z*** is the value of the least significant bit of the input field). Set the value of the input field to correspond to an Ground Speed of (1.5 – ***Z*** knots).

Verify that the value of the Ground Speed subfield in the output UAT Message is “2” (binary 00 0000 0010, representing 1 knot).

Set the value of the input field to correspond to an Ground Speed of (1.5 + ***Z*** knots).

Verify that the value of the Ground Speed subfield in the output UAT Message is “3” (binary 00 0000 0011, representing 2 knots).

Note: *If the resolution of the Ground Speed input is such that an Ground Speed of 1.5 knots cannot be represented (but is still greater than 1 knot, e.g., a resolution of 0.2 knot increments), then values corresponding to Ground Speed must be tested, and the output examined for each value to confirm that the output is within ±0.5 knots (inclusive) of the input value.*

2.4.4.5.2.6.3 Verification of Encoding as “East Velocity” Form (§2.2.4.5.2.6.3)

Appropriate test procedures required to validate the requirements of §2.2.4.5.2.6.3 are included in §2.4.4.5.2.6.3.1, §2.4.4.5.2.6.3.2 and §2.4.4.5.2.6.3.3.

2.4.4.5.2.6.3.1 Verification of the “East/West Velocity” Sign Flag (§2.2.4.5.2.6.3.a)

Purpose/Introduction:

The “E/W Sign” subfield (bit 4 of byte 13) **shall** be used to indicate the direction of the East/West Velocity vector as shown in Table 2-25.

This test procedure verifies that the “E/W Sign” bit in UAT Messages is correctly set to “0” for travel in a eastward direction, and “1” for travel in a westward direction.

These test procedures are intended for use for UAT Messages where the “A/G STATE” field is set to “0” or “1.” The values of the input Velocity data should be set so as to ensure that the “A/G STATE” is set to either “0” or “1.”

Measurement Procedure:

Step 1: East/West Sign Bit Verification – Velocity Data Not Available

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity data at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages. Verify that the ADS-B Transmitting Subsystem is set to Airborne status. Provide valid non-zero barometric pressure altitude data and valid non-zero velocity data to the ADS-B System.

Verify that when the East/West Velocity data is not provided to the ADS-B Transmitting Subsystem for a period of 2 seconds, that the East/West Direction Bit is set to ZERO (0), as specified in Table 2-25.

Step 2: East/West Direction Bit Verification – Directional Components

The method for testing this field depends largely upon the nature of the input for East/West Velocity Data.

CASE 1:

If the directional component of the input is a single bit or a “flag” type (i.e., a single discrete value is used to represent “EAST,” and another discrete value is used to represent “WEST”), then the procedure for this step shall be as follows:

Set this input to the value that indicates travel in a eastward direction, and check that ADS-B UAT Messages are generated with “A/G STATE” set to either “0” or “1,” and that all such messages contain a “E/W Sign” bit subfield with a value of “0.”

Next, set the input to the value that indicates travel in a westward direction, and verify that ADS-B UAT Messages are generated with “A/G STATE” set to either “0” or “1,” and that all such messages contain a “E/W Sign” bit subfield with a value of “1.”

CASE 2:

If the directional component of the input is variable (e.g., a heading expressed in degrees or other similar manner, so that the input value must be evaluated by the ADS-B transmission device in order to determine the proper value for the “E/W Sign” bit), then the test procedure shall be as follows.

In this case, the input variable must be made to assume values corresponding to movement in a eastward direction, and it must be verified, for each such value, that UAT Messages are generated with “A/G STATE” set to either “0” or “1,” and that all such messages contain a "E/W Sign" bit subfield with a value of "0."

The input must then be made to assume values corresponding to movement in a westward direction, and it must be verified, for each such value, that the transmitter generates UAT Messages with "A/G STATE" set to either "0" or "1," and that all such messages contain an "E/W Sign" bit subfield with a value of "1."

2.4.4.5.2.6.3.2 Verification of the "East Velocity Magnitude" Subfield - Subsonic (§2.2.4.5.2.6.3.b)

Purpose/Introduction:

When the "A/G STATE" field is set to "0" or "1," the "East Velocity or Track Angle/Heading" component **shall** assume the "East Velocity" format indicated in Table 2-24.

The "East Velocity Magnitude" subfield is a 10-bit (bit 8 of byte 14 through bit 1 of byte 16) field that **shall** be used to report the magnitude of the East/West Velocity of the ADS-B Transmitting Subsystem. The Range, Resolution and Not Available encoding of the "East Velocity Magnitude" subfield **shall** be as shown in Table 2-26.

If the East Velocity Magnitude Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "East Velocity Magnitude" subfield **shall** default to a value of ALL ZEROs.

This test procedure verifies that the East/West Velocity subfield in UAT Messages is correctly set for the subsonic condition where the "A/G STATE" field is set to ZERO (0).

Measurement Procedure:

Step 1: East/West Velocity Verification – Velocity Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set up the system to enable broadcast of UAT Messages with the "A/G STATE" set to "0." Verify that the ADS-B Transmitting Subsystem is set to Airborne status. Provide valid non-zero velocity data to the ADS-B System.

Discontinue East/West Velocity data for a period of 2 seconds and verify that when East/West Velocity Data is not provided to the ADS-B transmission device, the East/West Velocity subfield is set to ZERO (binary 00 0000 0000).

Step 2: East/West Velocity Verification – Velocity Equal ZERO

Set up the ADS-B Transmitting Subsystem as above and set the East/West Velocity input to represent a velocity of ZERO knots. Verify that the East/West Velocity subfield is set to "1."

Step 3: East/West Velocity Verification – Discrete Values

Verify that for each integer East/West Velocity input value in knots in Table 2-87 that the system generates UAT Messages with the “A/G STATE” set to “0,” and that the East/West Velocity subfield in each such message is set equal to the corresponding binary coding value in Table 2-87.

Table 2-87: Discrete Values for Subsonic East/West Velocity

East/West Velocity (Subsonic)		
Coding (binary)	**Coding** (decimal)	**Meaning** (E/W Velocity in knots)
00 0000 0010	2	E/W Velocity = 1 knot
00 0000 0101	5	E/W Velocity = 4 knots
00 0000 1010	10	E/W Velocity = 9 knots
00 0000 1111	15	E/W Velocity = 14 knots
00 0101 0000	80	E/W Velocity = 79 knots
00 0101 1010	90	E/W Velocity = 89 knots
00 1010 0101	165	E/W Velocity = 164 knots
00 1010 1010	170	E/W Velocity = 169 knots
01 0101 0101	341	E/W Velocity = 340 knots
10 0101 0101	597	E/W Velocity = 596 knots
10 1010 1010	682	E/W Velocity = 681 knots
11 0101 0101	853	E/W Velocity = 852 knots
11 1010 1010	938	E/W Velocity = 937 knots
11 1111 1110	1022	E/W Velocity = 1021 knots

Step 4: East/West Velocity Verification – Maximum Values

If the resolution of the input value is the same as the output resolution (i.e., 1 knot), verify that for an input corresponding to an eastward velocity of 1022 knots, UAT Messages are generated with “A/G STATE” set to “0,” and all such messages contain an East/West Velocity subfield with a value of 1023 (binary 11 1111 1111).

If the resolution of the input value is greater than the output resolution, verify that for an input value corresponding to the largest possible eastward velocity that is less than 1021.5 knots, UAT Messages are generated with “A/G STATE” of “0,” and all such messages contain a East/West Velocity subfield with a value of 1022 (binary 11 1111 1110).

If the resolution of the input data makes it possible to enter an input value that corresponds to exactly 1021.5 knots, then this value shall be input and it shall be verified that the resultant East/West Velocity output field is equal to either 1022 (binary 11 1111 1110, representing 1021 knots) or 1023 (binary 11 1111 1111, representing > 1021.5 knots).

Step 5: East/West Velocity Verification – Data Accuracy

If the input data used to establish the East/West Velocity subfield has more resolution than that required by the East/West Velocity subfield (i.e., more than 10 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the East/West Velocity subfield. If the input data field that is used to determine the output value of the East/West Velocity subfield consists of 10 bits or less, proceed to Step 6.

Enter an input value corresponding to an eastward velocity of 1.5 knots.

Verify that the value of the East/West Velocity subfield in the output message is either “2” (binary 00 0000 0010, representing 1 knot) or “3” (binary 00 0000 0011, representing 2 knots).

If the input field used to establish the East/West Velocity subfield has exactly 11 bits, skip to step 6. Otherwise (indicating that more than 11 bits are used to establish East/West Velocity subfield), let ***Z*** be equal to the smallest possible fraction that can be represented by the number of bits in the input field (i.e., ***Z*** is the value of the least significant bit of the input field). Set the value of the input field to correspond to an eastward velocity of (1.5 – ***Z*** knots).

Verify that the value of the East/West Velocity subfield in the output UAT Message is “2” (binary 00 0000 0010, representing 1 knot).

Set the value of the input field to correspond to an eastward velocity of (1.5 + ***Z*** knots).

Verify that the value of the East/West Velocity subfield in the output UAT Message is “3” (binary 00 0000 0011, representing 2 knots).

Note: *If the resolution of the East/West Velocity input is such that a eastward velocity of 1.5 knots cannot be represented (but is still greater than 1 knot, e.g., a resolution of 0.2 knot increments), then values corresponding to eastward velocity must be tested, and the output examined for each value to confirm that the output is within ±0.5 knots (inclusive) of the input value.*

Step 6: East/West Velocity Verification - Part 6

Note: *If the nature of the inputs is such that a separate bit or “flag” type field is input to the transmitter to indicate “East” or “West,” the following step is not necessary. However, if the transmitter must perform some interpretation of its inputs in order to determine the correct output value of the E/W Sign Bit, the following step must be performed.*

Repeat Steps 3, 4 and 5 so that each step is performed with East/West Velocity input data indicating travel in both EAST and WEST directions, i.e., replace the word “eastward” with “westward” in Steps 3, 4 and 5.

2.4.4.5.2.6.3.3 Verification of the “East Velocity Magnitude” Subfield - Supersonic (§2.2.4.5.2.6.3.b)

Purpose/Introduction:

When the “A/G STATE” field is set to “0” or “1,” the “East Velocity or Track Angle/Heading” component **shall** assume the “East Velocity” format indicated in Table 2-24.

The “East Velocity Magnitude” subfield is a 10-bit (bit 8 of byte 14 through bit 1 of byte 16) field that **shall** be used to report the magnitude of the East/West Velocity of the ADS-B Transmitting Subsystem. The Range, Resolution and Not Available encoding of the “East Velocity Magnitude” subfield **shall** be as shown in Table 2-26.

If the East Velocity Magnitude Input is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-98, then the “East Velocity Magnitude” subfield **shall** default to a value of ALL ZEROs.

This test procedure verifies that the East/West Velocity subfield in UAT Messages is correctly set for the supersonic condition where the “A/G STATE” field is set to ONE (1).

Measurement Procedure:

Step 1: East/West Velocity Verification – Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages with “A/G STATE” set to “1” by providing East/West Velocity input data with a value greater than 1022 knots.

Set the ADS-B Transmitting Subsystem to Airborne status. Discontinue East/West Velocity data for a period of 2 seconds and verify that when East/West Velocity Data is not provided to the ADS-B transmission device, the East/West Velocity subfield in output UAT Messages is set to ZERO (binary 00 0000 0000).

Step 2: East/West Velocity Verification – Velocity Equal ZERO

Setup the ADS-B Transmitting Subsystem as above and set the East/West Velocity input to represent a velocity of ZERO knots.

Verify that the East/West Velocity subfield in subsequent UAT Messages is set to ONE (binary 00 0000 0001).

Step 3: East/West Velocity Verification – Discrete Values

Verify that for each integer East/West Velocity input value in knots identified in Table 2-88 that the system generates UAT Messages with the East/West Velocity Subfield set equal to the corresponding binary coding value in the table.

Table 2-88: Discrete Values for Supersonic East/West Velocity

East/West Velocity (Supersonic)		
Coding (binary)	**Coding** (decimal)	**Meaning** (E/W Velocity in knots)
00 0000 0010	2	E/W Velocity = 4 knots
00 0000 0101	5	E/W Velocity = 16 knots
00 0000 1010	10	E/W Velocity = 36 knots
00 0000 1111	15	E/W Velocity = 56 knots
00 0101 0000	80	E/W Velocity = 316 knots
00 0101 1010	90	E/W Velocity = 356 knots
00 1010 0101	165	E/W Velocity = 656 knots
00 1010 1010	170	E/W Velocity = 676 knots
01 0101 0101	341	E/W Velocity = 1,360 knots
10 0101 0101	597	E/W Velocity = 2,384 knots
10 1010 1010	682	E/W Velocity = 2,724 knots
11 0101 0101	853	E/W Velocity = 3,408 knots
11 1010 1010	938	E/W Velocity = 3,748 knots
11 1111 1110	1022	E/W Velocity = 4,084 knots

Verify that for 4 knot increases in the input value, the East/West Velocity subfield in subsequent UAT Messages of “A/G STATE” equal “1” is incremented by one from the previous value (i.e., that the value of the East/West Velocity subfield corresponds to the values given in the table in the above referenced section).

Verify that the East/West Velocity subfield in the output message is not incremented until the input value reaches a number corresponding to an even multiple of 4 knots.

Step 4: East/West Velocity Verification – Maximum Velocity

Continue to increase the value of the East/West Velocity Data input.

Verify that, for discrete values greater than or equal to 4084 knots but less than or equal to 4086 knots, the East/West Velocity subfield continues to be set to “1022” (binary 11 1111 1110).

Continue to increase the value of the East/West Velocity input.

Verify that for discrete input values representing a East/West Velocity greater than 4086 knots, up to the maximum possible input value, that the transmitter continues to generate UAT Messages with a “A/G STATE” subfield equal to “1,” and that the East/West Velocity subfield for all such messages is set to “1023” (binary 11 1111 1111).

Step 5: East/West Velocity Verification – Input Resolution

If the input data used to establish the East/West Velocity subfield has finer resolution than that required by the East/West Velocity subfield, then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the East/West Velocity subfield. If the input data field that is used to determine the output value of the East/West Velocity subfield does not have finer resolution than that required by the East/West Velocity subfield, proceed to Step 6.

Enter an input value corresponding to a eastward velocity of 6 knots.

Verify that the value of the East/West Velocity subfield in the output message is either “2” (binary 00 0000 0010, representing 4 knots) or “3” (binary 00 0000 0011, representing 8 knots).

If the input field used to establish the East/West Velocity subfield does not have resolution finer than 2 knots, skip to step 6. Otherwise (East/West Velocity input resolution is finer than 2 knots), let ***Z*** be equal to the smallest possible value that can be represented by the number of bits in the input field (i.e., ***Z*** is the value of the least significant bit of the input field). Set the value of the input field to correspond to a eastward velocity of (6 – ***Z*** knots).

Verify that the value of the East/West Velocity subfield in the output UAT Message is “2” (binary 00 0000 0010, representing 4 knots). Set the value of the input field to correspond to a eastward velocity of (6 + ***Z*** knots).

Verify that the value of the East/West Velocity subfield in the output UAT Message is “3” (binary 00 0000 0011, representing 8 knots).

Note: *If the resolution of the East/West Velocity input is such that a eastward velocity of 6 knots cannot be represented (but is still finer than 4 knots, e.g., a resolution of 1.75 knot increments), then values corresponding to eastward velocity must be tested, and the output examined for each value to confirm that the output is within ±2 knots (inclusive) of the input value.*

Step 6: East/West Velocity Verification - Part 6

Note: *If the nature of the inputs is such that a separate bit or “flag” type field is input to the transmitter to indicate “East” or “West,” the following step is not necessary. However, if the transmitter must perform some interpretation of its inputs in order to determine the correct output value of the E/W Sign bit, the following step must be performed.*

Repeat Steps 3, 4 and 5 so that each step is performed with East/West Velocity input data indicating travel in both EAST and WEST directions, i.e., replace the word “eastward” with “westward” in Steps 3, 4 and 5.

2.4.4.5.2.6.4 Verification of Encoding as “Track Angle/Heading” Form (§2.2.4.5.2.6.4)

Appropriate test procedures required to validate the requirements of §2.2.4.5.2.6.4 are included in §2.4.4.5.2.6.4.1 and §2.4.4.5.2.6.4.2.

2.4.4.5.2.6.4.1 Verification of “Track Angle/Heading Type” Flag Subfield (§2.2.4.5.2.6.4.a)

Purpose/Introduction:

The Track Angle/Heading Type (“TA/H Type”) is a 2-bit subfield (bit 7 and 8 of byte 14) that **shall** be used to distinguish Track Angle from Heading as shown in Table 2-28.

If either the Track Angle/Heading Type or the Track Angle/Heading Inputs are "unavailable" for the "Data Lifetime" value listed for these inputs in Table 2-98, then the "Track Angle/Heading Type" and the "Track Angle/Heading" subfields **shall** default to values of ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing Track Angle/Heading information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Track Angle/Heading Flag Bit Verification – A/G STATE "2" Data Available

Set the ADS-B Transmitting Subsystem to ON GROUND status. Provide valid Ground Speed and Heading/Tracking data to the ADS-B system. This data should indicate ground velocity for testing messages with the "A/G STATE" set to "2."

Verify that for an "A/G STATE" set to "2," if the True Track Angle information is provided, that the "TA/H Type" subfield is set to ONE (binary 01).

Verify that if the True Heading information is provided, that the "TA/H Type" subfield is set to THREE (binary 11).

Verify that if the Magnetic Heading information is provided, that the "TA/H Type" subfield is set to TWO (binary 10).

Step 3: Track Angle/Heading Flag Bit Verification – A/G STATE "2" Data Lifetime

Discontinue the input of the Track Angle/Heading data to the ADS-B system. Verify that, after 2 seconds, the "TA/H Type" subfield is set to ZERO (binary 00).

Resume Heading data input with True Heading information to the ADS-B system and verify that "TA/H Type" field is set to THREE (binary 11).

2.4.4.5.2.6.4.2 Verification of the "Track Angle/Heading" Data Subfield (§2.2.4.5.2.6.4.b)

Purpose/Introduction:

The "Track Angle/Heading" subfield is a 9-bit (bit 1 of byte 15 through bit 1 of byte 16) that **shall** be used to report the Track Angle or Heading of the ADS-B Transmitting Subsystem as shown in Table 2-29.

If either the Track Angle/Heading Type or the Track Angle/Heading Inputs are "unavailable" for the "Data Lifetime" value listed for these inputs in Table 2-98, then the "Track Angle/Heading Type" and the "Track Angle/Heading" subfields **shall** default to values of ALL ZEROs.

This test procedure will verify that the ADS-B Transmitting Subsystem correctly outputs UAT Messages with the correct “Track Angle/Heading” subfield data.

Measurement Procedure:

Step 1: “Track Angle/Heading” Verification – Input Validation

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing position information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages at the nominal rate. Set the ADS-B Transmitting Subsystem to “On-Ground” status. Provide valid, non-zero “Track Angle/Heading” data to the ADS-B System. Verify that the “Track Angle/Heading” subfield is NOT set to ZERO (0). Set the “Track Angle/Heading” input to exactly ZERO degrees and verify that the encoding of the “Track Angle/Heading” subfield is set to ZERO (binary 0 0000 0000).

Step 2: “Track Angle/Heading” Verification – Discrete Values

Raw data used to establish the “Track Angle/Heading” subfield will normally have more resolution (i.e., more bits) than that required by the “Track Angle/Heading” subfield. When converting such data to the “Track Angle/Heading” subfield, the accuracy of the data shall be maintained such that it is not worse than ±½ LSB where the LSB is that of the “Track Angle/Heading” subfield.

Set up the ADS-B Transmitting Subsystem as above and set the “Track Angle/Heading” data input to 0.703125 degrees. Verify that the “Track Angle/Heading” subfield is set to ONE (binary 0 0000 0001). Continue increasing the “Track Angle/Heading” data input in increments of 0.703125 degrees and verify that for each such increment, the encoding of the “Track Angle/Heading” subfield is set to the corresponding binary code shown in Table 2-29, for all possible encodings.

Step 3: “Track Angle/Heading” Verification – Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing position information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages at the nominal rate. Set the ADS-B Transmitting Subsystem to “On-Ground” status. Provide valid, non-zero “Track Angle/Heading” data to the ADS-B System. Verify that the “Track Angle/Heading” subfield is NOT set to ZERO (0).

Discontinue the “Track Angle/Heading” data for a period of 2 seconds and verify that the “Track Angle/Heading Type” is set to ZERO (binary 00).

2.4.4.5.2.7 Verification of “VERTICAL VELOCITY or A/V SIZE” Field (§2.2.4.5.2.7)

No specific test procedure is required to validate §2.2.4.5.2.7.

2.4.4.5.2.7.1 Verification of Encoding as "Vertical Velocity" Form (§2.2.4.5.2.7.1)

Appropriate test procedures required to validate the requirements of §2.2.4.5.2.7.1 are included in §2.4.4.5.2.7.1.1 through §2.4.4.5.2.7.1.3.

2.4.4.5.2.7.1.1 Verification of "VV Src" Subfield Encoding (§2.2.4.5.2.7.1.1)

Purpose/Introduction:

The Vertical Velocity Source ("VV Src") subfield is a 1-bit (bit 2 of byte 16) field that **shall** be used to indicate the source of Vertical Rate information as defined in Table 2-31.

Measurement Procedure:

Step 1: Verification of Geometric Source

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages and ensure that there is a Geometric Vertical Velocity source. Verify that bit 2 of byte 16 is ZERO (0) in the next transmitted message. Repeat this Step for several Message transmission cycles and verify that bit 2 of byte 16 is ZERO (0) in each transmitted message.

Discontinue the Geometric Vertical Velocity input. Verify that, after 2 seconds, bit 2 of byte 16 is ONE (1) in the next transmitted message.

Step 2: Verification of Barometric Source

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages and ensure that there is a Barometric Vertical Velocity source. Verify that bit 2 of byte 16 is ONE (1) in the next transmitted message. Repeat this step for several Message transmission cycles and verify that bit 2 of byte 16 is ONE (1) in each transmitted message.

Discontinue the Barometric Vertical Velocity input. Verify that, after 2 seconds, bit 2 of byte 16 is ZERO (0) in the next transmitted message.

2.4.4.5.2.7.1.2 Verification of "VV Sign" Subfield Encoding (§2.2.4.5.2.7.1.2)

Purpose/Introduction:

The Sign Bit for Vertical Rate ("VV Sign") subfield is a 1-bit (bit 3 of byte 16) field used to indicate the direction of the "Vertical Rate" subfield. Encoding of this subfield **shall** be as indicated in Table 2-32.

Measurement Procedure:

Step 1: Vertical Rate Sign Bit Verification – Data Not Available

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set the ADS-B Transmitting Subsystem to Airborne status. Provide valid non-zero barometric pressure altitude data and valid non-zero velocity data to the ADS-B System.

Verify that when Vertical Rate Data is not provided to the ADS-B transmission device, the Vertical Rate Sign Bit is set to “0,” as specified in Table 2-32.

Step 2: Vertical Rate Sign Bit Directional Component Verification

The method for testing this field depends largely upon the nature of the input for Vertical Rate Data.

CASE 1:

If the directional component of the input is a single bit or a “flag” type (i.e., a single discrete value is used to represent “UP,” and another discrete value is used to represent “DOWN”), then the procedure for this step shall be as follows:

Set this input to the value that indicates an upward direction, and verify that ADS-B UAT Messages are generated with PAYLOAD TYPE, set to a value of ZERO (0), and verify that all such messages contain a Vertical Rate Sign Bit subfield with a value of ZERO (0). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate Sign Bit subfield with a value of ZERO (0).

Next, set the input to the value that indicates a downward direction, and verify that ADS-B UAT Messages are generated, and that all such messages contain a Vertical Rate Sign Bit subfield with a value of ONE (1). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate Sign Bit subfield with a value of ONE (1).

CASE 2:

If the directional component of the input is variable (e.g., a heading expressed in degrees or other similar manner, so that the input value must be evaluated by the ADS-B transmission device in order to determine the proper value for the Vertical Rate Sign Bit), then the test procedure shall be as follows.

In this case, the input variable must be made to assume values corresponding to an upward climb, and it must be verified, for each such value, that UAT Messages are generated with PAYLOAD TYPE set to a value of ZERO (0), and that all such messages contain a Vertical Rate Sign Bit subfield with a value of ZERO (0). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate Sign Bit subfield with a value of ZERO (0).

The input must then be made to assume values corresponding to a descent, and it must be verified, for each such value, that the transmitter generates UAT Messages with PAYLOAD TYPE, set to a value of ZERO (0), and that all such messages contain a Vertical Rate Sign Bit subfield with a value of ONE (1). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate Sign Bit subfield with a value of ONE (1).

2.4.4.5.2.7.1.3 Verification of "Vertical Rate" Subfield Encoding (§2.2.4.5.2.7.1.3)

Purpose/Introduction:

The "Vertical Rate" subfield is a 9-bit (bit 4 of byte 16 through bit 4 of byte 17) field is used to report the Vertical Rate (in feet/minute) of the ADS-B transmission device.

If the Vertical Rate Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "Vertical Rate" subfield **shall** default to a value of ALL ZEROs.

Range, Resolution, and Not Available encoding of the "Vertical Rate" subfield **shall** be as shown in Table 2-33.

Measurement Procedure:

Step 1: Vertical Rate Verification – Data Lifetime

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing velocity information at the nominal update rate. Provide the data externally at the interface to the ADS-B system. Set up the system to enable broadcast of UAT Messages. Set the ADS-B Transmitting Subsystem to Airborne status. Provide valid non-zero barometric pressure altitude data and valid non-zero velocity data to the ADS-B System.

Discontinue the Vertical Rate inputs. Verify that, after 2 seconds, the Vertical Rate subfield is set to ALL ZEROs (binary 0 0000 0000) in the next transmitted message.

Step 2: Vertical Rate Equal To ZERO Verification

The input for this field shall initially be set to represent a Vertical Rate of ZERO feet per minute.

Verify that the ADS-B transmission device generates UAT Messages with PAYLOAD TYPE, set to a value of ZERO (0), and that the Vertical Rate subfield in each such message contains the value "1" (binary 0 0000 0001). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate subfield with a value of ONE (binary 0 0000 0001).

Step 3: Vertical Rate Verification – Discrete Values

Increase the value of the Vertical Rate Data input so that it assumes each discrete decimal coding value from Table 2-89.

Verify that for each discrete decimal coding input value, the Vertical Rate subfield in subsequent UAT Messages with PAYLOAD TYPE set to a value of ZERO (0), matches identically to the corresponding Binary Coding value from Table 2-89. Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate subfield that matches identically to the corresponding Binary Coding value from Table 2-89.

Table 2-89: Vertical Rate Discrete Values

VERTICAL RATE		
Coding (binary)	**Coding** (decimal)	**Meaning** (VERTICAL RATE in feet / minute)
0 0000 0101	5	Vertical Rate = 256 feet / minute
0 0000 1010	10	Vertical Rate = 576 feet / minute
0 0000 1111	15	Vertical Rate = 896 feet / minute
0 0101 0000	80	Vertical Rate = 5,056 feet / minute
0 0101 1111	95	Vertical Rate = 6,016 feet / minute
0 1010 0000	160	Vertical Rate = 10,176 feet / minute
0 1010 1111	175	Vertical Rate = 11,136 feet / minute
0 1111 1111	255	Vertical Rate = 16,256 feet / minute
1 0000 0000	256	Vertical Rate = 16,320 feet / minute
1 0101 0101	341	Vertical Rate = 21,760 feet / minute
1 1010 1010	426	Vertical Rate = 27,200 feet / minute
1 1111 1110	510	Vertical Rate = 32,576 feet / minute

Verify that the Vertical Rate subfield in the output message is not incremented until the input value reaches a number corresponding to an even multiple of 64 feet/minute.

Step 4: Vertical Rate Verification – Out of Bounds Test

Continue to increase the value of the Vertical Rate Data input.

Verify that for values greater than 32,576 feet per minute but less than or equal to 32,608 feet per minute, the Vertical Rate subfield continues to be set to "510" (binary 1 1111 1110).

Continue to increase the value of the vertical rate input.

Verify that for values representing a vertical rate greater than 32,608 feet per minute, up to the maximum possible input value, that the transmitter continues to generate UAT Messages with PAYLOAD TYPE set to a value of ZERO (0) with the Vertical Rate subfield for all such messages is set to "511" (binary 1 1111 1111). Repeat this step for ADS-B UAT Messages generated with PAYLOAD TYPE set to values of ONE (1) through SIX (6), and verify that all such messages contain a Vertical Rate subfield that is set to "511" (binary 1 1111 1111).

Step 5: Vertical Rate Verification - Part 5

Note: *If the nature of the inputs is such that a separate bit or "flag" type field is input to the transmitter to indicate "Up" or "Down," the following step is not necessary. However, if the transmitter must perform some interpretation of its inputs in order to determine the correct output value of the Vertical Rate Sign Bit, the following step must be performed.*

Repeat steps 3 through 5, so that each step is performed with Vertical Rate input data indicating directional vectors of both UP (climb) and DOWN (descent) turns.

2.4.4.5.2.7.2 Verification of Encoding as "A/V Size" Form (§2.2.4.5.2.7.2)

Purpose/Introduction:

When the ADS-B Transmitting Subsystem is in the ON-GROUND condition, the "VERTICAL VELOCITY or A/V SIZE" field **shall** assume the "A/V Size" form as shown in Table 2-34. The encoding of the "A/V Size" **shall** be as shown in Table 2-35. The encoding of the "Position Offset Applied" (POA) flag shown in Table 2-36 indicates whether the reported position reflects application of a position offset to normalize the ownship navigation sensor position to the ADS-B reference point.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing aircraft size information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Verification of Transmission of "Aircraft Size" When in ON-GROUND Status

Set up the system to enable broadcast of UAT Messages with the A/G STATE set to "2," according to the conditions defined in §2.2.4.5.2.5.1.

Verify that each of the Length and Width values of the Aircraft, in meters, are encoded according to Table 2-35 in bits 2 through 5 of byte 16 of the "A/V Length and Width Format" subfield. Verify that the Position Offset Applied (POA) in bit 6 of byte 16 is set to either ZERO or ONE, based upon the input provided for the POA bit in Table 2-64.

Verify that the remaining 6 bits (bit 7 of byte 16 through bit 4 of byte 17) of the "A/V Length and Width Format" subfield are set to ALL ZEROs.

Remove the stimulus which indicates the input of the Length/Width values and verify that bits 2 through 5 of byte 16 of the "A/V Length and Width Format" subfield are set to ALL ZEROs.

Step 3: Verification of Transmission of "Aircraft Size" When in the "On-Ground" Status with GPS Antenna Offset Information Encoded

a. Verification of Lateral Axis GPS Antenna Offset

1. Set up the system to enable broadcast of UAT Messages with the A/G STATE set to "2," according to the conditions defined in §2.2.4.5.2.5.1.

2. Via an appropriate data interface provide the ADS-B Transmitting Subsytem with data necessary to establish each of the Lateral Axis GPS Antenna Offset Encodings indicated in Table 2.2.4.5.2.7.2A.

3. Verify that the Axis bit (bit 7 of byte 16) alternates between ZERO (0) and ONE (1) each successive second. Next verify that when the Axis bit is set to ZERO (0), the Lateral Offset encoding is as shown in Table 2.2.4.5.2.7.2A.

b. Verification of Longitudinal Axis GPS Antenna Offset

1. Set up the system to enable broadcast of UAT Messages with the A/G STATE set to "2," according to the conditions defined in §2.2.4.5.2.5.1.

2. Via an appropriate data interface provide the ADS-B Transmitting Subsytem with data necessary to establish each of the Longitudinal Axis GPS Antenna Offset Encodings indicated in Table 2.2.4.5.2.7.2B.

3. Verify that the Axis bit (bit 7 of byte 16) alternates between ZERO (0) and ONE (1) each successive second. Next verify that when the Axis bit is set to ONE (1), the Longitudinal Offset encoding is as shown in Table 2.2.4.5.2.7.2B.

Step 4: Verification of non-transmission of "Aircraft Size" when in AIRBORNE Status

Set up the ADS-B Transmitting Subsystem to enable broadcast of UAT Messages with the A/G STATE set to "0," signifying the AIRBORNE status.

Provide a Length value of 34 meters and a Width value of 34 meters. Provide Vertical Rate from a Barometric source. Provide a Vertical Rate of 64 feet/minute climbing. Verify that the 11 bits (bit 2 of byte 16 through bit 4 of byte 17) which represent the "VERTICAL VELOCITY" format (for an AIRBORNE condition) are set to binary 100 0000 0010, indicating that A/V is not transmitting the A/V Length and Width Format if the A/V is in the AIRBORNE status.

2.4.4.5.2.8 Verification of "UTC" Field Encoding (§2.2.4.5.2.8)

Purpose/Introduction:

The "UTC" field is a 1-bit field (bit 5 of byte 17) that indicates whether the ADS-B Transmitting Subsystem is in the "UTC Coupled" condition or the "Non-UTC Coupled" condition (§2.2.5). The encoding of this field **shall** be as indicated in Table 2-37.

If the UTC 1-PPS Timing Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "UTC" field **shall** default to a value of ZERO.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B Transmitting Subsystem to transmit UAT Messages by providing position, velocity and time (PVT) data via the appropriate Navigation Data Source interface at the nominal update rate.

Step 2: "UTC" Field Encoding Verification - Part 1

If the ADS-B Transmitting Subsystem accepts a GNSS TIME MARK, or equivalent input from the navigation data source, verify that the "UTC" subfield is set to ONE (1).

If the ADS-B Transmitting Subsystem is not capable of receiving a GNSS Time Mark, or if the input is not available, verify that the "UTC" subfield is set to ZERO (0).

Step 3: "UTC" Field Encoding Verification - Part 2

Disable the UTC Time Mark input, or equivalent. Provide a valid Ground Uplink Message to the ADS-B Transmitting Subsystem.

Verify that while receiving a ground uplink messages the "UTC" subfield is set to ZERO (0).

Step 4: "UTC" Field Encoding – Data Lifetime

Disable the UTC Time Mark input, or equivalent. Verify that, after 2 seconds, the "UTC" subfield is set to ZERO (0).

Resume UTC Time Mark input and verify that the ADS-B Message contains a "UTC" subfield that is set to ONE (1).

2.4.4.5.2.9 Verification of Uplink Feedback Encoding (§Error! Reference source not found.)

Purpose/Introduction:

The "Uplink Feedback" field is a 3-bit field (bits 6 through 8 of byte 17) that **shall** be transmitted whenever the "ADDRESS QUALIFIER" field is set to "0," "1," "4" or "5." This field reports on the number of successful Ground Uplink messages that were successfully received on a particular Data Channel in the previous 32 seconds.

The format of this field **shall** be as shown in Table 2-37A.

Transmit-only Equipage Classes (B0 through B3) **shall** set this field to ALL ZEROs.

Measurement Procedure:

For UUTs capable of receiving Ground Uplink Messages, follow Steps 1 through 6 below.

For Equipment Classes B0 through B3 follow Step 7.

Step 1: Test Set-up

Configure the UUT to receive messages from a UAT Ground Uplink Message source and to transmit ADS-B Payload Types according to the sequence specified for its particular Equipment Class.

Configure the ground station to be able to transmit valid Ground Uplink Messages on only Data Channel "N" as defined in §2.2.4.5.2.9. Adjust the power of the ground station's signal so that it is between -61 dBm and -51 dBm at the input to the UUT (approximately 30 dB to 40 dB above sensitivity).

Repeat the following Steps 2 through 6 for N = 1, 12 and 23.

Step 2: Perfect Reception (Score = 32)

Transmit one Ground Uplink message every second for at least 128 seconds. Verify that the ADS-B message transmitted in second Tk = (33-N) mod 32 + 32 k has the “Uplink Feedback” field encoding “111.” Verify that the “Uplink Feedback” field encoding is “000” for ADS-B messages transmitted during every other one-second interval.

Step 3: Imperfect Reception (Score = 31)

Transmit one Ground Uplink message every second, except if Tj = (33-N) mod 32 + 32 j -1, for at least 128 seconds. Verify that the ADS-B message transmitted in second Tk = (33-N) mod 32 + 32 k has the “Uplink Feedback” field encoding “110.” Verify that the “Uplink Feedback” field encoding is “000” for ADS-B messages transmitted during every other one-second interval.

Step 4: Imperfect Reception (Score = 30)

Transmit one Ground Uplink message every second, except if Tj = (33-N) mod 32 + 32 j -1 or Tj = (33-N) mod 32 + 32 j -2, for at least 128 seconds. Verify that the ADS-B message transmitted in second Tk = (33-N) mod 32 + 32 k has the “Uplink Feedback” field encoding “101.” Verify that the “Uplink Feedback” field encoding is “000” for ADS-B messages transmitted during every other one-second interval.

Step 5: Imperfect Reception (Score = 13)

Transmit a Ground Uplink message only in seconds Tj = (33-N) mod 32 + 32 j – i (with i = 1 through 13) for at least 128 seconds. Verify that the ADS-B message transmitted in second Tk = (33-N) mod 32 + 32 k has the “Uplink Feedback” field encoding “ 001.” Verify that the “Uplink Feedback” field encoding is “000” for ADS-B messages transmitted during every other one-second interval.

Step 6: No Reception (Score = 0)

Disconnect or turn off the ground station. Verify that the ADS-B message transmitted every second has the “Uplink Feedback” field encoding “000.”

Step 7: Transmit-Only Equipment Classes

For at least 128 seconds, verify that the ADS-B message transmitted by the UUT every second has the “Uplink Feedback” field encoding “000.”

2.4.4.5.2.10 Verification of Reserved Byte 18, Payload Type Zero (§2.2.4.5.2.10)

Purpose/Introduction:

Byte 18 of the ADS-B Message Payload definition in Table 2-10 is reserved for future use, and **shall** be set to ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing the Payload Type Code and other available information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Reserved Byte Verification

Set the ADS-B Transmitting Subsystem to transmit Type 0 Messages. Verify that the Reserved Byte "18" is set to ZERO.

2.4.4.5.3 Verification of STATE VECTOR Element (For TIS-B) (§2.2.4.5.3)

No specific test procedure is required to validate §2.2.4.5.3.

2.4.4.5.3.1 Verification of "TIS-B SITE ID" Field Encoding (§2.2.4.5.3.1)

No specific test procedure is required to validate §2.2.4.5.3.1.

2.4.4.5.3.2 Verification of Encoding for All Other Fields (§2.2.4.5.3.2)

No specific test procedure is required to validate §2.2.4.5.3.2.

2.4.4.5.4 Verification of MODE STATUS Element (§2.2.4.5.4)

Appropriate test procedures are provide in §2.4.4.5.4.1 through §2.4.4.5.4.15.

2.4.4.5.4.1 Verification of "EMITTER CATEGORY" Field (§2.2.4.5.4.1)

Purpose/Introduction:

The "EMITTER CATEGORY" field is encoded as a radix 40 value in the range of 0-39. The "EMITTER CATEGORY" field **shall** be encoded as shown in Table 2-40.

Measurement Procedure:

Step 1: "EMITTER CATEGORY" Field (§2.2.4.5.4.1)

Set the first two characters of the "CALL SIGN" to the '0' character (Base 40 Code value ZERO), and configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Type Code 3 for the A1H equipment class). For each case in Table 2-90 below, except for the "(Unassigned)," and "(reserved)" cases, select the "EMITTER CATEGORY" listed, and verify that Bytes 18 and 19 of the received ADS-B Long Message match the corresponding Binary Encoding value in the table.

Note: *It may be necessary to cycle power-on before verifying each selected code.*

Table 2-90: "EMITTER CATEGORY" Encoding Test Data

EMITTER CATEGORY ENCODING					
Base 40 Code	**Emitter Category (§2.2.4.5.4.1)**	**Binary Encoding Byte 18 MSB Byte 19 LSB**	**Base 40 Code**	**Emitter Category (§2.2.4.5.4.1)**	**Binary Encoding Byte 18 MSB Byte 19 LSB**
0	No aircraft type information	0000 0000 0000 0000	20	Cluster Obstacle	0111 1101 0000 0000
1	Light (ICAO) < 15 500 lbs	0000 0110 0100 0000	21	Line Obstacle	1000 0011 0100 0000
2	Small - 15 500 to 75 000 lbs	0000 1100 1000 0000	22	(reserved)	1000 1001 1000 0000
3	Large - 75 000 to 300 000 lbs	0001 0010 1100 0000	23	(reserved)	1000 1111 1100 0000
4	High Vortex Large (e.g., B757)	0001 1001 0000 0000	24	(reserved)	1001 0110 0000 0000
5	Heavy (ICAO) - > 300 000 lbs	0001 1111 0100 0000	25	(reserved)	1001 1100 0100 0000
6	Highly Maneuverable > 5G acceleration and high speed	0010 0101 1000 0000	26	(reserved)	1010 0010 1000 0000
7	Rotorcraft	0010 1011 1100 0000	27	(reserved)	1010 1000 1100 0000
8	(Unassigned)	0011 0010 0000 0000	28	(reserved)	1010 1111 0000 0000
9	Glider/sailplane	0011 1000 0100 0000	29	(reserved)	1011 0101 0100 0000
10	Lighter than air	0011 1110 1000 0000	30	(reserved)	1011 1011 1000 0000
11	Parachutist/sky diver	0100 0100 1100 0000	31	(reserved)	1100 0001 1100 0000
12	Ultra light/hang glider/paraglider	0100 1011 0000 0000	32	(reserved)	1100 1000 0000 0000
13	(Unassigned)	0101 0001 0100 0000	33	(reserved)	1100 1110 0100 0000
14	Unmanned aerial vehicle	0101 0111 1000 0000	34	(reserved)	1101 0100 1000 0000
15	Space/transatmospheric vehicle	0101 1101 1100 0000	35	(reserved)	1101 1010 1100 0000
16	(Unassigned)	0110 0100 0000 0000	36	(reserved)	1110 0001 0000 0000
17	Surface vehicle - emergency vehicle	0110 1010 0100 0000	37	(reserved)	1110 0111 0100 0000
18	Surface vehicle - service vehicle	0111 0000 1000 0000	38	(reserved)	1110 1101 1000 0000
19	Point Obstacle (includes tethered balloons)	0111 0110 1100 0000	39	(reserved)	1111 0011 1100 0000

2.4.4.5.4.2 Verification of "CALL SIGN/FLIGHT PLAN ID" Field (§2.2.4.5.4.2)

Appropriate test procedures required to validate the requirements of §2.2.4.5.4.2 are included in §2.4.4.5.4.3.1, §2.4.4.5.4.3.2, §2.4.4.5.4.3.3, and §2.4.4.5.4.3.4.

2.4.4.5.4.3 Verification of Compressed Format Encoding for "EMITTER CATEGORY" and "CALL SIGN/FLIGHT PLAN ID" (§2.2.4.5.4.3)

No specific test procedure is required to validate §2.2.4.5.4.3.

2.4.4.5.4.3.1 Verification of Bytes #18 and #19 (§2.2.4.5.4.3.1)

Purpose/Introduction:

Bytes #18 and #19 **shall** be encoded such that:

B_2 - Represents the "EMITTER CATEGORY" field (§2.2.4.5.4.1)

B_1 - Represents Character #1 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

B_0 - Represents Character #2 of the "CALL SIGN/FLIGHT PLAN ID" field (§2.2.4.5.4.2)

Measurement Procedure:

Step 1: Bytes 18 and 19 Field (§2.2.4.5.4.3.1)

Configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Code 3 for A1H equipment class). Provide the “Receiving ATC Services” Flag input to the UUT, set to FALSE. For each case in Table 2-91 below, select the “EMITTER CATEGORY” listed in column 1, select the Call Sign Characters listed in column 2, and verify that Bytes 18 and 19 of the received ADS-B Long Message match the corresponding Binary Encoding value in the table.

Table 2-91: “EMITTER CATEGORY” And Bytes 18 & 19 Encoding Test Data

”EMITTER CATEGORY” AND BYTES 18 & 19 ENCODING		
Emitter Category (§2.2.4.5.4.1)	**Call Sign Characters**	**Binary Encoding Byte 18 Byte 19 MSB LSB**
No aircraft type information	00000000	0000 0000 0000 0000
No aircraft type information	01000000	0000 0000 0000 0001
No aircraft type information	02000000	0000 0000 0000 0010
No aircraft type information	04000000	0000 0000 0000 0100
No aircraft type information	08000000	0000 0000 0000 1000
No aircraft type information	0H000000	0000 0000 0001 0001
No aircraft type information	0Y000000	0000 0000 0010 0010
No aircraft type information	1S000000	0000 0000 0100 0100
No aircraft type information	3G000000	0000 0000 1000 1000
No aircraft type information	6W000000	0000 0001 0001 0000
No aircraft type information	DO000000	0000 0010 0010 0000
No aircraft type information	R8000000	0000 0100 0100 0000
Light (ICAO) < 15 500 lbs	EG000000	0000 1000 1000 0000
Small - 15 500 to 75 000 lbs	SW000000	0001 0001 0000 0000
Heavy (ICAO) - > 300 000 lbs	HO000000	0010 0010 0000 0000
Lighter than air	Z8000000	0100 0100 0000 0000
Line Obstacle	UG000000	1000 1000 0000 0000
Small - 15 500 to 75 000 lbs	MG000000	0001 0000 0000 0000
Heavy (ICAO) - > 300 000 lbs	4W000000	0010 0000 0000 0000
Lighter than air	9O000000	0100 0000 0000 0000
Cluster Obstacle	J8000000	1000 0000 0000 0000

2.4.4.5.4.3.2 Verification of Bytes #20 and #21 (§2.2.4.5.4.3.2)

Purpose/Introduction:

Bytes #20 and #21 **shall** be encoded such that:

B_2 - Represents Character #3 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

B_1 - Represents Character #4 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

B_0 - Represents Character #5 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

Measurement Procedure:

Step 1: Bytes 20 and 21 Field (§2.2.4.5.4.3.2)

Configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Code 3 for A1H equipment class). Provide the “Receiving ATC Services” Flag input to the UUT, set to FALSE. For each case in Table 2-92 below, select the Call Sign Characters listed, and verify that Bytes 20 and 21 of the received ADS-B Long Message match the corresponding Binary Encoding value in the table.

Table 2-92: Bytes 20 & 21 Encoding Test Data

BYTES 20 & 21 ENCODING			
Call Sign Characters	**Binary Encoding** **Byte 20 Byte 21** **MSB LSB**	**Call Sign Characters**	**Binary Encoding** **Byte 20 Byte 21** **MSB LSB**
00001000	0000 0000 0000 0001	00FJC000	0110 0000 1100 0100
00003000	0000 0000 0000 0011	0042Y000	0001 1001 0111 0010
00007000	0000 0000 0000 0111	00IE5000	0111 0010 1011 0101
0000F000	0000 0000 0000 1111	00SPSB00	1110 0101 0110 1011
0000V000	0000 0000 0001 1111	009JN000	0011 1011 0100 1111
0001Q000	0000 0000 0100 0010	00JCA000	0111 1000 1010 1010
0003P000	0000 0000 1001 0001	002YU000	0001 0001 1110 1110
0007O000	0000 0001 0011 0000	00E5N000	0101 1000 0101 1111
000FL000	0000 0010 0110 1101	00SBK000	1011 0000 1100 1100
000VG000	0000 0100 1110 1000	00JND000	0111 1010 0110 0101
001Q5000	0000 1010 0101 0101	00CA0000	0100 1100 1001 0000
003PL000	0001 0110 1011 1101	00YUA000	1101 1001 0011 1010
007O6000	0010 1111 1000 0110	005NK000	0010 0010 1110 1100
00FLM000	0110 0001 0001 1110	00BK3000	0100 0111 1110 0011
00VG7000	1100 0100 0100 0111	00NDH000	1001 0001 1101 1001
00Q5P000	1010 0011 0110 0001	00A0Z000	0011 1110 1010 0011
00PLE000	1001 1111 1001 0110	00UA6000	1011 1101 0001 0110
00O61000	1001 0110 1111 0001	00NKC000	1001 0010 1110 1100
00LMD000	1000 0110 1011 1101	00K3O000	0111 1101 1001 0000
00G7R000	0110 0101 0011 0011	00DHB000	0101 0011 1111 0011
005PI000	0010 0011 0011 1010	000ZX000	0000 0101 1001 1001
00LE9000	1000 0101 0111 1001	00A62000	0011 1111 0111 0010
0061T000	0010 0101 1100 0101	00KC4000	0111 1110 1110 0100
00MDM000	1000 1011 1001 1110	003O8000	0001 0110 1000 1000
007RH000	0011 0000 0000 1001	00HBG000	0110 1100 0000 1000
00PI8000	1001 1111 0001 1000	00ZXW000	1110 0000 0000 1000
00E9Q000	0101 1001 0000 0010	00621000	0010 0101 1101 0001
001TF000	0000 1010 1101 0111	00C43000	0100 1011 1010 0011
00DM4000	0101 0100 1011 0100	00O87000	1001 0111 0100 0111
00RHI000	1010 1011 0111 1010	00BGF000	0100 0111 0100 1111
00I8SP000	0111 0001 1110 0100	00XWV00	1101 0011 0101 1111
009Q9000	0011 1100 0101 1001	0021Q000	0000 1100 1100 0010
00TFJ000	1011 0111 1010 1011	0043P000	0001 1001 1001 0001
00M42000	1000 1010 0010 0010	0087O000	0011 0011 0011 0000
00HIE000	0110 1101 0001 1110	00GFL000	0110 0110 0110 1101
008SPS000	0011 0111 1011 1100	00WVG00	1100 1100 1110 1000
00Q9J000	1010 0011 1111 1011	001Q5000	0000 1010 0101 0101

2.4.4.5.4.3.3 Verification of Bytes #22 and 23 (§2.2.4.5.4.3.3)

Purpose/Introduction:

Bytes #22 and #23 **shall** be encoded such that:

B_2 - Represents Character #6 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

B_1 - Represents Character #7 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

B_0 - Represents Character #8 of the “CALL SIGN/FLIGHT PLAN ID” field (§2.2.4.5.4.2)

Measurement Procedure:

Step 1: Bytes 22 and 23 Field (§2.2.4.5.4.3.3)

Configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Code 3 for A1H equipment class). Provide the “Receiving ATC Services” Flag input to the UUT, set to FALSE. For each case in Table 2-93 below, select the Call Sign Characters listed, and verify that Bytes 22 and 23 of the received ADS-B Long Message match the corresponding Binary Encoding value in the table.

Table 2-93: Bytes 22 & 23 Encoding Test Data

BYTES 22 & 23 ENCODING			
Call Sign Characters	Binary Encoding Byte 22 Byte 23 MSB LSB	Call Sign Characters	Binary Encoding Byte 22 Byte 23 MSB LSB
00000001	0000 0000 0000 0001	00000FJC	0110 0000 1100 0100
00000003	0000 0000 0000 0011	0000042Y	0001 1001 0111 0010
00000007	0000 0000 0000 0111	00000IE5	0111 0010 1011 0101
0000000F	0000 0000 0000 1111	00000SPSB	1110 0101 0110 1011
0000000V	0000 0000 0001 1111	000009JN	0011 1011 0100 1111
0000001Q	0000 0000 0100 0010	00000JCA	0111 1000 1010 1010
0000003P	0000 0000 1001 0001	000002YU	0001 0001 1110 1110
0000007O	0000 0001 0011 0000	00000E5N	0101 1000 0101 1111
000000FL	0000 0010 0110 1101	00000SBK	1011 0000 1100 1100
000000VG	0000 0100 1110 1000	00000JND	0111 1010 0110 0101
000001Q5	0000 1010 0101 0101	00000CA0	0100 1100 1001 0000
000003PL	0001 0110 1011 1101	00000YUA	1101 1001 0011 1010
000007O6	0010 1111 1000 0110	000005NK	0010 0010 1110 1100
00000FLM	0110 0001 0001 1110	00000BK3	0100 0111 1110 0011
00000VG7	1100 0100 0100 0111	00000NDH	1001 0001 1101 1001
00000Q5P	1010 0011 0110 0001	00000A0Z	0011 1110 1010 0011
00000PLE	1001 1111 1001 0110	00000UA6	1011 1101 0001 0110
00000O61	1001 0110 1111 0001	00000NKC	1001 0010 1110 1100
00000LMD	1000 0110 1011 1101	00000K3O	0111 1101 1001 0000
00000G7R	0110 0101 0011 0011	00000DHB	0101 0011 1111 0011
000005PI	0010 0011 0011 1010	000000ZX	0000 0101 1001 1001
00000LE9	1000 0101 0111 1001	00000A62	0011 1111 0111 0010
0000061T	0010 0101 1100 0101	00000KC4	0111 1110 1110 0100
00000MDM	1000 1011 1001 1110	000003O8	0001 0110 1000 1000
000007RH	0011 0000 0000 1001	00000HBG	0110 1100 0000 1000
00000PI8	1001 1111 0001 1000	00000ZXW	1110 0000 0000 1000
00000E9Q	0101 1001 0000 0010	00000621	0010 0101 1101 0001
000001TF	0000 1010 1101 0111	00000C43	0100 1011 1010 0011
00000DM4	0101 0100 1011 0100	00000O87	1001 0111 0100 0111
00000RHI	1010 1011 0111 1010	00000BGF	0100 0111 0100 1111
00000I8SP	0111 0001 1110 0100	00000XWV	1101 0011 0101 1111
000009Q9	0011 1100 0101 1001	0000021Q	0000 1100 1100 0010
00000TFJ	1011 0111 1010 1011	0000043P	0001 1001 1001 0001
00000M42	1000 1010 0010 0010	0000087O	0011 0011 0011 0000
00000HIE	0110 1101 0001 1110	00000GFL	0110 0110 0110 1101
000008SPS	0011 0111 1011 1100	00000WVG	1100 1100 1110 1000
00000Q9J	1010 0011 1111 1011	000001Q5	0000 1010 0101 0101

2.4.4.5.4.3.4 Verification of Unavailable "CALL SIGN/FLIGHT PLAN ID" Field (§2.2.4.5.4.2)

Purpose/Introduction:

When representing the Call Sign, if the Call Sign input is not available, then all eight characters of the "CALL SIGN" Field **shall** be set to the Base-40 digit code 37 ("Not Available").

Measurement Procedure:

Step 1: Call Sign – Data Lifetime

Configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Code 3 for A1H equipment class) as in §2.4.4.5.4.1. Provide the "Receiving ATC Services" Flag input to the UUT, set to FALSE. Input a "Call Sign" and a "Flight Plan ID" input to the UUT. While the ADS-B Transmitting Equipment transmits valid ADS-B Long Messages, stop updating the "CALL SIGN" field. Set the EMITTER CATEGORY Field to the appropriate value for the intended application, per Table 2-90. Verify that after 60 seconds, all eight of the character values associated with Bytes 18 through 23 contain the Base-40 Digit value 37 ("Not Available").

Step 2: Flight Plan ID – Data Lifetime

Configure the ADS-B Transmitting Equipment to transmit valid ADS-B Long Messages with Payload Type Code 1 (or Code 3 for A1H equipment class) as in §2.4.4.5.4.1. Provide the "Receiving ATC Services" Flag input to the UUT, set to TRUE. Input a "Call Sign" and a "Flight Plan ID" input to the UUT. While the ADS-B Transmitting Equipment transmits valid ADS-B Long Messages, stop updating the "FLIGHT PLAN ID" field. Set the EMITTER CATEGORY Field to the appropriate value for the intended application, per Table 2-90. Verify that after 60 seconds, all eight of the character values associated with Bytes 18 through 23 contain the Base-40 Digit value 37 ("Not Available"), when the CSID Flag is ZERO (0).

2.4.4.5.4.4 Verification of "EMERGENCY/PRIORITY STATUS" Field Encoding (§2.2.4.5.4.4)

Purpose/Introduction:

The "EMERGENCY/PRIORITY STATUS" field is a 3-bit (bits 1 through bit 3 of byte 24) field. The encoding of this field **shall** be as indicated in Table 2-42.

If the Emergency/Priority Status Selection Input is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "EMERGENCY/PRIORITY STATUS" field **shall** default to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Emergency/Priority Status Encoding (§2.2.4.5.4.4)

Configure the ADS-B Transmitting Equipment to transmit valid Long ADS-B Messages of Payload Type 1 and/or 3 according to the capability of the UAT equipage classes.

For each case in Table 2-42, select and/or create the Emergency/Priority Status Conditions listed, and verify that bits 1 through 3 of byte 24 of the transmitted ADS-B Long Message match the corresponding Binary Encoding value in the table.

Step 2: Emergency/Priority Status - Data Lifetime

While the ADS-B Transmitting Equipment continues to transmit valid Long ADS-B Messages, and for any case in Table 2-42, discontinue providing "EMERGENCY/PRIORITY STATUS" condition, and verify that after 60 seconds bits 1 through 3 of byte 24 of the transmitted Long ADS-B Message are set to ALL ZEROs (binary 000).

2.4.4.5.4.5 Verification of "UAT MOPS VERSION" Field Encoding (§2.2.4.5.4.5)

Purpose/Introduction:

The "UAT MOPS VERSION" field is a 3-bit (bits 4 through 6 of byte 24) field. The encoding of this field **shall** be internally hard coded to ONE (binary 001) by all ADS-B Transmitting Subsystems for equipment complying with this version of these MOPS.

Measurement Procedure:

Step 1: "UAT MOPS VERSION" Encoding (§2.2.4.5.4.5)

Configure the ADS-B Transmitting Equipment to transmit valid Long ADS-B Messages of Payload Type 1 and/or 3 according to the capability of the UAT equipage classes.

Verify that bits 4 through 6 of byte 24 of the received Long ADS-B Message are set to ONE (binary 001) signifying conformance with this version of these MOPS.

2.4.4.5.4.6 Verification of "SIL" Field Encoding (§2.2.4.5.4.6)

Purpose/Introduction:

The Surveillance Integrity Level ("SIL") field is a 2-bit (bits 7 and 8 of byte 24) field used to define the probability of the the reported horizontal position exceeding the radius of containment defined by the NIC, without alerting, assuming no avionics faults. Although the SIL assumes there are no unannunciated faults in the avionics system, the SIL must consider the effects of a faulted Signal-in-Space, if a Signal-in-Space is used by the position source.

The SIL probability can be defined as either "per sample" or "per hour" as defined in the SIL Supplement (SIL_{SUPP}) in §2.2.4.5.4.16.

The encoding of the "SIL" field is indicated in Table 2-44. For installations where the SIL value is being dynamically updated, if the "SIL" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "SIL" field defaults to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B UAT Transmitting System to broadcast Long ADS-B Messages by providing SIL data at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class.

Step 2: "SIL" Encoding (§2.2.4.5.4.6)

Verify that for each "SIL" parameter input condition that is specified by the Probability of Exceeding the R_C Integrity Containment Radius without detection (i.e., the value in Table 2-44), that the system generates UAT Messages with the "SIL" subfield set equal to the corresponding binary coding value shown in Table 2-44.

Step 3: "SIL" Encoding – Data Lifetime

Discontinue providing update of SIL data. After 2 seconds, verify that the "SIL" subfield in the next transmitted Message is encoded ZERO (binary 00).

Resume providing SIL data and verify that the next transmitted message contains the "SIL" subfield set equal to the corresponding binary coding value shown in the Table 2-44.

2.4.4.5.4.7 Verification of "TRANSMIT MSO" Field Encoding (§2.2.4.5.4.7)

Purpose/Introduction:

The "TRANSMIT MSO" field is a 6-bit (bits 1 through 6 of byte 25) field that **shall** be used to encode the 6 LSBs of the Message Start Opportunity (§2.2.6.2.1) determined for this message transmission.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast Long ADS-B Messages by providing position information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class.

Step 2: "TRANSMIT MSO" Encoding (§2.2.4.5.4.7)

Verify that for each transmission, the "TRANSMIT MSO" is the 6 LSBs of Message Start Opportunity (MSO) assigned for each transmission.

Note: *Test procedure §2.4.6.2 verifies the correct MSO assignment.*

2.4.4.5.4.8 Verification of System Design Assurance (SDA) Field Encoding (§2.2.4.5.4.8)

Purpose/Introduction:

The "System Design Assurance" (SDA) field is a 2-bit (bits 7 and 8 of byte 25) field that defines the failure condition that the ADS-B system is designed to support as defined in Table 2.2.4.5.4.8.

Measurement Procedure:

Step 1: Verification of "System Design Assurance" (SDA) Subfield

Configure the ADS-B UAT Transmitting System to broadcast UAT Messages. Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class. Provide data externally at the interface to the ADS-B Transmit subsystem to establish each of the "System Design Assurance" (SDA) encoding defined in Table 2.2.4.5.4.8.

Verify that each "System Design Assurance" (SDA) parameter input condition that is identified in Table 2.2.4.5.4.8 that the system generates ADS-B Messages with the "System Design Assurance" (SDA) subfield set equal to the corresponding binary coding value indicated in Table 2.2.4.5.4.8.

Step 2: Verification of "System Design Assurance" (SDA) – Data Lifetime

Rerun the Test Procedure in Step 1. Remove the data source input for "System Design Assurance" (SDA) information for a period of at least 5 seconds. Verify that ADS-B Messages are properly transmitted having the "System Design Assurance" (SDA) subfield set to ZERO (0).

2.4.4.5.4.9 Verification of "NAC$_P$" Field Encoding (§2.2.4.5.4.9)

Purpose/Introduction:

The Navigation Accuracy Category for Position ("NAC$_P$") field is a 4-bit (bits 1 through bit 4 of byte 26) field used for applications to determine if the reported State Vector has sufficient position accuracy for the intended use. The encoding of the "NAC$_P$" field **shall** be as indicated in Table 2-45. The value of the NAC$_P$ parameter **shall** be the highest value in Table 2-45 consistent with the NAC$_P$ Input with the exception that if the NAC$_P$ Input is consistent with a value of "10" or "11" and the ADS-B equipment does not support the timing requirements for the Precision condition (§2.2.7.2.2), a NAC$_P$ value of "9" **shall** be transmitted.

If the "NAC$_P$" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "NAC$_P$" field **shall** default to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B UAT Transmitting System to broadcast Long ADS-B Messages by providing NAC$_P$ data at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class.

Step 2: "NAC_P" Encoding (§2.2.4.5.4.9)

Verify that for each "NAC_P" parameter input condition that is specified by the EPU value in Table 2-45, that the system generates UAT Messages with the "NAC_P" subfield set equal to the corresponding binary coding value shown in Table 2-45. If the ADS-B equipment does not support the timing requirements for the precision condition (§2.2.7.2.2), then verify that the NAC_P subfield in the transmitted UAT Messages is equal to "9," when the test cases are being run with NAC_P input data that is provided to the ADS-B Transmitting Subsystem that is consistent with the values of "10" or "11."

Step 3: "NAC_P" Encoding – Data Lifetime

Discontinue providing update of NAC_P data. After 60 seconds, verify that "NAC_P" subfield in the ADS-B Message is set to ALL ZEROs (binary 0000).

Resume providing the update of NAC_P data and verify that the ADS-B Message contains a "NAC_P" subfield set equal to the corresponding binary coding values shown in the Table 2-44.

2.4.4.5.4.10 Verification of "NAC_V" Field Encoding (§2.2.4.5.4.10)

Purpose/Introduction:

The Navigation Accuracy Category for Velocity ("NAC_V") field is a 3-bit (bits 5 through bit 7 of byte 26) field used for applications to determine if the reported State Vector has sufficient velocity accuracy for the intended use. The "NAC_V" field reflects the least accurate velocity component being transmitted. The "NAC_V" field **shall** be encoded as indicated in Table 2-46.

If the "NAC_V" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "NAC_V" field **shall** default to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B UAT Transmitting System to broadcast Long ADS-B Messages by providing NAC_V data at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class.

Step 2: "NAC_V" Encoding (§2.2.4.5.4.10)

Verify that for each "NAC_V" parameter input condition that is specified by the Horizontal Velocity Error and Vertical Geometric Velocity Error in Table 2-46, that the system generates UAT Messages with the "NAC_V" subfield set equal to the corresponding binary coding values shown in the Table 2-46.

Step 3: "NAC_V" Encoding – Data Lifetime

Discontinue providing update of NAC_V data. After 60 seconds, verify that the "NAC_V" subfield in the ADS-B Message is set to ALL ZEROs (binary 000).

Resume providing update of NAC_V data and verify that the ADS-B Message contains a "NAC_V" subfield set equal to the corresponding binary coding values shown in the Table 2-44.

2.4.4.5.4.11 Verification of "NIC_{BARO}" Field Encoding (§2.2.4.5.4.11)

Purpose/Introduction:

The Barometric Altitude Integrity Code ("NIC_{BARO}") field is a 1-bit (bit 8 of byte 26) field that indicates whether or not the barometric pressure altitude provided in the State Vector element of the payload has been cross checked against another source of pressure altitude. The "NIC_{BARO}" field **shall** be encoded as indicated in Table 2-47.

If the "NIC_{BARO}" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "NIC_{BARO}" field **shall** default to a value of ZERO.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B UAT Transmitting System to broadcast Long ADS-B Messages by providing NIC_{BARO} data at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: "NIC_{BARO}" Encoding (§2.2.4.5.4.11)

Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class.

Operationally select Barometric Pressure Altitude as the Primary Altitude information and verify that the "ALTITUDE TYPE" field in bit 8 of byte 10 is set to ZERO (0).

Input to the ADS-B Transmitting Subsystem the condition that signifies that the barometric pressure altitude has been cross checked against another source of pressure altitude. Verify that NIC_{BARO} field is set to ONE (1).

Input to the ADS-B Transmitting Subsystem the condition that signifies that the barometric pressure altitude has NOT been cross checked against another source of pressure altitude. Verify that NIC_{BARO} field is set to ZERO (0).

Step 3: "NIC_{BARO}" Encoding – Data Lifetime

Set up the ADS-B Transmitting Subsystem to enable the transmission of ADS-B Messages that include the contents of the "NIC_{BARO}" field. Discontinue providing update of altitude information including "NIC_{BARO}" data. Verify that, after 60 seconds, the "NIC_{BARO}" subfield in the transmitted ADS-B Message is set to ZERO (0).

Resume transmitting altitude information including "NIC_{BARO}" data input, with a value of "ONE," and verify that resultant ADS-B Message contains a "NIC_{BARO}" field set to ONE (1).

2.4.4.5.4.12 Verification of "CAPABILITY CODES" Field Encoding (§2.2.4.5.4.12)

Appropriate test procedures to validate the requirements of §2.2.4.5.4.12 are included in §2.4.4.5.4.12.1 and §2.4.4.5.4.12.3.

2.4.4.5.4.12.1 Verification of "UAT IN Capability" Subfield (§2.2.4.5.4.12.1)

Purpose/Introduction:

The "UAT IN Capability" field is set to ONE (1) if the transmitting aircraft has the capability to receive ADS-B UAT Messages. Otherwise, this field is set to ZERO (0).

If the "UAT IN Capability" field is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "UAT IN Capability" field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Verification of "UAT IN" Capability Code

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages. Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class. Provide appropriate data externally at the interface to the ADS-B Transmit Subsystem to indicate that the installation IS fitted with a properly functioning ADS-B UAT Receiving subsystem. Verify that the UAT IN Capability field is set to ONE (1).

Repeat this step while indicating that the aircraft has NO UAT IN Receive capability, and verify that the UAT IN Capability field is set to ZERO (0).

Step2: Verification of "UAT IN" Capability Code – Data Lifetime

Rerun the Test Procedure in Step 1. Remove the data source input for "UAT IN" Capability Code information for a period of at least 5 seconds. Verify that the UAT IN Capability field is set to a value of ZERO (0).

2.4.4.5.4.12.2 Verification of "1090ES IN Capability Subfield Encoding (§2.2.4.5.4.12.2)

Purpose/Introduction:

The "1090ES IN Capability" subfield denotes whether the aircraft is equipped with the capability to receive ADS-B 1090ES Messages. The "1090ES IN Capability" subfield is set to ONE (1) if the aircraft has the capability to receive 1090ES ADS-B Messages. Otherwise, this field is set to ZERO (0).

If the “1090ES IN Capability” subfield is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-98, then the “1090ES IN Capability” subfield defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Verification of “1090ES IN” Capability Code

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages. Set the ADS-B Transmitting Subsystem to transmit ADS-B Message Payload Type 1 or Type 3 according to the capability of the UAT equipage class. Provide appropriate data externally at the interface to the ADS-B Transmit Subsystem to indicate that the installation IS fitted with a properly functioning ADS-B 1090ES Receiving subsystem. Verify that the 1090ES IN field is set to ONE (1).

Repeat this step while indicating that the aircraft has NO 1090ES IN Receive capability, and verify that the 1090ES IN field is set to ZERO (0).

Step 2: Verification of “1090ES IN” Capability Code ˜ Data Lifetime

Rerun the Test Procedure in Step 1. Remove the data source input for “1090ES IN” Capability Code information for a period of at least 5 seconds. Verify that the 1090ES IN field is set to a value of ZERO (0).

2.4.4.5.4.12.3 Verification of “TCAS/ACAS Operational” Subfield (§2.2.4.5.4.12.3)

Purpose/Introduction:

The Capability Code for “TCAS/ACAS Operational” (byte 27, bit 3) is used to indicate whether the TCAS/ACAS System is Operational, or NOT Operational.

a. The ADS-B Transmitting Subsystem accepts information from an appropriate interface that indicates whether or not the TCAS/ACAS System is Operational.

b. The ADS-B Transmitting Subsystem sets the TCAS/ACAS Operational bit to ONE (1) if the TCAS/ACAS System is Operational.

c. The ADS-B Transmitting Subsystem sets the TCAS/ACAS Operational bit to ZERO (0) if the TCAS/ACAS System is NOT Operational.

d. If the input for the “TCAS/ACAS Operational” flag is “unavailable” for the “Data Lifetime” value listed for this input in Table 2-98, then the “TCAS/ACAS Installed and Operational” flag defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Verification of TCAS/ACAS Operational – Affirmative

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the TCAS/ACAS Operational input to Affirmative. Verify that bit 2 of byte 27 is set to ONE (1).

Step2: Verification of TCAS/ACAS Operational – Negative

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the TCAS/ACAS Operational input to Negative. Verify that bit 2 of byte 27 is set to ZERO (0).

Step 3: Verification of Data Lifetime (§2.2.7.1)

Set up the ADS-B Transmitting Subsystem to enable transmission of ADS-B Messages that include the contents of the "TCAS/ACAS Operational" subfield. Disable the "TCAS/ACAS Operational" input and verify that, after 60 seconds, bit 2 of byte 27 in the next transmitted message is set to ZERO (0).

Resume the "TCAS/ACAS Operational" input and verify that the value of ONE (1) is reflected in the next transmitted message.

2.4.4.5.4.13 Verification of "OPERATIONAL MODES" Field Encoding (§2.2.4.5.4.13)

Appropriate test procedures required to validate the requirements of §2.2.4.5.4.13 are included in §2.4.4.5.4.13.1, §2.4.4.5.4.13.2, and §2.4.4.5.4.13.3.

2.4.4.5.4.13.1 Verification of "TCAS/ACAS Resolution Advisory" Flag (§2.2.4.5.4.13.1)

Purpose/Introduction:

A transmitting ADS-B participant sets the TCAS/ACAS Resolution Advisory Active Flag (byte 27, bit 4) to ONE (1) in the messages that it transmits to support the MS report so long as a TCAS/ACAS Resolution Advisory is in effect. At all other times, the transmitting ADS-B participant sets the TCAS/ACAS Resolution Advisory Active Flag to ZERO (0).

If the input for the "TCAS/ACAS Resolution Advisory" flag is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "TCAS/ACAS Resolution Advisory" flag defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Verification of "TCAS/ACAS Resolution Advisory Transmission

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide data externally at the interface to the ADS-B Transmit subsystem to indicate that the installation DOES NOT have an active TCAS/ACAS Resolution Advisory in effect. Verify that the TCAS/ACAS Resolution Advisory Flag is set to ZERO (0).

Repeat this step while indicating that the installation DOES have an active TCAS/ACAS Resolution Advisory in effect and verify that the TCAS/ACAS Resolution Advisory Flag is set to ONE (1).

Step 2: Verification of Data Lifetime (§2.2.7.1)

Rerun the Test Procedure in Step 1. Remove the data source input for RA Active OM Code information for a period of at least 2 seconds. Verify that in the TCAS/ACAS Resolution Advisory Flag is set to a value of ZERO (0).

2.4.4.5.4.13.2 Verification of "IDENT Switch Active" Flag (§2.2.4.5.4.13.2)

Purpose/Introduction:

The "IDENT Switch Active" Flag (byte 27, bit 5) is activated by an IDENT switch. Initially, the "IDENT switch active" code is ZERO (0). Upon activation of the IDENT switch, this flag will be set to ONE in all scheduled ADS-B Messages containing the MODE STATUS element for an interval of 20 seconds ±4 seconds. After the time interval expires, the flag will be set to ZERO (0).

If the input for the "IDENT Switch Active" flag is "unavailable" for the "Data Lifetime" value listed for this input in Table 2-98, then the "IDENT Switch Active" flag will default to a value of ZERO (0).

Measurement Procedure:

Step 1: Verification of IDENT Switch Active Flag – Affirmative

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the IDENT Switch Active input to Affirmative. Verify that bit 4 of byte 27 is set to ONE (1).

Step 2: Verification of IDENT Switch - 20 Second Timeout

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the IDENT Switch Active input to Affirmative and verify that bit 4 of byte 27 is set to ONE (1). Wait 20 seconds ±4 seconds. Verify that after the 20 second ±4 seconds interval, that bit 4 of byte 27 is set to ZERO (0).

Step 3: Verification of IDENT Switch Active Flag – Negative

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the IDENT Switch Active input to Negative. Verify that bit 4 of byte 27 is set to ZERO (0).

Step 4: Verification of Data Lifetime (§2.2.7.1)

Set up the ADS-B Transmitting Subsystem to enable transmission of ADS-B Messages that include the contents of the "IDENT Switch Active" field. Disable the "IDENT Switch Active" input and verify that, after 60 seconds, bit 4 of byte 27 in the next transmitted message is set to ZERO (0).

Resume the "IDENT Switch Active" input with a value of "1" and verify that this value is reflected in the next transmitted message.

2.4.4.5.4.13.3 Verification of "Reserved for Receiving ATC Services" Flag (§2.2.4.5.4.13.3)

Purpose/Introduction:

The "Reserved for Receiving ATC Services" flag (byte 27, bit 6) is reserved for future use. In this version of these MOPS, this field will be set to ZERO (0).

Measurement Procedure:

Step 1: Verification of Reserved for Receiving ATC Services Flag – Affirmative

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Verify that bit 5 of byte 27 is set to ZERO (0).

2.4.4.5.4.14 Verification of Call Sign Identification (CSID) Flag (§2.2.4.5.4.14)

Purpose/Introduction:

The requirements of this section apply only when the UAT transmitter is configured for the CSID Logic ENABLED state as described in §2.2.4.5.4.16.

The Call Sign Identification (CSID) Flag in the Mode Status Element is a one-bit flag (bit 7 of byte 27) which is used to identify the contents of the "CALL SIGN//FLIGHT PLAN ID" field. When the CSID Flag is set to the value ONE (1), then the "CALL SIGN/FLIGHT PLAN ID" field contains the Call Sign. When the CSID Flag is set to the value ZERO (0), then the "CALL SIGN/FLIGHT PLAN ID" field contains the Flight Plan ID.

Measurement Procedure:

Step 1: Call Sign Reporting Verification

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages and ensure that the CSID Logic Configuration Item is set to ENABLED. Input a "Call Sign" consisting of the character sequence "ABCDEF". Input a "Flight Plan ID" consisting of the 4 character sequence "3562." Input an Emitter Category value of ZERO. Verify that all Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, contain the Call Sign Identification (CSID) Flag, bit 7 of byte 27, set to ONE (1). Verify that CALL SIGN/FLIGHT PLAN ID field contains the following values:

Message Byte 18 = 0000 0001 Binary
Message Byte 19 = 1001 1011 Binary
Message Byte 20 = 0100 1101 Binary
Message Byte 21 = 0001 0110 Binary
Message Byte 22 = 0110 0011 Binary
Message Byte 23 = 1000 0100 Binary

Step 2: Flight Plan ID Reporting Verification

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Input a “Call Sign” consisting of the character sequence “ABCDEF”. Input a “Flight Plan ID” consisting of the 4 character sequence “3562.” Input an Emitter Category value of ZERO. Verify that Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, alternate the contents of the Call Sign Identification (CSID) Flag, bit 7 of byte 27. Verify that when transmitting Payload Type ONE (1) or THREE (3), the contents of the CALL SIGN/FLIGHT PLAN ID field reflects the proper encoding for the transmitted CSID Flag value. When the CSID Flag is ONE (1), verify that the contents of the CALL SIGN/FLIGHT PLAN ID field corresponds to the values as depicted in Step 1 above. When the CSID Flag is ZERO (0), verify that the contents of the CALL SIGN/FLIGHT PLAN ID field corresponds to the following values:

Message Byte 18 = 0000 0000 Binary
Message Byte 19 = 0111 1101 Binary
Message Byte 20 = 0010 0101 Binary
Message Byte 21 = 1111 0101 Binary
Message Byte 22 = 1110 1101 Binary
Message Byte 23 = 0010 1101 Binary

Step 3: Reverting to Call Sign Reporting Verification

Set the CSID Logic Configuration Item to DISABLED. Verify that all Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, contain the Call Sign Identification (CSID) Flag, bit 7 of byte 27, set to ONE (1). Verify that the contents of the CALL SIGN/FLIGHT PLAN ID field correspond to the values as depicted in Step 1 above.

2.4.4.5.4.15 Verification of CSID Logic Configuration Item (§2.2.4.5.4.15)

Purpose/Introduction:

The UAT Transmitting Subsystem **shall** provide an installer configuration item that will place the UAT Transmitting Subsystem in one of 2 states:

a. CSID Logic ENABLED: Causes the UAT Transmitting Subsystem to satisfy the requirements of §2.2.4.5.4.14 “Call Sign Identification (CSID) Flag.”

b. CSID Logic DISABLED: Causes the UAT Transmitting Subsystem to ignore the requirements of §2.2.4.5.4.14 “Call Sign Identification (CSID) Flag” with Call Sign ALWAYS encoded in the CALL SIGN field and with the CSID field ALWAYS encoded as ONE.

Measurement Procedure:

Step 1: Call Sign Reporting Verification

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages and ensure the CSID Logic Configuration Item is set to DISABLED. Provide the

"Receiving ATC Services" Flag Input to the UUT set to FALSE. Input a "Call Sign" consisting of the character sequence "ABCDEF". Input a "Flight Plan ID" consisting of the 4 character sequence "3562." Input an Emitter Category value of ZERO. Verify that all Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, contain the Call Sign Identification (CSID) Flag, bit 7 of byte 27, set to ONE (1). Verify that CALL SIGN/FLIGHT PLAN ID field contains the following values:

Message Byte 18 = 0000 0001 Binary
Message Byte 19 = 1001 1011 Binary
Message Byte 20 = 0100 1101 Binary
Message Byte 21 = 0001 0110 Binary
Message Byte 22 = 0110 0011 Binary
Message Byte 23 = 1000 0100 Binary

Step 2: Flight Plan ID Reporting Verification

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Provide the "Receiving ATC Services" Flag Input to the UUT set to TRUE. Input a "Call Sign" consisting of the character sequence "ABCDEF". Input a "Flight Plan ID" consisting of the 4 character sequence "3562." Input an Emitter Category value of ZERO. Verify that all Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, contain the Call Sign Identification (CSID) Flag, bit 7 of byte 27, set to ONE . Verify that the contents of the CALL SIGN/FLIGHT PLAN ID field contains the values shown in Step 1 above.

Step 3: Reverting to Call Sign Reporting Verification

Reset the "Receiving ATC Services" Flag Input to the UUT to FALSE. Verify that all Transmitted Messages of Payload Type Codes of ONE (1) or THREE (3), depending upon the equipment class, contain the Call Sign Identification (CSID) Flag, bit 7 of byte 27, set to ONE (1). Verify that the contents of the CALL SIGN/FLIGHT PLAN ID field correspond to the values as depicted in Step 1 above.

2.4.4.5.4.16 Verification of "SIL Supplement (SIL_{SUPP}) (§2.2.4.5.4.16)

Purpose/Introduction:

The "SIL Supplement" (SIL_{SUPP}) Flag in the Mode-Status Element is a one-bit flag (bit 8 of byte 27), that defines whether the reported SIL probability is based on a per hour probability or a per sample probability as defined in Table 2.2.4.5.4.16.

Measurement Procedure:

Step 1: Verification of SIL Supplement for "Per Hour" Probability

Via the appropriate data input interface, provide the ADS-B Transmitting Subsystem with valid data indicating that the integrity of the geometric position source is being established on a "Per Hour" basis.

Note: *If an actual interface is not used to provide "SIL Supplement" information, then ensure that a GNSS position source is being used to* *provide geometric positon data for the purpose of establishing position in the ADS-B Message.*

Verify that the "SIL Supplement" subfield is set to "ZERO" (0).

Step 2: Verification of SIL Supplement for "Per Sample" Probability

Via the appropriate data input interface, provide the ADS-B Transmitting Subsystem with valid data indicating that the integrity of the geometric position source is being established on a "Per Sample" basis.

Note: *If an actual interface is not used to provide "SIL Supplement" information, then ensure that a Non-GNSS position source is being used to provide geometric positon data for the purpose of establishing position in the ADS-B Message.*

Verify that the "SIL Supplement" subfield is set to "ONE" (1).

2.4.4.5.4.17 Verification of "Geometric Vertical Accuracy (GVA) (§2.2.4.5.4.17)

Purpose/Introduction:

The Geometric Vertical Accuracy (GVA) field is a 2-bit field (bits 1 and 2 of byte 28) that will be set by using the Vertical Field of Merit (VFOM) (95%) from the GNSS position source used to encode the geometric altitude field per Table 2.2.4.5.17.

Measurement Procedure:

Step 1: Verification of GVA Transmission

Configure the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Set the Vertical Figure of Merit (VFOM) field to each of the following values in Table 2.4.4.5.4.17 and verify that the corresponding encoding is set in the GVAQ field of the Aircraft Operational Status Message.

Table 2.4.4.5.4.17: Geometric Vertical Accuracy Validation Values

Row	VFOM (meters)	GVA Encoding
1	Invalid	0
2	30.0	1
3	44.5	1
4	45.5	0
5	327.1	0

Step 2: Verification of GVA – Data Lifetime

Rerun Table 2.4.4.5.4.17, Row 2 from Step 1. Remove the data source input for GVA for a period of at least 2 seconds. Verify that the GVA subfield is set to ZERO (binary 00).

2.4.4.5.4.18 Verification of "Single Antenna (SA) Flag) (§2.2.4.5.4.18)

Purpose/Introduction:

The Single Antenna (SA) Flag is a 1-bit (bit 8 of byte 27) field that is used to indicate that the ADS-B Transmitting Subsystem is operating with a single antenna.

a. Non-Diversity, i.e., those transmitting subsystems that use only one antenna, will set the Single Antenna subfield to "ONE" (1) at all times.

b. Diversity, i.e., those transmitting functions designed to use two antennas, will set the Single Antenna subfield to ZERO (0) at all times that both antenna channels are functional.

At any time that the diversity configuration cannot guarantee that both antenna channels are functional, then the "Single Antenna" subfield will be set to ONE (1).

Measurement Procedure:

Step 1: Non-Diversity Configuration

For ADS-B Transmitting Subsystems that operate with a single antenna, configure the system to broadcast ADS-B Messages. Verify that the Single Antenna subfield is set to "ONE" (1) at all times in the UAT Message.

Step 2: Diversity Configuration

For ADS-B Transmitting Subsystems that operate in the diversity mode, configure the system to broadcast ADS-B Messages. Verify that the Single Antenna subfield is set to "ZERO" (0) at all times in the UAT Message.

Disable one antenna channel by whatever means that the ADS-B Transmitting Subsystem utilizes to detect a non-functioning antenna channel. Verify that the Single Antenna subfield is set to "ONE" (1) in the UAT Message. Repeat, except disable the alternate channel and verify that the Single Antenna subfield is set to ONE (1) in the UAT Message.

2.4.4.5.4.19 Verification of Reserved Bits (§2.2.4.5.4.19)

Purpose/Introduction:

This Reserved Bits field is a 13-bit (bit 4 of byte 28 through bit 8 of byte 29) field used that may be used in the future to indicate the capability of a participant to support engagement in various operations. This Reserved Bits field is reserved for future use and will be set to ALL ZEROs.

Measurement Procedure:

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Input a message and verify that bit 4 of byte 28 through bit 8 of byte 29 are set to ALL ZEROs.

2.4.4.5.5 Verification of AUXILIARY STATE VECTOR Element (§2.2.4.5.5)

Appropriate test procedures required to validate the requirements of §2.2.4.5.5 are included in §2.4.4.5.5.1 and §2.4.4.5.5.2.

2.4.4.5.5.1 Verification of "SECONDARY ALTITUDE" Field Encoding (§2.2.4.5.5.1)

Purpose/Introduction:

The "SECONDARY ALTITUDE" field is a 12-bit (bit 1 of byte 30 through bit 4 of byte 31) field used to encode either the geometric altitude or barometric pressure altitude depending on the setting of the "ALTITUDE TYPE" field (§2.2.4.5.2.2). The altitude encoded in the "SECONDARY ALTITUDE" field is the opposite type to that specified by the "ALTITUDE TYPE" field. The encoding **shall** be consistent with that used for "ALTITUDE" described in Table 2-16.

Measurement Procedure:

Step 1: Establish Initial Conditions

Configure the ADS-B/UAT Transmitting System to broadcast UAT Messages by providing Altitude information at the nominal update rate. Provide the data externally at the interface to the ADS-B system.

Step 2: Selection of Secondary Altitude Information

Operationally select Geometric Pressure Altitude as the Secondary Altitude information for the following steps (step 3 through step 7) and verify that the "ALTITUDE TYPE" field in (bit 8 of byte 10) is set to ZERO.

Step 3: Verify Secondary Altitude Field Encoding – Altitude Data Lifetime

Set up the ADS-B/UAT Transmitting System to transmit ADS-B Message Payload Types "1" and/or "2" and/or "5" and/or "6" according to the capability of the UAT equipage classes.

Provide valid non-zero Altitude data and valid non-zero velocity data to the ADS-B system.

Discontinue providing the update of Altitude data to the ADS-B system. Verify that after the Altitude data has not been provided to the ADS-B Transmitting Subsystem for 2 seconds, that the "SECONDARY ALTITUDE" field is set to a value of "0" (binary 0000 0000 0000).

Resume altitude data input with a value of –775 feet and verify that the ADS-B Message contain "SECONDARY ALTITUDE" field is set to a value of "10" (binary 0000 0000 1010).

Step 4: Verify Secondary Altitude Field Encoding – Altitude Equal ZERO

Set the Altitude input data to represent an altitude of ZERO feet. Verify that the "SECONDARY ALTITUDE" field is set to a value of "41" (binary 0000 0010 1001).

Step 5: Verify Secondary Altitude Field Encoding – Discrete Values

Verify that for each integer Altitude input value in feet in Table 2-81 that the system generates UAT Messages such that the secondary Altitude subfield in each such message is set to the corresponding binary coding value in Table 2-81.

Verify that the Secondary Altitude subfield in the transmitted message is not incremented until the input value reaches a number corresponding to a multiple of 25 feet.

Table 2-94: Secondary Altitude Field Encoding

Altitude Data		
Meaning (Altitude in feet)	**Coding (decimal)**	**Coding (binary)**
-1000	1	0000 0000 0001
-900	5	0000 0000 0101
-775	10	0000 0000 1010
-500	21	0000 0001 0101
25	42	0000 0010 1010
1100	85	0000 0101 0101
3225	170	0000 1010 1010
7500	341	0001 0101 0101
16025	682	0010 1010 1010
33100	1365	0101 0101 0101
67225	2730	1010 1010 1010
86425	3498	1101 1010 1010
92825	3754	1110 1010 1010
99225	4010	1111 1010 1010
100425	4058	1111 1101 1010
100825	4074	1111 1110 1010
101225	4090	1111 1111 1010
101300	4093	1111 1111 1101
101325	4094	1111 1111 1110

Step 6: Verify Secondary Altitude Field Encoding – Maximum Values

Continue to increase the Altitude value. If the resolution of the input value is the same as the output resolution (i.e, 25 feet), then verify that for an input corresponding to an altitude of 101,350 feet, the secondary altitude field is set to “4095” (binary 1111 1111 1111).

If the resolution of input value is greater than output resolution, then verify that for an input corresponding to an altitude of greater than 101,325 feet but less than or equal to 101,337.5 feet, the secondary altitude field continues to be set to “4094” (binary 1111 1111 1110).

If the resolution of the input data makes it possible to enter an input value that corresponds to exactly 101,337.5 feet, then this value shall be input and it shall verify that the Secondary Altitude subfield for all such messages is set to either

"4094" (binary 1111 1111 1110, representing 101,325 feet) or "4095" (binary 1111 1111 1111, representing 101,337.5 feet).

Step 7: Verify Secondary Altitude Field Encoding – Input Resolution

If the input data used to establish the SECONDARY ALTITUDE subfield has more resolution than that required by the SECONDARY ALTITUDE subfield (i.e., more than 12 bits), then this step shall be used to ensure that the accuracy of the data is maintained such that it is not worse than ±½ LSB, where the LSB is the least significant bit of the SECONDARY ALTITUDE subfield.

If the input data field that is used to determine the output value of the SECONDARY ALTITUDE subfield does not have finer resolution than that required by the SECONDARY ALTITUDE subfield, skip Step 7 and stop.

Enter an input value corresponding to an altitude of 37.5 feet. Verify that the value of the SECONDARY ALTITUDE subfield in the output message is either "42" (binary 0000 0010 1010, representing 25 feet) or "43" (binary 0000 0010 1011, representing 50 feet).

If the input field used to establish the Secondary Altitude subfield does not have resolution finer than 12.5 feet, skip the rest of Step 7 and stop. Otherwise (Altitude input resolution is finer than 12.5 feet), let **Z** be equal to the smallest possible value that can be represented by the number of bits in the input field (i.e., **Z** is the value of the least significant bit of the input field). Set the value of the input field to correspond to an altitude of (37.5 – **Z** feet).

Verify that the value of secondary altitude subfield in the output UAT message is "42" (binary 0000 0010 1010, representing 25 feet). Set the value of input field to correspond to an altitude of (37.5+**Z** feet).

Verify that the value of the secondary altitude subfield in the output UAT message is "43" (binary 0000 0010 1011, representing 50 feet).

Note: *If the resolution of the Altitude input is such that an altitude of 37.5 feet can be represented (but still finer than 12.5 feet, e.g., a resolution of 10 feet increments), then values corresponding to altitude must be tested, and the output examined for each value to confirm that output is within ±12.5 feet (inclusive) of the input value.*

Step 8: Reselection of Secondary Altitude Information

Operationally select Barometric Pressure Altitude as the Secondary Altitude information Steps 3 through 7 and verify that the "ALTITUDE TYPE" field in bit 8 of byte 10 is set to ONE.

Repeat Steps 3 through 7 with Barometric Pressure Altitude as the Secondary Altitude data and verify the encoding.

2.4.4.5.5.2 Verification of Reserved Bits (§2.2.4.5.5.2)

Purpose/Introduction:

Bit 5 of byte 31 through bit 8 of byte 34 are reserved for future use, and **shall** be set to ALL ZEROs.

Note: *This field is reserved for future definition to contain either air-referenced velocity or perhaps wind vector and temperature.*

Measurement Procedure:

Set up the ADS-B Transmitting Subsystem to transmit ADS-B Messages. Input a message and verify that bit 5 of byte 31 through bit 8 of byte 34 are set to ALL ZEROs.

2.4.4.5.6 Verification of TARGET STATE Element (Payload Type Codes "3" and "4") (§2.2.4.5.6)

Appropriate test procedures required to validate the requirements in §2.2.4.5.6 are included in §2.4.4.5.6.1 through §2.4.4.5.6.9.

2.4.4.5.6.1 Verification of "SELECTED ALTITUDE TYPE (SAT)" Field Encoding (§2.2.4.5.6.1)

Purpose/Introduction:

The "SELECTED ALTITUDE TYPE (SAT)" subfield is a 1-bit (Bit 1 of Byte 30) field that is used to indicate the source of Selected Altitude data that is being used to encode Bit 2 of Payload Byte 30, through Bit 4 of Payload Byte 34. Encoding of the "Selected Altitude Type" **shall** be in accordance with Table 2-52.

If the source for the SAT field is unavailable, or if the "Data Lifetime" timeout listed for the SAT field in Table 2-64 has expired, then the SAT field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Selected Altitude from MCP/FCU

Via an appropriate means, indicate to the ADS-B Transmitting Subsystem that the Selected Altitude source is an MCP or FCU. Verify that the SAT field is set to ZERO (0).

Step 2: Selected Altitude from FMS

Via an appropriate means, indicate to the ADS-B Transmitting Subsystem that the Selected Altitude source is an FMS. Verify that the SAT field is set to ONE (1).

Step 3: Source Timeout

If appropriate for the installation, make the data source unavailable to the ADS-B Transmitting Subsystem, and verify that the SAT field is set to ZERO (0) after the appropriate data lifetime has expired.

2.4.4.5.6.2 Verification of "Selected Altitude" Field Encoding (§2.2.4.5.6.2)

Purpose/Introduction:

The "Selected Altitude" field (bit 2 of byte 30 through bit 4 of byte 31) contains the Selected Altitude of the ADS-B Transmitting Subsystem as defined in Table 2-53.

If a source for the Selected Altitude field is unavailable, or if the "Data Lifetime" timeout listed for the Selected Altitude field in Table 2-64 has expired, then the Selected Altitude field defaults to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of Selected Altitude data to the ADS-B Transmitting Subsystem.

Step 2: Selected Altitude Encoding

For each row of Table 2.4.4.5.6.2, provide the given altitude to the ADS-B Transmitting Subsystem, and verify that the Selected Altitude field contains the corresponding value.

Table 2.4.4.5.6.2: Selected Altitude Encoding Values

Altitude	**Coding** MSB (binary) LSB
0 ft	000 0000 0001
32 ft	000 0000 0010
96 ft	000 0000 0100
224 ft	000 0000 1000
480 ft	000 0001 0000
992 ft	000 0010 0000
2016 ft	000 0100 0000
4064 ft	000 1000 0000
8160 ft	001 0000 0000
16352 ft	010 0000 0000
32736 ft	100 0000 0000
65472 ft	111 1111 1111

Step 3: Source Timeout

Make the source of Selected Altitude data unavailable to the ADS-B Transmitting Subsystem, and verify that the Selected Altitude field is set to ZERO after the appropriate data lifetime has expired.

2.4.4.5.6.3 Verification of "Baromatric Pressure Setting" (Minus 800 millibars) Field Encoding (§2.2.4.5.6.3)

Purpose/Introduction:

a. The "Barometric Pressure Setting (Minus 800 millibars)" subfield is a 9-bit (bit 5 of byte 31 through bit 5 of byte 32) field that contains Barometric Pressure Setting data that has been adjusted by subtracting 800 millibars from the data received from the Barometric Pressure Setting source.

b. After adjustment by subtracting 800 millibars, the Barometric Pressure Setting will be encoded in accordance with Table 2-54.

c. If a source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the Barometric Pressure Setting defaults to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of Barometric Pressure Setting data to the ADS-B Transmitting Subsystem.

Step 2: Barometric Pressure Setting Encoding

For each row of Table 2.4.4.5.6.3, provide the given pressure setting to the ADS-B Transmitting Subsystem, and verify that the Barometric Pressure Setting field contains the corresponding value.

Table 2.4.4.5.6.3: Barometric Pressure Setting Encoding Values

Barometric Pressure Setting (millibars)	**Coding** MSB (binary) LSB
0.0	0 0000 0001
0.8	0 0000 0010
2.4	0 0000 0100
5.6	0 0000 1000
12.0	0 0001 0000
24.8	0 0010 0000
50.4	0 0100 0000
101.6	0 1000 0000
204.0	1 0000 0000
408.0	1 1111 1111

Step 3: Source Timeout

Make the source of pressure setting data unavailable to the ADS-B Transmitting Subsystem, and verify that the Barometric Pressure Setting field is set to ALL ZEROS after the appropriate data lifetime has expired.

2.4.4.5.6.4 Verification of "Selected Heading" Field Encoding (§2.2.4.5.6.4)

Purpose/Introduction:

The Selected Heading field (bit 6 of byte 32 through bit 7 of byte 33) contains the Selected Heading of the ADS-B Transmitting Subsystem.

The Selected Heading Status (bit 6 of byte 32) is set to ONE (1) if the contents of the Selected Heading sign and magnitude subfields are VALID, or set to ZERO (0) otherwise.

The Selected Heading Sign (bit 7 of byte 32) is set to ZERO (0) if the Selected Heading is a positive angle, or to ONE (1) if the Selected Heading is a negative angle.

The magnitude of the Selected Heading subfield (bit 8 of byte 32 through bit 7 of byte 33) is encoded as defined in Table 2-55.

If a source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the entire Selected Heading field defaults to a value of ALL ZEROs.

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of Selected Heading data to the ADS-B Transmitting Subsystem.

Step 2: Selected Heading Encoding

For each row of Table 2.4.4.5.6.4, provide the given selected heading value to the ADS-B Transmitting Subsystem, and verify that the Selected Heading and Sign fields contain the corresponding value, and that the Selected Heading Status field is set to ONE (1).

Table 2.4.4.5.6.4: Selected Heading Encoding Values

Selected Heading (degrees)	Coding sign	Coding Magnitude MSB (binary) LSB
0	0	0000 0000
0.7	0	0000 0001
+45.0	0	0010 0000
+90.0	0	1000 0000
+135.0	0	1100 0000
+179.3	0	1111 1111
-180	1	1111 1111
-135	1	1100 0000
-90	1	1000 0000
-45	1	0010 0000

Step 3: Source Timeout

Make the source of selected heading data unavailable to the ADS-B Transmitting Subsystem, and verify that all of the Selected Heading fields are set to ALL ZEROs after the appropriate data lifetime has expired.

2.4.4.5.6.5 Verification of "Status of MCP/FCU Mode Bits" (ST) Field Encoding (§2.2.4.5.6.5)

Purpose/Introduction:

The "Status of MCP/FCU Mode Bits (ST)" field (bit 8 of byte 33) is set to ONE (1) when any of the "Mode:" fields defined in §2.2.4.5.6.6 through §2.2.4.5.6.9 are valid, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the ST field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of MCP/FCU Mode Bits to the ADS-B Transmitting Subsystem.

Step 2: Status of the MCP/FCU Mode Bits

Verify that the ST Field is set to ONE (1).

Step 3: Source Timeout

Make the source of MCP/FCU Mode Bits unavailable to the ADS-B Transmitting Subsystem, and verify that the ST Field is set to ZERO (0) after the appropriate data lifetime has expired.

2.4.4.5.6.6 Verification of “Mode Indicators: Autopilot Engaged” (AP) Field Encoding (§2.2.4.5.6.6)

Purpose/Introduction:

The “Mode Indicators: Autopilot Engaged (AP)” field (bit 1 of byte 34) is set to ONE (1) when the MCP/FCU source indicates that the Autopilot function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the “Data Lifetime” timeout listed for this field in Table 2-64 has expired, then the AP field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of MCP/FCU Mode Bits to the ADS-B Transmitting Subsystem.

Step 2: Status of the AP Field

Verify that the AP Field is set to ONE (1) when the Autopilot is engaged. Verify that the AP Field is set to ZERO (0) when the Autopilot is disengaged.

Step 3: Source Timeout

Make the source of the AP Field unavailable to the ADS-B Transmitting Subsystem, and verify that the AP Field is set to ZERO (0) after the appropriate data lifetime has expired.

2.4.4.5.6.7 Verification of “Mode Indicators: VNAV Mode Engaged” (VNAV) Field Encoding (§2.2.4.5.6.7)

Purpose/Introduction:

The “Mode Indicators: VNAV Mode Engaged (VNAV)” field (bit 2 of byte 34) is set to ONE (1) when the MCP/FCU source indicates that the VNAV function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the “Data Lifetime” timeout listed for this field in Table 2-64 has expired, then the VNAV field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of MCP/FCU Mode Bits to the ADS-B Transmitting Subsystem.

Step 2: Status of the VNAV Field

Verify that the VNAV Field is set to ONE (1) when the VNAV mode is engaged. Verify that the VNAV Field is set to ZERO (0) when the VNAV mode is disengaged.

Step 3: Source Timeout

Make the source of the VNAV Field unavailable to the ADS-B Transmitting Subsystem, and verify that the VNAV Field is set to ZERO (0) after the appropriate data lifetime has expired.

2.4.4.5.6.8 Verification of "Mode Indicators: Altitude Hold Mode" (ALT) Field Encoding (§2.2.4.5.6.8)

Purpose/Introduction:

The "Mode Indicators: Altitude Hold Mode (ALT)" field (bit 3 of byte 34) is set to ONE (1) when the MCP/FCU source indicates that the Altitude Hold function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the ALT field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of MCP/FCU Mode Bits to the ADS-B Transmitting Subsystem.

Step 2: Status of the ALT Field

Verify that the ALT Field is set to ONE (1) when the Altitude Hold mode is engaged. Verify that the ALT Field is set to ZERO (0) when the Altitude Hold mode is disengaged.

Step 3: Source Timeout

Make the source of the ALT Field unavailable to the ADS-B Transmitting Subsystem, and verify that the ALT Field is set to ZERO (0) after the appropriate data lifetime has expired.

2.4.4.5.6.9 Verification of "Mode Indicators: Approach Mode" (APP)" Field Encoding (§2.2.4.5.6.9)

Purpose/Introduction:

The "Mode Indicators: Approach Mode (APP)" field (bit 4 of byte 34) is set to ONE (1) when the MCP/FCU source indicates that the Approach Mode function is engaged, or set to ZERO (0) otherwise.

If the source for this field is unavailable, or if the "Data Lifetime" timeout listed for this field in Table 2-64 has expired, then the APP field defaults to a value of ZERO (0).

Measurement Procedure:

Step 1: Initial Conditions

Provide a source of MCP/FCU Mode Bits to the ADS-B Transmitting Subsystem.

Step 2: Status of the APP Field

Verify that the APP Field is set to ONE when the Approach mode is engaged. Verify that the APP Field is set to ZERO when the Approach mode is disengaged.

Step 3: Source Timeout

Make the source of the APP Field unavailable to the ADS-B Transmitting Subsystem, and verify that the APP Field is set to ZERO after the appropriate data lifetime has expired.

2.4.4.5.7 Verification of TARGET STATE Element (Payload Type Code "6") (§2.2.4.5.7)

Appropriate test procedures required to validate the requirement of §2.2.4.5.7 are included in §2.4.4.5.6.1 through §2.4.4.5.6.9.

2.4.4.5.8 Verification of TRAJECTORY CHANGE Element (§2.2.4.5.8)

Purpose/Introduction:

This element contains 96 bits that are reserved for future definition. Equipment conforming to these MOPS **shall** insert ALL ZEROs in this element whenever present in a transmitted message. See Appendix L to see how this reserved field could be used to meet the requirements of reporting TCR+0 and TCR+1 in the future.

Measurement Procedure:

Set up the ADS-B Transmitting Subsystem to transmit UAT messages. Send a message with a Payload Type Code of "4." Verify that bytes 18 through 29 are all set to ZERO (0). Repeat this procedure with a message with Payload Type Code of "5," and again verify that bytes 18 through 29 are all set to ZERO (0).

2.4.5 Verification of Procedures for Processing of Time Data (§2.2.5)

Appropriate test procedures required to validate the requirements of §2.4.5 are included in §2.4.6.2.1, §2.4.6.2.2, §2.4.7.2.1, §2.4.7.2.2 and §2.4.8.3.5.

2.4.5.1 Verification of UTC Coupled Condition (§2.2.5.1)

Purpose/Introduction:

The "UTC Coupled" subfield **shall** be set to ONE, except under the conditions discussed in §2.2.5.2.

Note: *Operation of the UAT system in normal mode presumes GNSS, or equivalent, equipage on system participants to, for example, prevent media access conflict with the UAT ground up-link transmissions. Short-term GNSS outages are mitigated by UAT ground infrastructure providing timing information and/or by the ability of the UAT avionics to prevent Airborne UAT Transmitting Subsystems from transmitting in the Ground Uplink segment for a minimum of 20 minutes in the absence of GNSS (§2.2.5.2[d]). In areas without ground up-link transmissions, there is no media access conflict.*

This test procedure verifies that the UUT meets the requirements for use of an external UTC coupled time source that are contained in §2.2.5.1.

Notes:

1. *This test procedure is only necessary if the UUT is intended for use with an external UTC timing source.*

2. *This procedure assumes that the test procedure of §2.4.6.3 has been performed, so the ownship reports can be used to monitor the UUT performance. If this is not the case, a UAT test receiver is required.*

Equipment Required:

External UTC Time Mark source.

Step 1: Verify the processing of the external UAT Time Mark signal.

Provide the UUT with an external Time Mark signal that is marked as invalid. Verify that the "UTC Coupled" subfield in the ADS-B ownship report contains the ZERO value.

Provide the UUT with an external Time Mark signal that is marked as valid. Verify that the "UTC Coupled" subfield in the ADS-B ownship report contains the ONE value. This verifies the requirements of §2.2.5.1.a and §2.2.5.1.c.

Step 2: Verify the receiver time of applicability reporting.

Provide the UUT with an external Time Mark signal that is marked as valid. Verify that the Time of Applicability field of the ownship ADS-B report correctly indicates the proper transmission epoch for each UUT ADS-B Message transmission. This verifies the requirement of §2.2.5.1.b.

Note: *Step 2 does not validate the processing of an invalid external Time Mark signal.*

2.4.5.2 Verification of Non-UTC Coupled Condition (§2.2.5.2)

Purpose/Introduction:

a. This condition **shall** be entered when the ADS-B equipment has not been provided a GPS/GNSS, or equivalent, time mark. This is not the normal condition; it is a degraded mode of operation.

b. Within 2 seconds of entering the non-UTC Coupled Condition, the UAT equipment **shall** set the “UTC Coupled” subfield to ZERO in any transmitted messages.

c. While in the non-UTC Coupled Condition, Class A0, A1, A2 and A3 equipment with operational receivers **shall** be capable of aligning to within ±6 milliseconds of UTC time based upon successful message reception of any Ground Uplink Message with the “UTC Coupled” bit set.

Note: *This assumes the Ground Uplink Message is aligned with UTC time.*

d. While in the non-UTC Coupled Condition when Ground Uplink Messages cannot be received, the UAT transmitter **shall** estimate — or “coast” — time through the outage period such that the drift rate of estimated time, relative to actual UTC-coupled time, is no greater than 12 milliseconds in 20 minutes.

e. While in the non-UTC Coupled Condition, ADS-B transmissions **shall** continue.

f. The UAT equipment **shall** change state to the UTC coupled condition within 2 seconds of availability of the UTC coupled source.

Notes:

1. *Item “d” above is consistent with an initial drift rate of 10 PPM in the baud clock over the 12-millisecond air-ground segment guard time. Clock drift can be compensated up to the time coasting begins.*

2. *In the non-UTC Coupled Condition, the estimated 1-second UTC epoch signal does NOT indicate the time of validity of Position, Velocity and Time (PVT) information.*

3. *Any installations of Class A equipment involving separated transmitters and receivers must provide a mechanism to fulfill the requirement stated in subparagraph (c) above.*

4. *This reversionary timing exists for the following reasons:(**a**) to support ADS-B Message transmission using an alternate source of position and velocity, if available; (**b**) to support ADS-B Message transmission in absence of position and velocity data in order that any available fields are conveyed (e.g., barometric altitude) and (**c**) that a signal is provided in the event the ground network can perform an ADS-B-independent localization of the A/V (e.g., multilateration).*

This test verifies that the UUT meets the requirements when the non-UTC coupled condition exists, that are contained in §2.2.5.2.

Note: *This procedure assumes that the test procedure of §2.4.6.3 has been performed, so the ownship reports can be used to monitor the UUT performance. If this is not the case, a UAT test receiver is required.*

Equipment Required:

- UAT ground station Uplink generator with the following characteristics:

  Message rate: 1.000 Hz.

Payload data: Time Slot field must correspond with the time slot of the uplink message. The "UTC Coupled" field of the Uplink message is set to ONE. Other payload fields may contain pseudo-random data.

- UAT test receiver with data logging and UTC 1 second time mark.

- Uplink transmitter with timing referenced to UTC 1 second time mark.

Step 1: Verify the processing of the external UAT Time Mark signal.

The requirements of §2.2.5.2.a and §2.2.5.2.b are validated through the test procedure of §2.4.5.1, step 1.

Step 2: Verify the time alignment for Class A equipment in the non-UTC case.

Through use of a test mode, force the UUT to transmit using MTO 752. While receiving Uplink messages, and without supplying the UUT with a valid UTC timing reference, observe the Time of Message Receipt value reported by the UAT test receiver. Verify that the Time of Message Receipt values are consistent with the timing accuracy requirement in §2.2.5.2.c; i.e., that the timing of the ADS-B ownship messages does exceed 6 milliseconds from the nominal timing for ADS-B Messages sent at MTO 752.

Note: *The purpose of this requirement is to prevent the loss of UTC time reference from causing the UUT equipment to transmit ADS-B Messages during the Uplink time segment.*

Step 3: Measure the UUT reference time.

Disable the UAT Uplink generator. Through use of a test mode, force the UUT transmitter to always transmit using Tx MSO 752. Record the current time, and measure the time offset between the UTC 1 second time reference and the Time of Message Reception by the UAT test receiver.

Step 4: Observe continued ADS-B transmissions.

Verify that while in the non-UTC coupled condition, the UUT continues to transmit ADS-B Messages. This validates the requirements of §2.2.5.2.e.

Step 5: Validate the rate of reference time drift.

Allow the UUT to continue transmitting ADS-B Messages. Measure the rate at which the Time of Message Reception reported by the UAT test receiver diverges from the time reference measured in Step 4.

Validate that the rate of message transmission time drift is less than the requirements stated in §2.2.5.2.d (i.e. 12 milliseconds in 20 minutes).

Step 6: Measure the response to the application of the UTC timing source.

Record the current time, and provide the UUT a valid UTC timing source, so that the equipment achieves the UTC Coupled condition. Verify that the elapsed time between application of the valid timing source and the reporting of the 'UTC Coupled" condition is not more than 2.0 seconds. This validates the requirements of §2.2.5.2.f.

2.4.6 Verification of Procedures for ADS-B Message Transmission (§2.2.6)

No specific test procedure is required to validate §2.2.6.

2.4.6.1 Verification of Scheduling of ADS-B Message Types (§2.2.6.1)

No specific test procedure is required to validate §2.2.6.1.

2.4.6.1.1 Verification of Payload Selection Cycle (§2.2.6.1.1)

No specific test procedure is required to validate §2.2.6.1.1.

2.4.6.1.2 Verification of ADS-B Payload Type Allocation (§2.2.6.1.2)

Appropriate test procedures required to validate the requirements in §2.2.6.1.2 are included in §2.4.6.1.3.

2.4.6.1.2.1 Verification of Event-Driven ADS-B Payload Allocation (§2.2.6.1.2.1)

Appropriate test procedures required to validate the requirements in §2.2.6.1.2.1 are included in §2.4.6.1.3.

2.4.6.1.3 Verification of Message Transmission Cycle (§2.2.6.1.3)

Purpose/Introduction:

A message transmission cycle of 16 seconds is defined to ensure a proper mix of message payloads. When an aircraft is determined to be in the AIRBORNE condition, transmissions **shall** occur through Top (T) (if so equipped) and Bottom (B) antennas each Message Transmission Cycle as shown in Figure 2-8.

When an aircraft is determined to be in the ON-GROUND condition (§2.2.4.5.2.5.1), the Top antenna (if so equipped) **shall** be selected for all transmissions. The transmission sequences are as shown in Figure 2-8, second and third rows.

This test procedure verifies the compliance of the ADS-B UAT transmitter with the Payload Type allocation and Message Transmission cycle requirements (including transmit antenna selection) of §2.2.6.1.2, §2.2.6.1.2.1 and §2.2.6.1.3.

Equipment Required:

Supply the UUT with data interfaces appropriate for the equipment class and intended application. Provide two UAT test receivers that can provide data logging of all received messages.

Measurement Procedure:

Step 1: Prepare the transmitting UUT and adjust signal levels.

Connect each UUT antenna port to a UAT test receiver. Use RF attenuators to adjust the signal to each UAT test receiver to 10 dB above the receiver's sensitivity threshold.

Note: *This provides that each receiver will only respond to messages transmitted on the antenna port that it is connected to.*

Step 2: Record the sequence of transmitted messages from the UUT While AIRBORNE.

Place the UUT into the AIRBORNE condition and allow it to transmit ADS-B Messages for a minimum of two Message Transmission Cycles (32 seconds). The test receivers will record the Payload Types for each received message on its antenna port.

Step 3: Analyze the recorded messages.

For each receiver, determine that the proper sequence of Payload Types has been recorded for the appropriate class of equipment, per Table 2-96.

Step 4: Record the sequence of transmitted messages from the UUT while in ON-GROUND.

Place the UUT into the ON-GROUND condition and allow the UUT to transmit ADS-B Messages for a minimum of two Message Transmission Cycles (32 seconds). The test receivers will record the Payload Types for each received message on its antenna port.

Step 5: Analyze the recorded messages.

For each receiver, determine that the proper sequence of Payload Types has been recorded for the appropriate class of equipment, per Table 2-96, and that the ADS-B Message is always transmitted from the Top antenna.

Table 2-96: Payload Type and Tx Antenna Selection versus Equipment Class

Equipment Class →	A0, A1S, B0, B1S	A1L, A1H, B1		A1H, B1 (w/TS)		A2		A3	
Time (sec)	**Antenna**	**Bot**	**Top**	**Bot**	**Top**	**Bot**	**Top**	**Bot**	**Top**
1	1		1		3		1		1
2	0		0		6		4		4
3	2	2		0		4		5	
4	0	0		6		4		4	
5	0		0		6		4		4
6	1		1		3		1		1
7	0	0		6		4		4	
8	2	2		0		4		5	
9	2		2		0		4		5
10	0		0		6		4		4
11	1	1		3		1		1	
12	0	0		6		4		4	
13	0		0		6		4		4
14	2		2		0		4		5
15	0	0		6		4		4	
16	1	1		3		1		1	

Step 6: Record the sequence of transmitted messages from the UUT after a change to the Flight ID.

For units which can support such a change, change the Flight ID while the UUT is transmitting its normal sequence shown in Table 2-96 and allow it to continue to transmit for an additional 16 seconds. Test receivers will record the Payload Types for each received message on its antenna port.

Step 7: Record the sequence of transmitted messages from the UUT after a change to the Emergency/Priority Status.

For units which can support such a change, change the Emergency/Priority Status while the UUT is transmitting its normal sequence shown in Table 2-96 and allow it to continue to transmit for an additional 16 seconds. Test receivers will record the Payload Types for each received message on its antenna port.

Step 8: Record the sequence of transmitted messages from the UUT after a change to both the Flight ID and Emergency/Priority Status within 6 seconds.

For units which can support such a change, change the Emergency/Priority Status while the UUT is transmitting its normal sequence shown in Table 2-96. Prior to 6 seconds after changing the Emergency/Priority Status change the Flight ID and allow the UUT to continue to transmit for an additional 16 seconds. Test receivers will record the Payload Types for each received message on its antenna port.

Step 9: Analyze the messages recorded in Steps 6, 7 and 8.

For each receiver, determine that the proper sequence of Payload Type has been recorded as per §2.2.6.1.2.1 and that the Pay Type sequence returns to that shown in Table 2-96 TBD seconds after the final change in Emergency/Priority Status or Flight ID. Verify that the Fight ID is transmitted in every message as required.

2.4.6.2 Verification of ADS-B Message Transmit Timing (§2.2.6.2)

No specific test procedure is required to validate §2.2.6.2.

2.4.6.2.1 Verification of The Message Start Opportunity (MSO) (§2.2.6.2.1)

Purpose/Introduction:

ADS-B Messages **shall** be transmitted at discrete Message Start Opportunities (MSO) chosen by a pseudo-random process. The specific pseudo-random number (*R*) chosen by an aircraft depends on the most recent valid position estimate available at the beginning of each second and on the previously chosen random number *R(m-1)*. Let:

N(0) = 12 L.S.B.'s of the most recent valid "LATITUDE"
N(1) = 12 L.S.B.'s of the most recent valid "LONGITUDE"

where the "LATITUDE" and "LONGITUDE" are as defined in §2.2.4.5.2.1.

Using *N(0)* and *N(1)* the procedure below **shall** be employed to establish the transmission timing for the current UAT frame *m*.

When $m = 0$, $R(0) = N(0) \bmod 3200$

When $m >= 1$, $R(m) = \{ 4001\ R(m-1) + N(m \bmod 2) \} \bmod 3200$

1. When in the first frame after power up, and whenever the Vertical Status is determined to be in the AIRBORNE condition, the transmitter **shall** be in the *full MSO range* mode, where the MSO is determined as follows:

   MSO = 752 + R(m)

2. Under all other conditions the transmitter **shall** be in the *restricted MSO range* mode, where the MSO is determined as follows:

   MSO = 752 + R* + R(m)mod800

   With R* = R(k) – R(k)mod800, where "k" is the frame just prior to entering the *restricted MSO range* mode.

This test procedure verifies that the UAT Transmitter output transmission timing meets the requirements of §2.2.6.2.1. The transmitter is required to output at the discrete MSO determined by a pseudo-random calculation based on the last ownship valid latitude and longitude position. The following procedure verifies that the output occurs at the proper MSO based on the calculation.

Equipment Required:

The test configuration requires data sources be provided to the appropriate UAT Transmitter interfaces to enable transmission of ADS-B Messages. This could also be accomplished by the use of an internally generated ADS-B test message with controllable data content. Determine the elapsed time by an external timing source capable of measuring the time from message transmission relative to the UTC time mark. The interval may vary from the time to the first MSO to the last MSO in the one-second epoch.

Measurement Procedures:

Set up the UAT Transmitting equipment as configured in Figure 2-13. The time of transmission is measured relative to the UTC Time Mark or equivalent to the start of the first bit of the synchronization sequence of the transmitted message. The timing measurement is required to provide a minimum of a 50 nanosecond timing resolution.

Provide a means to indicate the Vertical Status to the UAT equipment, if the UAT equipment supports such an interface.

Step 1: Airborne Message Start Opportunity Verification

Apply a Vertical Status of AIRBORNE to the UAT equipment, if provided. Provide data to the UAT transmitting equipment to output the following fixed latitude and longitude values:

Latitude:	000 1000 1010 1000 0110 1000 (MSB) (LSB)
Longitude:	0000 0101 1010 0010 0011 1010

Maintain this input to the latitude and longitude inputs to enable verification of correct MSO assignment. Power down the transmitter so that the last valid latitude and longitude values stored by the UAT transmitting equipment are as indicated. Power on the UAT Transmitting equipment with the latitude and longitude data input maintained at the fixed values. The sequence of MSOs that are valid assuming an initialization at t = 0 are as indicated in Table 2-97. Because of differences in power up timing and initialization procedures, the transmission sequence may not commence from the very beginning of the table but once aligned with the table, verify the transmission times for a minimum of 10 transmissions. The time interval from the UTC Time Mark to the first bit of the synchronization sequence establishes the MSO number. If the MSO is contained in the output message, it can be used to validate the proper MSO timing.

If the UAT equipment does not support a Vertical Status interface, the remaining Steps of this procedure do not need to be performed.

Table 2-97: MSO Sequence Validation

m	N(0)	N(1)	temp	R(m)	MSO
0	2152	570	undefined	2152	2904
1	2152	570	8610722	2722	3474
2	2152	570	10892874	74	826
3	2152	570	296644	2244	2996
4	2152	570	8980396	1196	1948
5	2152	570	4785766	1766	2518
6	2152	570	7067918	2318	3070
7	2152	570	9274888	1288	2040
8	2152	570	5155440	240	992
9	2152	570	960810	810	1562
10	2152	570	3242962	1362	2114
11	2152	570	5449932	332	1084
12	2152	570	1330484	2484	3236
13	2152	570	9939054	3054	3806
14	2152	570	12221206	406	1158
15	2152	570	1624976	2576	3328
16	2152	570	10308728	1528	2280
17	2152	570	6114098	2098	2850
18	2152	570	8396250	2650	3402
19	2152	570	10603220	1620	2372
20	2152	570	6483772	572	1324
21	2152	570	2289142	1142	1894
22	2152	570	4571294	1694	2446
23	2152	570	6778264	664	1416
24	2152	570	2658816	2816	3568
25	2152	570	11267386	186	938
26	2152	570	746338	738	1490
27	2152	570	2953308	2908	3660
28	2152	570	11637060	1860	2612
29	2152	570	7442430	2430	3182
30	2152	570	9724582	2982	3734

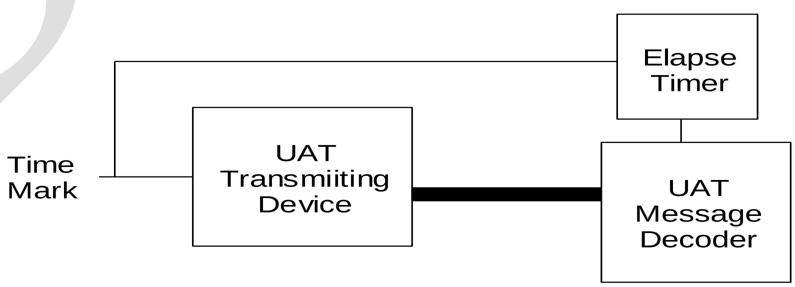


Figure 2-13: MSO Timing Measurement Configuration

Step 2: On-Ground Message Start Opportunity Verification

Without powering-off the equipment, change the Vertical Status from AIRBORNE to ON-GROUND. By observing the Elapse Timer values, verify that not more than 1,200 milliseconds elapse between each pair of sequential UAT transmissions. Verify that the time of transmission for all messages remains within one of the following four time intervals after the UTC time reference:

- 194 to 394 milliseconds after UTC time
- 394 to 594 milliseconds after UTC time
- 594 to 794 milliseconds after UTC time
- 794 to 994 milliseconds after UTC time

Step 3: Verify All Four Possible Timing Alignments

Without powering-off the UAT equipment, repeat Step 2 as necessary to verify that the UAT equipment can transmit messages when in the ON-GROUND condition using all four possible timing alignments.

Step 4: Verify ON-GROUND Startup Condition

With the UAT equipment powered-off, apply an ON-GROUND indication to the Vertical Status input interface. Power-up the UAT equipment. Verify that the time of transmission for all messages remains within one of the time intervals specified in Step 2. Repeat this Step as necessary to verify that the UAT equipment can transmit messages using all four possible timing alignments.

2.4.6.2.2 Verification of Relationship of the MSO to the Modulated Data (§2.2.6.2.2)

Purpose/Introduction:

The optimum sample point of the first bit of the UAT synchronization sequence at the antenna terminal of the UAT equipment **shall** occur at T_{TX} microseconds after the 1 second UTC epoch, as supplied to the UAT Transmitting Subsystem, according to the following formula:

$$T_{TX} \text{ (microseconds)} = 6000 + (250{*}\text{MSO})$$

within the following tolerances:

a. ±500 nanoseconds for UAT equipment with an internal UTC coupled time source,

b. ±500 nanoseconds for UAT equipment with an external UTC coupled time source.

Notes:

1. *This is required to support ADS-B range validation by a receiving application. This requirement sets the ultimate timing accuracy of the transmitted messages under the*

UTC Coupled condition. See Appendix I for a discussion of UAT Timing Considerations.

2. *Referencing this measurement to the optimum sampling point is convenient since this is the point in time identified during the synchronization process.*

3. *There is no requirement to demonstrate this relationship when in the non-UTC Coupled condition.*

This test procedure verifies that the timing relationship between the Transmit MSO number and the data modulation complies with the requirements of §2.2.6.2.2.

Equipment Required:

Supply the UUT with a pseudorandom stream of payload data.

Provide a 1 PPS timing signal to act as a reference for that being used by the UUT.

Provide a Vector Signal Analyzer (VSA), per §2.4.2.1, configured per Table 2-71 excepting use of external trigger mode.

Provide a trigger timing delay generator connected between the UTC 1 second timing source, and the VSA external trigger input. Timing delay range is from 194.000 milliseconds to 993.750 milliseconds.

Provide access to GPS constellation signals or a simulated signal source.

Measurement Procedure:

Step 1: Configure the UUT transmitter

Configure the UUT in a test mode that causes the Transmitted MSO to be selected in sequence from the following list: MSO = (752, 2352, 3951).

Note: *This sequence causes the UUT transmitter to transmit at the earliest, middle, and latest possible MSOs in the Air segment.*

Step 2: Trigger delay setup.

Set the trigger delay generator so that the 1 PPS timing source is delayed by 194.000 milliseconds for MSO 752, 594.000 milliseconds for MSO 2352, or 993.750 milliseconds for MSO 3951.

Step 3: Measure the Modulated Data Timing

On Trace A on the VSA, find the optimum sample point of the first bit of the 36-bit synchronization sequence. The time offset between the trigger point and this optimum sample point, minus 34.56 microseconds, should meet the timing requirements of §2.2.6.2.2.a or ‘b’ as appropriate (i.e., ±500 nanoseconds).

Note: *Measurement to other reference points within the modulation data stream may be used to verify the timing requirements. Apply time compensation as necessary from the measurement point to the optimum sample point of the first bit of the synchronization sequence applied at the receiver terminals.*

2.4.6.3 Verification of Report Assembly on Transmission of Ownship ADS-B Message (§2.2.6.3)

Purpose/Introduction:

The transmitter **shall** issue a report reflecting each ADS-B Message transmission and explicitly identify the report as "ownship."

Reports **shall** contain all elements of the transmitted message payload with range, resolution and units of each payload field preserved.

Notes:

1. *This is to aid any application process that uses ADS-B Message propagation time to perform a validity check of received ADS-B Messages by providing a reference point for measured ranges.*

2. *Allows independent monitoring of the transmitted position.*

This test procedure verifies that the UUT transmitter generates an ADS-B report for each of its transmissions in compliance with §2.2.6.3.

Equipment Required:

Supply the UUT with data interfaces appropriate for the equipment class and intended application. Provide one UAT test receiver that provides data logging of all received messages is required for this test procedure.

Step 1: Verifying the ownship report.

Verify that each UUT ADS-B transmission is accompanied by a message on the UUT report interface, indicating that the report is of the "ownship" type.

Step 2: Verify the ownship report contents.

Compare the data received by the UAT test receiver, with the contents of the UUT ownship reports, and verify that the range and accuracy of each of the report fields is preserved.

2.4.7 Verification of UAT Transmitter Message Data Characteristics (§2.2.7)

No specific test procedure is required to validate §2.2.7.

2.4.7.1 Verification of UAT Transmitter Input Requirements (§2.2.7.1)

Appropriate test procedures required to validate the requirements of §2.2.7.1 are included in the respective subparagraphs identified in each line item of Table 2-98.

Table 2-98: UAT ADS-B Transmitter Input Requirements

Element #	Input Data Element	Relevant Paragraph	Data Lifetime (seconds)	Applicable UAT Equipment Class						
				A0, B0	A1L A1S B1S	A1H, B1	A2	A3	B2	B3
1	ICAO 24-bit Address	2.4.4.5.1.3.1	n/a	M	M	M	M	M	M (1)	M (1)
2	Address Selection (ICAO vs Temporary) (3)	2.4.4.5.1.3.1 2.4.4.5.1.3.2	60	Input required only if installation is to have selectable address						
3	Latitude (2)	2.4.4.5.2.1	1.5	M	M	M	M	M	M	M
4	Longitude (2)	2.4.4.5.2.1	1.5	M	M	M	M	M	M	M
5	Altitude Type Selection (Barometric vs Geometric) (3)	2.4.4.5.2.2	60	O	O	O	O	O	n/a	M
6	Barometric Pressure Altitude	2.4.4.5.2.3	2	M	M	M	M	M	n/a	n/a
7	Geometric Altitude	2.4.4.5.2.3	1.5	M	M	M	M	M	n/a	M
8	NIC	2.4.4.5.2.4	2	M	M	M	M	M	M	M
9	Automatic AIRBORNE / ON-GROUND Indication (3)	2.4.4.5.2.5	2	O	O	M	M	M	n/a	n/a
10	North Velocity (2)	2.4.4.5.2.6.1	2	M	M	M	M	M	M	M
11	East Velocity (2)	2.4.4.5.2.6.3	2	M	M	M	M	M	M	M
12	Ground Speed	2.4.4.5.2.6.2	2	O	O	M	M	M	O	n/a
13	Track Angle	2.4.4.5.2.6.4	2	O	O	M	M	M	n/a	n/a
14	Heading	2.4.4.5.2.6.4	2	O	O	M	M	M	n/a	n/a
15	Barometric Vertical Rate	2.4.4.5.2.7.1.1 2.4.4.5.2.7.1.3	2	M	M	M	M	M	n/a	n/a
16	Geometric Vertical Rate (2)	2.4.4.5.2.7.1.1 2.4.4.5.2.7.1.3	2	O	O	O	O	O	n/a	n/a
17	A/V Length and Width, and POA	2.4.4.5.2.7.2	n/a	M	M	M	M	M	M	M
18	UTC 1 PPS Timing (2)	2.4.4.5.2.8	2	M	M	M	M	M	M	M
19	Emitter Category	2.4.4.5.4.1	n/a	M	M	M	M	M	M	M
20	Call Sign	2.4.4.5.4.2	60	M	M	M	M	M	O	O
21	Emergency / Priority Status Selection	2.4.4.5.4.4	60	M	M	M	M	M	O	n/a
22	Source Integrity Level (SIL)	2.4.4.5.4.6	60	M	M	M	M	M	M	M
23	System Design Assurance (SDA)	2.4.4.5.4.8	60	M	M	M	M	M	M	M
24	SIL Supplement	2.4.4.5.4.16	60	M	M	M	M	M	M	M
25	NAC_P (2)	2.4.4.5.4.9	2	M	M	M	M	M	M	M
26	NAC_V (2)	2.4.4.5.4.10	2	M	M	M	M	M	n/a	n/a
27	NIC_{BARO}	2.4.4.5.4.11	2	Can be internally "hard coded"		M	M	M	n/a	n/a
28	Capability Codes	2.4.4.5.4.12	60	M	M	M	M	M	n/a	n/a
29	TCAS Installed and Operational	2.2.4.5.4.12.2	60	M	M	M	M	M	n/a	n/a
30	TCAS/ACAS Resolution Advisory Flag	2.4.4.5.4.13.1	18	Required only if ADS-B Transmitting Subsystem is intended for installation with TCAS/ACAS; otherwise can be "hard coded"						
31	IDENT Switch Active	2.4.4.5.4.13.2	60	M	M	M	M	M	M	n/a
32	Call Sign Identification	2.4.4.5.4.14	2	Require only if CSID logic is Enabled						
33	Geometric Vertical Accuracy (GVA)	2.4.4.5.4.17	60	M	60	M	60	M	60	M
34	Single Antenna Flag	2.4.4.5.4.18	n/a	M	n/a	M	n/a	M	n/a	M
35	Selected Altitude Type	2.4.4.5.6.1	60	n/a	60	n/a	60	n/a	60	n/a
36	Selected Altitude Setting	2.4.4.5.6.2	60	n/a	60	n/a	60	n/a	60	n/a
37	Barometric Pressure Setting	2.4.4.5.6.3	60	n/a	60	n/a	60	n/a	60	n/a
38	Selected Heading	2.4.4.5.6.4	60	n/a	60	n/a	60	n/a	60	n/a
39	Status of MCP/FCU Mode	2.4.4.5.6.5	60	n/a	60	n/a	60	n/a	60	n/a
40	Mode Indicators: Autopilot Engaged	2.4.4.5.6.6	60	n/a	60	n/a	60	n/a	60	n/a
41	Mode Indicators: VNAV Engaged	2.4.4.5.6.7	60	n/a	60	n/a	60	n/a	60	n/a
42	Mode Indicators: Altitude Hold Mode	2.4.4.5.6.8	60	n/a	60	n/a	60	n/a	60	n/a
43	Mode Indicators: Approach Mode	2.4.4.5.6.9	60	n/a	60	n/a	60	n/a	60	n/a
44	Radio Height	2.4.4.5.2.5.1	2	O	O	O	O	O	n/a	n/a
45	Pressure Altitude Disable	2.4.4.5.2.2	n/a	M	M	M	M	M	n/a	n/a
46	Airspeed	2.4.4.5.2.5.1	2	O	O	O	O	O	n/a	n/a
47	Flight Plan ID	2.4.4.5.4.2	60	M	M	M	M	M	n/a	n/a

O = Optional   M = Mandatory (the equipment must have the ability to accept the data element)

Notes:

(1) Non-Aircraft Identifier may be assigned by Regulatory Authority.

(2) If input is not directly accessible, a means to verify the encoding must be demonstrated.

(3) These elements are control inputs and are not themselves directly contained in the transmitted ADS-B Messages.

2.4.7.2 Verification of Time Registration and Latency (§2.2.7.2)

No specific test procedure is required to validate §2.2.7.2.

2.4.7.2.1 Verification of Requirements When in Non-Precision Condition and UTC Coupled (§2.2.7.2.1)

Appropriate test procedures required to validate the requirements of §2.2.7.2.1 are included in §2.4.7.2.1.1 and §2.4.7.2.1.2.

2.4.7.2.1.1 Verification of Latitude and Longitude Requirements When in Non-Precision Condition and UTC Coupled (§2.2.7.2.1.a, §2.2.4.5.2.1, §2.2.4.5.2.6)

Purpose/Introduction:

When the UAT Transmitting Subsystem is in the Non-Precision Condition, and is UTC Coupled:

a. At the time of the ADS-B Message transmission, position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a Geometric Altitude, **shall** be applicable as of the start of the current 1 second UTC Epoch.

b. All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

Notes:

1. *Specifically, any extrapolation of position performed should be to the start of the 1-second UTC Epoch and not the time of transmission.*

2. *Velocity information cannot be extrapolated and may therefore have additional ADS-B imposed latency.*

The following test procedure verifies the UAT Transmitting equipment meets the time registration and latency requirements of §2.2.7.2.1 for NAC_P values less than or equal to 9 or NIC values less than or equal to 8. The Latitude, Longitude and Altitude data contained in the transmitted ADS-B Message is applicable at the one second UTC Epoch. All other data contained in the transmitted message reflects all values that were updated 200 milliseconds or more prior to the transmission time of the message.

Equipment Required:

The test configuration must include data sources to be provided at the input interfaces of the UAT Transmitting equipment so that the appropriate data is available and loaded into the corresponding fields in the transmitted message. Equipment that serves as a source for the latitude, longitude, altitude and velocity data must be capable of providing position updates synchronized to the UTC Time Mark at a minimum of a 1 second update rate. The position updates must be recomputed each second according to the velocity data required by the test procedure. The position data must be provided to the UAT Transmitting equipment within 200 milliseconds of the UTC Time Mark. The UTC Time Mark or its equivalent will serve as the synchronization for all timing measurements. The transmitted messages from the UAT Transmitting equipment must be received and decoded by appropriate receiving equipment with either the capability of internally tagging time of message receipt within 1 millisecond of the time of message receipt relative to UTC Time Mark, or of providing an external signal representing time of message receipt for external time measurement. External timing relative to the UTC Time Mark is required to measure elapsed time with a resolution of 100 nanoseconds or better.

Measurement Procedure

Step 1: Verify Latitude Data

Set up the UUT to transmit ADS-B Messages. Initialize the equipment providing position data to the UUT to the following conditions:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
N/S Velocity:	1,200	knots	SOUTH

Initialize the UUT and after stable, apply the initial position values to the equipment. Provide latitude, longitude and altitude data at the input interface to the UUT. The UTC Time Mark prior to the first position data is the initial data collection point at the output of the UUT. Take 60 consecutive samples and compare the reported latitude in the UAT Transmitted Message to the Computed Latitude derived from the initial conditions. The position will change approximately 617.333 meters each one-second update. Verify that the Latitude data transmitted is within 2.5 meters of the Computed Latitude.

Step 2: Verify Longitude Data

Set up the UUT to transmit ADS-B Messages. Initialize the equipment providing position data to the UUT to the following conditions:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
E/W Velocity:	1,200	knots	WEST

Initialize the UUT and after stable, apply the initial position values to the equipment. Provide latitude, longitude and altitude data at the input interface to the UUT. The UTC Time Mark prior to the first position data is the initial data collection point at the output of the UUT. Take 60 consecutive samples and compare the reported Longitude in the UAT Transmitted Message to the Computed Longitude derived from the initial conditions. The position will change approximately 617.333 meters each one-second update. Verify that the Longitude data transmitted is within 1.25 meters of the Computed Longitude.

Step 3: Verify Latitude Data – Crossing the Equator

Repeat the procedure in Step 1 for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	0.0625	degrees	NORTH
N/S Velocity:	1,200	knots	SOUTH

Step 4: Verify Longitude Data – Crossing the Equator

Repeat the procedure in Step 2 for the following data:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
E/W Velocity:	1,200	knots	WEST

Step 5: Verify Latitude Data – Crossing the North Pole

Repeat the procedure in Step 1 for the following data:

Longitude:	45.0	degrees	EAST
Latitude:	89.937	degrees	NORTH
N/S Velocity:	1,200	knots	NORTH

Step 6: Verify Longitude Data – Crossing the North Pole

Repeat the procedure in Step 2 for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	89.937	degrees	NORTH
E/W Velocity:	1,200	knots	WEST

Step 7: Verify Latitude Data – Crossing the South Pole

Repeat the procedure in Step 1 for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	89.937	degrees	SOUTH
N/S Velocity:	1,200	knots	SOUTH

Step 8: Verify Longitude Data – Crossing the South Pole

Repeat the procedure in Step 2 for the following data:

Longitude:	45.0	degrees	EAST
Latitude:	89.937	degrees	SOUTH
E/W Velocity:	1,200	knots	EAST

2.4.7.2.1.2 Verification of Requirements for Other ADS-B Message Fields When in Non-Precision Condition and UTC Coupled (§2.2.7.2.1.b)

Purpose/Introduction:

When the UAT Transmitting Subsystem is in the Non-Precision Condition, and is UTC Coupled:

a. At the time of the ADS-B Message transmission, position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a Geometric Altitude, **shall** be applicable as of the start of the current 1 second UTC Epoch.

b. All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

Notes:

1. *Specifically, any extrapolation of position performed should be to the start of the 1-second UTC Epoch and not the time of transmission.*

2. *Velocity information cannot be extrapolated and may therefore have additional ADS-B imposed latency.*

<u>Equipment Required:</u>

The test configuration must include data sources to be provided at the input interfaces of the UAT Transmitting equipment so that the appropriate data is available and loaded into the corresponding fields in the transmitted message. Equipment that serves as a source for the latitude, longitude, altitude and velocity data must be capable of providing position updates synchronized to the UTC Time Mark at a minimum of a one second update rate. The position updates must be recomputed each second according to the velocity data required by the test procedure. The position data must be provided to the UAT Transmitting equipment within 200 milliseconds of the UTC Time Mark. The UTC Time Mark or its equivalent will serve as the synchronization for all of the timing measurements. The transmitted messages from the UAT Transmitting equipment must be received and decoded by the appropriate receiving equipment with either the capability of internally tagging time of message receipt within 1 millisecond of the time of message receipt relative to the UTC Time Mark, or of providing an external signal representing the time of message receipt for an external time measurement. External timing relative to the UTC Time Mark is required to measure the elapsed time with a resolution of 100 nanoseconds or better.

<u>Measurement Procedure:</u>

<u>Step 1:</u> <u>Verify Data Updates Prior to 200 Milliseconds of the Transmission Time</u>

Set up the UUT to transmit ADS-B Messages. Input an ADS-B Message and update the input values each second at least 200 milliseconds prior to the next scheduled message transmission. Verify that each transmitted message reflects the updated values input each second.

<u>Step 2:</u> <u>Verify Data Updates Within 200 Milliseconds of the Transmission Time</u>

Set up the UUT to transmit ADS-B Messages. Input an ADS-B Message and update the input values each second within 200 milliseconds of the next scheduled message transmission.

Verify that if the updated values are not reflected in the next transmitted message, then they are reflected no later than the message following that one and likewise for each subsequent input.

2.4.7.2.2 Verification of Requirements When in Precision Condition and UTC Coupled (§2.2.7.2.2)

Appropriate test procedures required to validate the requirements of §2.2.7.2.2 are included in §2.4.7.2.2.1 and §2.4.7.2.2.2.

2.4.7.2.2.1 Verification of Latitude and Longitude Requirements When in Precision Condition and UTC Coupled (§2.2.7.2.2.a, §2.2.4.5.2.1, §2.2.4.5.2.6)

Purpose/Introduction:

When the UAT Transmitting Subsystem is in the Precision Condition, and is UTC Coupled:

a. At the time of the ADS-B Message transmission, the position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a Geometric Altitude, **shall** be applicable as of the start of the current 0.2 second UTC Epoch.

b. All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

Notes:

1. *Specifically, any extrapolation of position performed should be to the start of the 0.2 second UTC Epoch and not the time of transmission.*

2. *Operation in this condition assumes a GPS/GNSS sensor output rate of 5 Hz or greater is available to the ADS-B Transmitting Subsystem.*

The following test procedure verifies that the UAT Transmitting equipment meets the time registration and latency requirements of §2.2.7.2.2 for NAC_P values greater than or equal to 10 or NIC values greater than or equal to 9. The Latitude, Longitude and Altitude data contained in the transmitted ADS-B Message is applicable at the 0.2 second UTC Epoch. All other data contained in the transmitted message reflects all values that were updated 200 milliseconds or more prior to the transmission time of the message.

Equipment Required:

The test configuration must include data sources to be provided at the input interfaces of the UAT Transmitting equipment so that the appropriate data is available and loaded into the corresponding fields in the transmitted message. Equipment that serves as a source for the latitude, longitude, altitude and velocity data must be capable of providing position updates synchronized to the UTC Time Mark at a minimum of a 0.2 second update rate. The position updates must be recomputed each 0.2 second according to the velocity data required by the test procedure. The position data must be provided to the UAT Transmitting equipment within 200 milliseconds of the UTC Time Mark. The UTC Time Mark or equivalent will serve as the synchronization for all timing measurements. The transmitted messages from the UAT Transmitting equipment must be received and decoded by appropriate receiving equipment with either the capability of internally tagging time of message receipt within 1 millisecond of the time of message receipt relative to UTC Time Mark, or of providing an external signal representing time of receipt for external time measurement. External timing relative to the UTC Time Mark is required to measure elapsed time with a resolution of 100 nanoseconds or better.

Measurement Procedure:

Step 1: Verify Latitude Data

Set up the UUT to transmit ADS-B Messages. Initialize the equipment providing position data to the UUT to the following conditions:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
N/S Velocity	1,200	knots	SOUTH

Initialize the UUT and, after stable, apply the initial position values to the equipment. Provide Latitude, Longitude and Altitude data at the input interface to the UUT. The 0.2 second UTC Epoch prior to the first position data is the initial data collection point at the output of the UUT. The data should reflect the change over time, in 0.2 second increments, since the UTC time mark. Take 60 consecutive samples and compare the reported Latitude in the UAT Transmitted Message to the Computed Latitude derived from the initial conditions. The position will change approximately 617.333 meters for each one second update, and so will change approximately 123.466 meters for each 200 milliseconds. Verify that the Latitude data transmitted reflects the change over time in position of 123.466 meters since the start of the previous 0.2 seconds interval and is within 2.5 meters of the Computed Latitude.

Step 2: Verify Longitude Data

Set up the UUT to transmit ADS-B Messages. Initialize the equipment providing position data to the UUT to the following conditions:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
E/W Velocity	1,200	knots	WEST

Initialize the UUT and, after stable, apply the initial position values to the equipment. Provide Latitude, Longitude and Altitude data at the input interface to the UUT. The 0.2 second UTC Epoch prior to the first position data is the initial data collection point at the output of the UUT. The data should reflect the change over time, in 0.2 second increments, since the UTC time mark. Take 60 consecutive samples and compare the reported Latitude in the UAT Transmitted Message to the Computed Longitude derived from the initial conditions. The position will change approximately 617.333 meters for each one second update, and so will change approximately 123.466 meters for each 200 milliseconds. Verify that the Longitude data transmitted reflects the change over time in position of 123.466 meters since the start of the previous 0.2 seconds interval and is within 1.25 meters of the Computed Longitude.

Step 3: Verify Latitude Data – Crossing the Equator

Repeat the procedure in step one for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	0.0625	degrees	NORTH
N/S Velocity	1,200	knots	SOUTH

Step 4: Verify Longitude Data – Crossing the Equator

Repeat the procedure in step two for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	0.0625	degrees	NORTH
E/W Velocity	1,200	knots	WEST

Step 5: Verify Latitude Data – Crossing the North Pole

Repeat the procedure in step one for the following data:

Longitude:	45.0	degrees	EAST
Latitude:	89.937	degrees	NORTH
N/S Velocity	1,200	knots	NORTH

Step 6: Verify Longitude Data – Crossing the North Pole

Repeat the procedure in step two for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	89.937	degrees	NORTH
E/W Velocity	1,200	knots	WEST

Step 7: Verify Latitude Data – Crossing the South Pole

Repeat the procedure in step one for the following data:

Longitude:	45.0	degrees	WEST
Latitude:	89.937	degrees	SOUTH
N/S Velocity	1,200	knots	SOUTH

Step 8: Verify Longitude Data – Crossing the South Pole

Repeat the procedure in step two for the following data:

Longitude:	45.0	degrees	EAST
Latitude:	89.937	degrees	SOUTH
E/W Velocity	1,200	knots	EAST

2.4.7.2.2.2 Verification of Requirements for Other ADS-B Message Fields When in Precision Condition and UTC Coupled (§2.2.7.2.2.b)

Purpose/Introduction:

When the UAT Transmitting Subsystem is in the Precision Condition, and is UTC Coupled:

All other updated ADS-B Message fields that are provided at the ADS-B equipment input interface at least 200 milliseconds prior to the time of a scheduled ADS-B Message transmission that involves those fields, **shall** be reflected in the transmitted message.

Equipment Required:

The test configuration must include data sources to be provided at the input interfaces of the UAT Transmitting equipment so that the appropriate data is available and loaded into the corresponding fields in the transmitted message. Equipment that serves as a source for the latitude, longitude, altitude and velocity data must be capable of providing position updates synchronized to the UTC Time Mark at a minimum of a one second update rate. The position updates must be recomputed each one second according to the velocity data required by the test procedure. The position data must be provided to the UAT Transmitting equipment within 200 milliseconds of the UTC Time Mark. The UTC Time Mark or its equivalent will serve as the synchronization for all of the timing measurements. The transmitted messages from the UAT Transmitting equipment must be received and decoded by the appropriate receiving equipment with either the capability of internally tagging time of message receipt within 1 millisecond of the time of message receipt relative to the UTC Time Mark or of providing an external signal representing the time of message receipt for an external time measurement. External timing relative to the UTC Time Mark is required to measure the elapsed time with a resolution of 100 nanoseconds or better.

Measurement Procedure:

Step 1: Verify Data Updates Prior to 200 Milliseconds of the Transmission Time

Set up the UUT to transmit ADS-B Messages. Input an ADS-B Message and update the input values each second at least 200 milliseconds prior to the next scheduled message transmission. Verify that each transmitted message reflects the updated values input each second.

Step 2: Verify Data Updates Within 200 Milliseconds of the Transmission Time

Set up the UUT to transmit ADS-B Messages. Input an ADS-B Message and update the input values each second within 200 milliseconds of the next scheduled message transmission.

Verify that if the updated values are not reflected in the next transmitted message, then they are reflected no later than the message following that one and likewise for each subsequent input.

2.4.7.2.3 Verification of Requirements When Non-UTC Coupled (§2.2.7.2.3)

Purpose/Introduction:

When the UAT Transmitting Subsystem is in the Non-UTC Coupled Condition any change in an ADS-B Message field provided to the transmitter **shall** be reflected in any transmitted message containing that message field that is transmitted more than 1.0 second after the new value is received by the transmitter.

Note: *A UAT Transmitting Subsystem that is capable of meeting the requirements of §2.2.7.2.2 makes no adjustment to the NIC or NAC that it receives as input. It is not expected that a single transmitted message would ever indicate both the Non-UTC Coupled condition and a NIC or* NAC_P *consistent with the Precision condition.*

Equipment Required:

The test configuration must include data sources to be provided at the input interfaces of the UAT Transmitting equipment so that the appropriate data is available and loaded into the corresponding fields in the transmitted message. Equipment that serves as a source for the latitude, longitude, altitude and velocity data must be capable of providing position updates synchronized to the UTC Time Mark at a 1 second update rate. The position updates must be recomputed each second according to the velocity data required by the test procedure. The UTC Time Mark or equivalent will serve as the synchronization for all timing measurements even though the UUT will not be provided the UTC Time Mark. The transmitted messages from the UAT Transmitting equipment must be received and decoded by appropriate receiving equipment with either the capability of internally tagging time of receipt within 1 millisecond time of receipt relative to UTC Time Mark or of providing an external signal representing time of receipt for external time measurement. External timing relative to the UTC Time Mark is required to measure elapsed time with a resolution of 100 nanoseconds or better. Disconnect the UTC Time Mark from the ADS-B Transmitting System so that the UUT is Non-UTC Coupled.

Measurement Procedure:

Step 1: Verify Latitude and Longitude Data

Set up the UUT to transmit ADS-B Messages. Initialize the equipment providing position data to the UUT to the following conditions:

Longitude:	30.0	degrees	WEST
Latitude:	60.0	degrees	NORTH
N/S Velocity:	1,200	knots	SOUTH
E/W Velocity:	1,200	knots	WEST

Initialize the UUT and after stable, apply the initial position values to the equipment. Provide Latitude, Longitude and Altitude data at the input interface to the UUT and record the time that the information is input to the UUT. The UTC Time Mark prior to the first position data is the initial data collection point at the output of the UUT. Take 60 consecutive samples and record the Time of Receipt of each transmitted message. Verify that for each reported latitude and longitude in each of the messages, the Latitude and Longitude values reported in the transmitted message reflects the last input values prior to the transmitted message or the previous input values input the prior one-second interval.

Step 2: Verify Updates For All Other Data

Set up the UUT to transmit ADS-B Messages. For each of the applicable input elements in Table 2-64 for the equipage class under test, provide the applicable input element at its nominal input rate. Verify that the input values received one second or more prior to the transmission time are reflected in the transmitted messages.

2.4.7.2.4 Verification of Total Latency of Position Measurements (§2.2.7.2.4)

Purpose/Introduction:

This test verifies that when transmitting non-precision position data, all transmitted messages reflect position data with a total latency of no more than 1.5 seconds at the time of message transmission.

Additionally, when transmitting precision position data, all transmitted messages reflect position data with a total latency of no more than 0.7 seconds at the time of message transmission.

Measurement Procedure:

For this test, a capability is required to generate a test stimulus ownship track with registered position and velocity output at one second periodic intervals. Additionally, the setup needs to output a 1pps signal a maximum of 200 milliseconds in advance of the position and velocity data being available to the UAT under test. This signal represents the UTC epoch, but need not be the actual UTC second. A recorder is required to capture all of the following: the baseband track stimulus, the 1 pps signal, and the output of a UAT receiver to capture the messages transmitted. All recordings must include a timestamp from a common or synchronized clock.

Step 1: Non-Precision Case

Hook up the test track stimulus to the UAT under test along with the 1pps signal. The test stimulus should use a NIC and NAC_P consistent with the non-precision condition. Allow the UAT transmitter to run for 60 seconds in order that a mix of MSOs is selected. From the recordings, verify that all transmitted messages reflect position data with a total latency of no more than 1.5 seconds at the time of message transmission.

Step 2: Precision Case

Hook up the test track stimulus to the UAT under test along with the 1 pps signal. The test stimulus should use a NIC and NAC_P consistent with the precision condition. Allow the UAT transmitter to run for 60 seconds in order that a mix of MSOs is selected. From the recordings, verify that all transmitted messages reflect position data with a total latency of no more than 0.7 seconds at the time of message transmission.

2.4.7.2.5 Verification of Data Timeout (§2.2.7.2.5)

Appropriate test procedures required to validate the requirements of §2.2.7.2.5 are included in the respective subparagraphs identified in each line item of Table 2-98.

2.4.8 Verification of Receiver Characteristics (§2.2.8)

No specific test procedure is required to validate §2.2.8.

2.4.8.1 Verification of Receiving Diversity (§2.2.8.1)

Appropriate test procedures required to validate the requirements of §2.2.8.1 are included in §2.4.8.1.1 and §2.4.8.1.2.

2.4.8.1.1 Verification of Full Receiving Diversity (§2.2.8.1.a and §2.2.8.1.b)

Purpose/Introduction:

"Receiving diversity" refers to an ADS-B Receiving Subsystem's use of signals received from either the Top antenna, or the Bottom antenna, or both antennas. For the purpose of these requirements, several alternate ADS-B Receiving Subsystem architectures that employ receiving antenna "diversity" are illustrated in Figure 2-9.

a. Full receiver and message processing function diversity:

   (see Figure 2-9, part a.)

   There are two receiver input channels, each with its own receiver front end, message synchronization, bit demodulation, and FEC decoding. All Successful Message Receptions from both channels **shall** be provided to the Report Assembly function. In the event both channels result in Successful Message Reception of identical messages, a single copy of this message may be provided.

b. Other diversity techniques: Other diversity implementations may be used. Any implementation must demonstrate equivalent or better performance to (a) above.

Measurement Procedure:

If receiver diversity is implemented using a diversity technique as specified in §2.2.8.1.a or §2.2.8.1.b, the following procedure will verify that the receiver properly receives simultaneously from both the Top and Bottom antenna ports.

Step 1: Receiver Diversity Verification – Full Diversity

This procedure is required for only those systems implementing full receiver diversity. Input a valid Time Mark to the ADS-B Transceiver but do not enable the Transmitter so that reception will not be inhibited. Separate messages are required as input to the two antenna ports. Input Message "A," a valid Long ADS-B Message, to the Top antenna port of the receiver. Input Message "B," a valid Long ADS-B Message with a different data content than Message "A," to the Bottom antenna port. Input Message "A" and Message "B" at exactly the same time. Timing of the generated ADS-B Message in the one-second epoch is relative to the leading edge of the UTC Time Mark, measured from the optimum sampling point of the first bit of the synchronization pattern input. Generate Message "A" and Message "B" with timing of 0.20 milliseconds from the leading edge of the UTC Time Mark. Monitor and record the output of the receiver. Verify that Message "A" and Message "B" are both received. Repeat for the following times relative to the UTC Time Mark: 50, 100 to 950 milliseconds in 50 millisecond intervals and 999.95 milliseconds.

2.4.8.1.2 Verification of Switching Receiving Diversity (§2.2.8.1.c)

Purpose/Introduction:

c. Receiving antenna switching:

(see Figure 2-9, part b.)

A single receiver input channel, consisting of receiver RF front end, message synchronization, bit demodulation and FEC decoding, is internally connected alternately and periodically, between the Top and Bottom antennas. If this method is implemented, switching when in the AIRBORNE condition **shall** occur such that:

1. Bottom and Top antennas are alternated for the ADS-B Segments of successive frames, AND

2. The Bottom antenna is used for the Ground Segment of all frames, AND

3. No more than a single Long type ADS-B Message arriving at the receiver is lost because of an antenna switch, AND

   Note: *The purpose of this requirement is to place an upper bound on the time to switch antennas.*

4. Antenna switching is initiated at the UTC Time Mark (±2 ms) and/or at the UTC Time Mark plus 188 milliseconds (±2 ms).

When an aircraft is determined to be in the ON-GROUND condition (§2.2.4.5.2.5.1), if a single receiver is switched between two antennas, the aircraft **shall** always select the Top antenna for reception.

Measurement Procedure:

This test procedure only applies if receiver diversity is implemented using a switching technique as specified in §2.2.8.1.c. The following procedure will verify that the receiver properly alternates between the Top and Bottom antenna ports for the ADS-B Segment of each one-second frame. Additionally, the receiver selects the bottom antenna port for the Ground Segment and antenna switching occurs at the designated times and completes within a time interval that results in the loss of no more than one Long ADS-B Message.

Input signal levels for the following test procedures will be –85 dBm. Unless otherwise indicated, place the ADS-B System in the AIRBORNE condition.

Step 1: Receiver Switching Verification – ADS-B Segment

Input a valid Time Mark to the ADS-B Transceiver but do not enable the Transmitter so that reception will not be inhibited for the following step. Separate messages are required as input to the two antenna ports. Input Message "A," a valid Long ADS-B Message, to the Top antenna port of the receiver. Input Message "B," a valid Long ADS-B Message with a different data content than Message "A," to the Bottom antenna port. Input Message "A" every other one-second epoch and Message "B" every other one-second epoch on the alternate one-second epoch to Message "A." Timing in the one-second epoch is relative to the leading edge of the UTC Time Mark, measured from the start of the first bit of the synchronization pattern, anywhere between 2.50 milliseconds into the ADS-B segment of the epoch and 2.5 milliseconds of the end of the epoch. Each second for exactly 100 seconds, input Message "A" to the Top antenna port or Message "B" to the Bottom antenna port, alternating each one-second epoch. Monitor and record the output of the receiver over the 100 seconds time interval. Verify that Message "A" is received exactly 50 times and Message "B" is received exactly 50 times over the 100 second interval.

Step 2: Receiver Switching Verification – Ground Segment

Input a valid Time Mark to the ADS-B Transceiver but do not enable the Transmitter so that reception will not be inhibited for the following step. Separate messages are required as input to the two antenna ports. Input Message "A," a valid Long ADS-B Message, to the Top antenna port of the receiver. Input Message "B," a valid Long ADS-B Message with a different data content than Message "A," to the Bottom antenna port. Input Message "A" and Message "B" every one-second epoch. Timing in the one-second epoch is relative to the lead edge of the UTC Time Mark, measured from the start of the first bit of the synchronization pattern input. Start the sequence with Message "A" and Message "B" starting at 2.4 milliseconds from the lead edge of the UTC Time Mark. Monitor and record the output of the receiver over a 100 second time interval. Verify that Message "A" is not received and Message "B" is received exactly 100 times over the 100 second interval. Repeat for the following times relative to the UTC Time Mark: 50, 100, 150, and 185.58 milliseconds.

Step 3: Receiver Switching Verification – Switching Interval at UTC Time Mark

Input two Long ADS-B Messages separated by 450 microseconds between the start of the first bit of the synchronization sequences of the messages. Input the messages on both the Top and Bottom antenna ports. For each of the following start times relative to the UTC Time Mark, verify that at least one of the two messages is received: -2.4, -1.6, -.8, 0, .8, 1.6 and 2.4 milliseconds.

Step 4: Receiver Switching Verification – Switching Interval at Ground Segment Start

Repeat Step 3 except using the following start times relative to the UTC Time Mark and verify that at least one of the two messages is received: 185.6, 186.4, 187.2, 188.0, 188.8, 189.6 and 190.4 milliseconds.

Step 5: Receiver Switching Verification – No Message Loss – Top Antenna

Input a sequence of 79 Long ADS-B Messages to the Top antenna port of the receiver and terminate the Bottom antenna port. Generate the sequence of ADS-B Messages such that the time between successive message starts is 10 milliseconds. Start time of the sequence in the one-second epoch is relative to the lead edge of the UTC Time Mark, measured from the start of the first bit of the synchronization pattern input. Synchronize the input of the sequence to a one-second epoch that has the Top antenna port as the selected input. Have the initial start time of the sequence begin at 190.42 milliseconds relative to the Time Mark. Verify that all 79 messages are received. Repeat the test by moving the sequence 400 microseconds each iteration and repeat verification. Repeat until the start time relative to the UTC Time mark equals 207.58 milliseconds. For each of the start times relative to the UTC Time Mark, verify that all 79 messages are received.

Step 6: Receiver Switching Verification – No Message Loss – Bottom Antenna

Input a sequence of 79 Long ADS-B Messages to the Bottom antenna port of the receiver and terminate the Top antenna port. Generate the sequence of ADS-B Messages such that the time between successive message starts is 10 milliseconds. Start time of the sequence in the one-second epoch is relative to the lead edge of the UTC Time Mark, measured from the start of the first bit of the synchronization pattern input. Synchronize the input of the sequence to a one-second epoch that has the Bottom antenna port as the selected input. Have the initial start time of the sequence begin at 190.42 milliseconds relative to the Time Mark. Verify that all 79 messages are received. Repeat the test by moving the sequence 400 microseconds each iteration and repeat verification. Repeat until the start time relative to the UTC Time mark equals 207.58 milliseconds. For each of the start times relative to the UTC Time Mark, verify that all 79 messages are received.

Step 7: Receiver Switching Verification – ON-GROUND Condition

This procedure is required for only those systems capable of reporting the ON-GROUND condition. Set up the ADS-B Receiving Subsystem to ON-GROUND condition. Terminate the bottom antenna port. Input a valid Long ADS-B Message to the Top antenna port, once per second for 100 seconds, with a time relative to the UTC Time Mark that varies from 5 milliseconds to 905 milliseconds in 10 millisecond increments. Monitor and record the output of the receiver over the 100 second time interval. Verify that the ADS-B Message is received exactly 100 times over the 100 second interval.

2.4.8.2 Verification of Receiver Performance (§2.2.8.2)

No specific test procedure is required to validate §2.2.8.2.

2.4.8.2.1 Verification of Receiver Sensitivity (§2.2.8.2.1)

No specific test procedure is required to validate §2.2.8.2.1.

2.4.8.2.1.1 Verification of Long ADS-B Message As Desired Signal (§2.2.8.2.1.1)

Purpose/Introduction:

A desired signal level of –93 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offsets, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

Note: *The receiver criteria for Successful Message Reception of UAT ADS-B Messages are provided in §2.2.8.3.1.*

This test verifies the compliance of the UAT receiver with the sensitivity requirements when the desired signal is a Long ADS-B Message, under conditions of maximum frequency offset, Doppler shift, and modulation distortion.

Equipment Required:

Desired Message Signal:

Provide a method of supplying the UUT with ADS-B Messages having:

- RF Power Level: -93 dBm
- Center Frequency: 978 MHz ±2.0 kHz ±19.560 kHz (see Note below)
- FM Deviation: 560 kHz (measured at the minimum eye pattern opening per §2.2.2.4)
- Message Contents: Long ADS-B Message with pseudo-random payload data, and valid FEC Parity field per §2.2.3.1.3.
- Message Rate: 100 per second

Note: *Maximum Doppler shift at 1200 knot closing rate is derived as follows: Velocity (m/s) = 1200 NM/hr * 1853 m/NM / 3600 sec/hr = 617 m/sec. Doppler shift = 617 m/sec / 3e+08 m/sec = 2.06 PPM. Frequency deviation due to Doppler shift is 978 MHz * 2.06 PPM = ±2.01 kHz.*

Measurement Procedures:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply ADS-B Input Messages at maximum negative frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the minimum value (978 MHz – 2.0 kHz – 19.56 kHz) at the UUT receiver port.

Step 2: Measure the UUT receiver sensitivity

Decrease the input power level and determine the minimum RF signal required to produce an average reception rate of 90 percent by the UUT receiver. Verify that this RF signal level is in compliance with the limits specified in §2.2.8.2.1.1.

Step 3: Apply ADS-B Input Messages at maximum positive frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the minimum value (978 MHz + 2.0 kHz + 19.56 kHz) at the UUT receiver port.

Step 4: Repeat UUT receiver sensitivity measurement

Repeat Step 2 to measure the UUT receiver sensitivity at the maximum positive frequency offset.

Step 5: Repeat for all Applicable Receiver Input Ports

Repeat Steps 1 through 4 for each applicable receiver RF input port of the UUT.

2.4.8.2.1.2 Verification of Basic ADS-B Message As Desired Signal (§2.2.8.2.1.2)

Purpose/Introduction:

A desired signal level of –94 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offset, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to air-to-air Doppler shift at 1200 knots closure/opening.

Note: *The receiver criteria for Successful Message Reception of UAT ADS-B Messages are provided in §2.2.8.3.1.*

Equipment Required:

Desired Message Signal:

Provide a method of supplying the UUT with ADS-B Messages having:

- RF Power Level: -94 dBm
- Center Frequency: 978 MHz ±2.0 kHz ±19.560 kHz (see Note below)
- FM Deviation: 560 kHz (measured at the minimum eye pattern opening per §2.2.2.4)
- Message Contents: Basic ADS-B Message with pseudo-random payload data, and valid FEC Parity field per §2.2.3.1.3.
- Message Rate: 100 per second

Note: *Maximum Doppler shift at 1200 knot closing rate is derived as follows: Velocity (m/s) = 1200 NM/hr * 1853 m/NM / 3600 sec/hr = 617 m/sec. Doppler shift = 617 m/sec / 3e+08 m/sec = 2.06 PPM. Frequency deviation due to Doppler shift is 978 MHz * 2.06 PPM = ±2.01 kHz.*

Measurement Procedures:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply ADS-B Input Messages at maximum negative frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the minimum value (978 MHz – 2.0 kHz – 19.56 kHz) at the UUT receiver port.

Step 2: Measure the UUT receiver sensitivity

Decrease the input power level and determine the minimum RF signal required to produce an average reception rate of 90 percent by the UUT receiver. Verify that this RF signal level is in compliance with the limits specified in §2.2.8.2.1.1.

Step 3: Apply ADS-B Input Messages at maximum positive frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the minimum value (978 MHz + 2.0 kHz + 19.56 kHz) at the UUT receiver port.

Step 4: Repeat UUT receiver sensitivity measurement

Repeat Step 2 to measure the UUT receiver sensitivity at the maximum positive frequency offset.

Step 5: Repeat for all Applicable Receiver Input Ports

Repeat Steps 1 through 4 for each applicable receiver RF input port of the UUT.

2.4.8.2.1.3 Verification of Ground Uplink Message As Desired Signal (§2.2.8.2.1.3)

Purpose/Introduction:

A desired signal level of –91 dBm applied at the antenna end of the feedline **shall** produce a rate of Successful Message Reception of 90% or better under the following conditions:

a. When the desired signal is of nominal modulation (i.e., FM deviation is 625 KHz) and at the maximum signal frequency offsets, and subject to ground-to-air Doppler shift at 850 knots closure/opening.

   Note: *The 850 knot ground station closure rate is derived from a 600 knot true air speed, added to a 250 knot worst-case wind velocity. The 1200 knot air-to-air closure remains valid because both aircraft are assumed to be within the same air mass, so the wind velocity makes no difference to the closure rate.*

b. When the desired signal is of maximum modulation distortion allowed in §2.2.2.4, at the nominal transmission frequency ±1 PPM, and subject to ground-to-air Doppler shift at 850 knots closure/opening.

Note: *This requirement assumes that the baud rate accuracy of the ground transmitter is 2 PPM.*

This test verifies the compliance of the UAT receiver with the sensitivity requirements when the desired signal is a Ground Uplink Message, under conditions of maximum frequency offset, Doppler shift, and modulation distortion.

Equipment Required:

Desired Message Signal:

Provide a method of supplying the UUT with ADS-B Messages having:

- RF Power Level: -91 dBm
- Center Frequency: 978 MHz ±1.0 kHz (see Note below)
- FM Deviation: 560 kHz (measured at the minimum eye pattern opening per §2.2.2.4)
- Message Contents: Ground Uplink Message with pseudo-random payload data, with valid FEC Parity field and Interleaving per §2.2.3.2.
- Message Rate: 10 per second in the Uplink segment only.

Note: *Maximum Doppler shift at 850 knot ground speed is derived as follows: Velocity (m/s) = 850 NM/hr * 1853 m/NM / 3600 sec/hr = 438 m/sec. Doppler shift = 438 m/sec / 3e+08 m/sec = 1.46 PPM. Frequency deviation due to Doppler shift is 978 MHz * 1.46 PPM = ±1.5 kHz.*

Measurement Procedures:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply Ground Uplink Input Messages at maximum negative frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the minimum value (978 MHz – 1.5 kHz) at the UUT receiver port.

Step 2: Measure the UUT receiver sensitivity

Decrease the input power level and determine the minimum RF signal required to produce a reception rate of 90 percent by the UUT receiver, averaged over a minimum of 100 received messages. Verify that this RF signal level is in compliance with the limits specified in §2.2.8.2.1.3.

Step 3: Apply Ground Uplink Input Messages at maximum positive frequency offset

Apply the **Desired Message Signal** with the Center Frequency set to the maximum value (978 MHz + 1.5 kHz) at the UUT receiver port.

Step 4: Repeat UUT receiver sensitivity measurement

Repeat Step 2 to measure the UUT receiver sensitivity at the maximum positive frequency offset.

Step 5: Repeat for all Applicable Receiver Input Ports

Repeat Steps 1 through 4 for each applicable receiver RF input port of the UUT.

2.4.8.2.2 Verification of Receiver Desired Signal Dynamic Range (§2.2.8.2.2)

Purpose/Introduction:

The receiver **shall** achieve a Successful Message Reception rate for Long ADS-B Messages of 99% or better when the desired signal level is between –90 dBm and –10 dBm at the antenna in the absence of any interfering signals.

Notes:

1. *The value of –10 dBm represents 120-foot separation from an A3 transmitter at maximum allowed power.*

2. *Certain installations that rely on over-air reception of the ownship transmission to meet the requirements of* §2.2.6.3 *may need to achieve Successful Message Reception at significantly higher levels than –10 dBm.*

This test verifies the compliance of the UAT receiver with the dynamic range requirements. The desired signal is the Long ADS-B Message.

Equipment Required:

Desired Message Signal:

Provide a method of supplying the UUT with ADS-B Messages having:

- RF Power Level: -90 dBm
- Frequency: 978.0 MHz
- FM Deviation: 625 kHz (measured at the minimum eye pattern opening per §2.2.2.4)
- Message Contents: Long ADS-B Message with pseudo-random payload data, and valid FEC Parity field per §2.2.3.1.3.
- Message Rate: 100 per second (recommended minimum)

Measurement Procedures:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply ADS-B Input Messages

Apply the **Desired Message Signal** at the UUT receiver input port.

Step 2: Measure the UUT receiver sensitivity

Decrease the input power level and determine the minimum RF signal required to produce an average reception rate of 99 percent by the UUT receiver. At least 1000 message receptions should be measured in making this determination. Verify that this RF signal level is in compliance with the limits specified in §2.2.8.2.2.

Step 3: Verify the UUT receiver dynamic range

Starting from the signal level measured in Step 2, increase the input signal by 10 dB steps, up to a level of –10 dBm. At each step, verify that the receiver properly detects and decodes at least 99% of the Desired Messages received per §2.2.8.2.2.

Step 4: Repeat for all Applicable Receiver Input Ports

Repeat Steps 1 through 4 for each applicable receiver RF input port of the UUT.

2.4.8.2.3 Verification of Receiver Selectivity (§2.2.8.2.3)

Purpose/Introduction:

These test procedures verify that the receiver **shall** provide the following minimum signal rejection ratios as a function of frequency offset as listed in Table 2-65 for reception of Long ADS-B Messages at a 90% Successful Message Reception rate, applied at a level of –90 dBm. The interference source is an un-modified carrier applied at the frequency offset.

Equipment Required:

The tests performed in this subparagraph require the following equipment:

a. Vector Signal Analyzer (VSA), or an equivalent Signal Analyzer, with minimum capabilities of displaying the envelope of a captured ADS-B Long message, displaying the associated spectrum, band power markers, and the corresponding computed band power. Examples: Agilent HP89441A, or the Agilent HP89600 series.

b. Signal Generator (SG), with minimum capabilities of up to 1 GHz carrier, power levels up to 0 dBm, continuous wave (CW) and digital two-state FSK modulation at a rate greater than 1 megabits/second, selectable root raised cosine and rectangular filtering, internal and external triggering, programmable power levels and bit states. Example: Rohde & Schwarz (Tektronix) SMIQ-02B.

c. Four Terminal Hybrid Junction with a frequency range covering 1 GHz.

For this subparagraph, configure the Vector Signal Analyzer equipment for Vector Mode according to Table 2-99.

Note: *Equipment parameter labels, menus, setup options, and units may vary from one manufacturer to another, and parameter labels are usually abbreviated. In Table 2-99 and Table 2-100, text enclosed in brackets is not displayed on the HP89441A display. The bracketed text is added to clarify the functional terms and setting values for those using neither the HP89441A, nor the SMIQ-02B.*

Table 2-99: Vector Mode Configuration

VECTOR SIGNAL ANALYZER PARAMETER SETTINGS	
Parameter Item/Function	**Parameter Setting Value**
Preset	(press to Preset Equipment)
Instrument Mode	Vector
Frequency / center frequency	978 MHz
Frequency / frequency span	preferably 5 MHz
ResBW/Window / main length	450 us
ResBW/Window / main window	Hanning
ResBW/Window / num[ber of] freq[uency] p[oin]ts	3201
Range / ch[annel] 1 [signal] range	–35 dBm
Time / gate	off
Time / gate length	400 us
Time / ch[annel]1 gate d[e]l[a]y	25 us
Average / average	on
Average / num[ber of] averages	50
Average / average type	rms expo[nential]
Trigger / trigger type	IF ch[annel]1
Trigger / ext[ernal] level	0.0005 V[olts]
Trigger / ch1 delay	-17.5 us
Display	2 grids
Trace A – Measurement Data	main time
Trace A – Data Format	magnitude linear
Trace A – RefLvl/Scale / Y ref level	0 uVpk
Trace A – RefLvl/Scale / Y per div[ision]	700 uVpk
Trace A – RefLvl/Scale / ref[erence] position	0 %
Trace B – Measurement Data	spectrum
Trace B – Data Format	magnitude log(dB)
Trace B – RefLvl/Scale / Y ref level	-70 dBm
Trace B – RefLvl/Scale / Y per div[ision]	7.5 dB
Trace B – RefLvl/Scale / ref[erence] position	100 %
Trace B – Marker Function / band power markers / band pwr mkr	on
Trace B – Marker Function / band power markers / band center	978 MHz
Trace B – Marker Function / band power markers / band width	2.5 MHz
Trace B – Marker Function / band power markers / [computation]	band power

For this subparagraph, configure the Signal Generator equipment according to Table 2-100.

Table 2-100: Signal Generator Configuration

SIGNAL GENERATOR PARAMETER SETTINGS	
Parameter Item/Function	**Parameter Setting Value**
Preset	(press to Preset Equipment)
RF ON/OFF	RF OFF
FREQUENCY	979 MHz
LEVEL	-35 dBm
DIGITAL MOD[ULATION] / STATE	OFF

Measurement Procedures:

Step 1: Equipment Setup (§2.2.8.2.3)

For the tests in this subparagraph, configure the Vector Signal Analyzer according to the Vector Mode setup listed in Table 2-99. See Appendix N for the state file "UAT-VECT.STA" to automatically setup the HP89441A Vector Signal Analyzer. As the very last configuration step, set Time / gate to "on."

Configure the Signal Generator equipment according to the setup listed in Table 2-100.

Step 2: Receiver Selectivity Pre-Test Setup (§2.2.8.2.3)

Using a Four Terminal Hybrid Junction, connect the Signal Generator, and an attenuated ADS-B Transmitter, to the ADS-B Receiving Equipment, and to the Vector Signal Analyzer. At the output of the ADS-B Transmitter, adjust the attenuation to present a signal of –50 ± 0.5 dBm to the ADS-B Receiving Equipment, and initiate a series of Long ADS-B test messages, each having the following message elements: the 36 bit SYNCH, followed by a 272 bit Payload having a pseudo-random series of bits which changes for each successive message, and a 112 bit FEC as generated by the Reed-Solomon algorithm. Trace A should show: 1) a stable triggered message envelope, 2) that the leftmost vertical gating line occurs just after the rise of the envelope, and 3) that the rightmost gating line occurs just before the fall of the envelope (reduce "Time/gate length" by 5 microseconds, if necessary, to satisfy this setup).

Step 3: Receiver Selectivity Pre-Test Setup (§2.2.8.2.3)

The Vector Signal Analyzer Trace A display should resemble the upper trace of Figure 2-14, and the Vector Signal Analyzer Trace B display should resemble the lower trace of Figure 2-14. Verify that the ADS-B Receiving Equipment is reporting all received test messages.

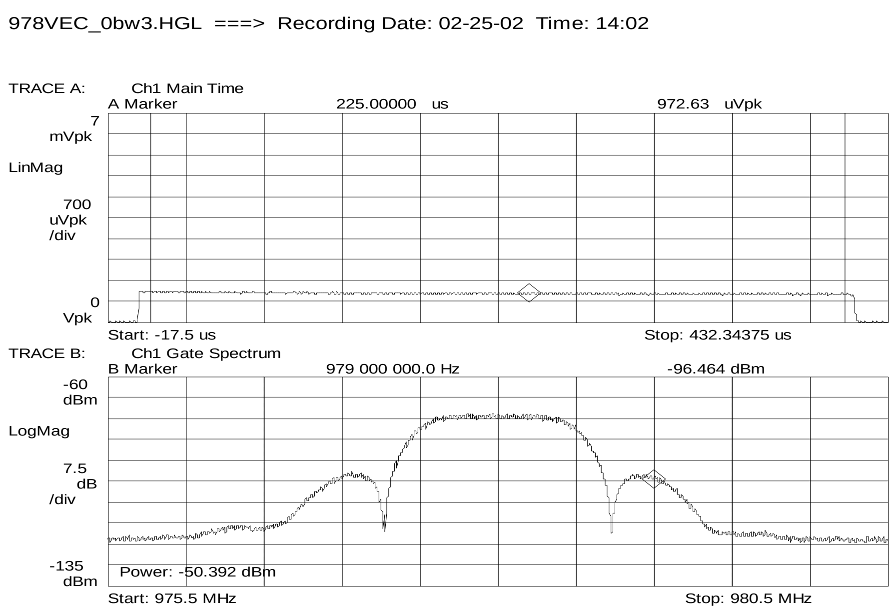
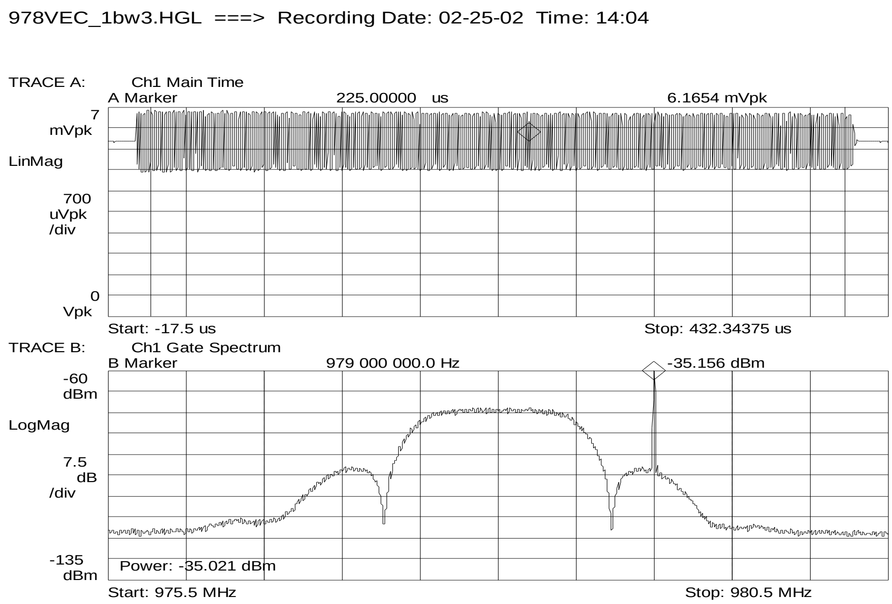


Figure 2-14: ADS-B Long Message Envelope & Spectrum – No Interference

Step 4: Receiver Selectivity Pre-Test Setup (§2.2.8.2.3)

Ensure that the Signal Generator is programmed for Continuous Wave at a frequency of 979 MHz, and ensure that the Vector Signal Analyzer Range / ch[annel] 1 [signal] range is –35 dBm. Turn the Signal Generator RF ON/OFF to "ON," place the Trace B marker at 979 MHz, temporarily turn the Vector

Signal Analyzer Average / average to “off,” and adjust the received Signal Generator signal level P_{CW} (“Power” displayed at lower-left of Trace B) to be –35 ± 0.5 dBm. The Vector Signal Analyzer Trace A display should resemble the upper trace of Figure 2-15, and the Vector Signal Analyzer Trace B display should resemble the lower trace of Figure 2-15. Verify that the ADS-B Receiving Equipment is reporting all received test messages.



<u>Figure 2-15:</u> ADS-B Long Message Envelope & Spectrum – With CW

<u>Step 5:</u> <u>Receiver Selectivity Test (§2.2.8.2.3)</u>

Reduce the Signal Generator output by 43 dB, and reduce the ADS-B Transmitter output by 43 dB so that the UAT test message power level at the ADS-B Receiver input is P_{RCVR} = –93 dBm. Using Table 2-101, for each class of equipment, and for each frequency offset (above and below center frequency), adjust the Signal Generator Continuous Wave level at the ADS-B Receiver input to the level shown (adjusting the Vector Signal Analyzer Trace B - Marker Function / band center frequency as needed), and adjust the Vector Signal Analyzer Range per column 4 of the Table (or as needed to avoid distorted results). In each case, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 90% Message Success Rate.

Table 2-101: Selectivity Rejection Ratios

Center Frequency Offset, f_0	Continuous Wave Interference Level (dBm)		Vector Signal Analyzer Range
	Equipment Class A0, A1L, A1S, A1H, A2	Equipment Class A3	
-1.0 MHz	-83	-63	-50 dBm
+1.0 MHz	-78	-53	-45 dBm
±2.0 MHz	-43	-43	-35 dBm
±10.0 MHz	-33	-33	-25 dBm

2.4.8.2.4 Verification of Receiver Tolerance to Pulsed Interference (§2.2.8.2.4)

Purpose/Introduction:

The receiver **shall** be capable of receiving messages in the presence of interference from on channel and off channel sources of pulsed interference, such as DME/TACAN and JTIDS/MIDS. Informative Appendix G indicates, in Table G-2, the levels and pulse density of interference scenarios, against which UAT has been designed to operate effectively, as reported in Appendix K. The UAT receiver must also be tolerant of pulsed interference from other L-Band systems operating and located on the aircraft. These may include 1030 MHz ATCRBS/Mode S interrogation signals from on-board TCAS and 1090 MHz ATCRBS/Mode S reply signals from on-board ATCRBS/Mode S Transponders.

The UAT receiver may experience pulsed interference from DME/TACAN channels operating in the internationally allocated 978 MHz to 1215 MHz frequency range. The receiver **shall** be tolerant to pulsed interference from DME/TACAN. The receiver **shall** meet the reception probability dictated under the following conditions:

a. For all equipment classes:

   The receiver **shall** be capable of achieving 99% reception probability of ADS-B Messages when the desired signal level is between –90 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at either 12 or 30 microseconds pulse spacing at a level of –36 dBm for any 1 MHz channel frequency between 980 MHz and 1215 MHz inclusive.

b. For the A0, A1L, A1S, A1H, and A2 equipment classes:

   1. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –56 dBm and a frequency of 979 MHz.

   2. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a

12 microseconds pulse spacing at a level of –70 dBm and a frequency of 978 MHz.

c. For the A3 equipment class:

1. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –43 dBm and a frequency of 979 MHz.

2. The receiver **shall** be capable of achieving 90% reception probability of ADS-B Messages when the desired signal level is between –87 dBm and –10 dBm when subjected to DME/TACAN interference under the following conditions: DME/TACAN pulse pairs at a nominal rate of 3600 pulse pairs per second at a 12 microseconds pulse spacing at a level of –79 dBm and a frequency of 978 MHz.

d. For all equipment classes, following a 21 microsecond pulse at a level of 0 dBm and at a frequency of 1090 MHz, the receiver **shall** return to within 3 dB of normal sensitivity level within 12 microseconds.

Equipment Required:

The tests performed in this subparagraph require Vector Signal Analyzer and Signal Generator equipment as described in §2.4.8.2.3, and a Four Terminal Hybrid Junction.

Also required is a DME/TACAN source, which is capable of producing 3600 pulse pairs per second, with pulse pair spacings of 12 and 30 microseconds, at a power level of up to –30 dBm, and with “Ident Tone.” Example: IFR ATC-1400A Transponder/DME Test Set.

Measurement Procedures:

Step 1: Pulsed Interference Tolerance Pre-Test Setup (§2.2.8.2.4)

For the tests in this subparagraph, configure the Vector Signal Analyzer according to the Vector Mode setup listed in Table 2-99. See Appendix N for the state file “UAT-VECT.STA” to automatically setup the HP89441A Vector Signal Analyzer. As the very last configuration step, set Time / gate to “on.”

Configure the DME/TACAN source to output 3600 DME pulse pairs per second, spaced at 12 microseconds apart, at a frequency of 980 MHz, with the output level set to –56 dBm, with Ident Tone ON, and with output power initially “OFF.”

Step 2: Pulsed Interference Tolerance Pre-Test Setup (§2.2.8.2.4)

Using a Four Terminal Hybrid Junction, connect the attenuated DME/TACAN, and an attenuated ADS-B Transmitter, to the ADS-B Receiving Equipment, and to the Vector Signal Analyzer. At the output of the ADS-B Transmitter, adjust the attenuation to present a signal of –50 ± 0.5 dBm to the ADS-B Receiver input, and initiate a series of Long ADS-B test messages, each having the following message elements: the 36 bit SYNCH, followed by a 272 bit Payload having a pseudo-random series of bits which changes for each successive message, and a 112 bit FEC as generated by the Reed-Solomon algorithm. Trace A should show: 1) a stable triggered message envelope, 2) that the leftmost vertical gating line occurs just after the rise of the envelope, and 3) that the rightmost gating line occurs just before the fall of the envelope.

Step 3: Pulsed Interference Tolerance Pre-Test Setup (§2.2.8.2.4)

The Vector Signal Analyzer Trace A display should resemble the upper trace of Figure 2-14. The Vector Signal Analyzer Trace B display should resemble the lower trace of Figure 2-14. Verify that the ADS-B Receiving Equipment is reporting all received test messages.

Step 4: Pulsed Interference Tolerance Pre-Test Setup (§2.2.8.2.4)

Turn the DME/TACAN source "ON," and adjust the Vector Signal Analyzer Time / gate length and Time / ch[annel]1 gate d[e]l[a]y to bracket one of the DME pulses, and adjust the received DME/TACAN source signal level P_{DME} ("Power" displayed at lower-left of Trace B) to be –56 ± 0.5 dBm. Adjust the Vector Signal Analyzer Trigger / IF level to about 900 uV to present a stable display of the ADS-B test message. The Vector Signal Analyzer Trace A display should resemble the upper trace of Figure 2-16, and the Vector Signal Analyzer Trace B display should resemble the lower trace of Figure 2-16. Verify that the ADS-B Receiving Equipment is reporting all received test messages.

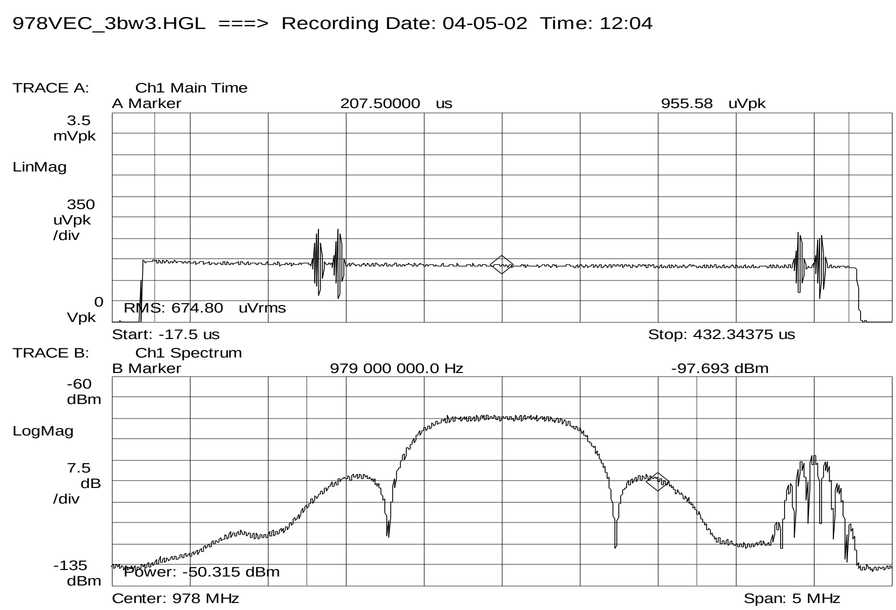


Figure 2-16: ADS-B Long Message Envelope & Spectrum – With DME/TACAN

Step 5: Off Channel Pulsed Interference Tolerance Test (12 microsecond pulse spacing) – Greater than 1 MHz Offset (§2.2.8.2.4.a)

Increase the Vector Signal Analyzer Range / ch[annel]1 range to –35 dBm, increase the attenuated DME output by 17 dB so that the DME level at the

ADS-B Receiver input is P_{RCVR} = –39 ±0.5 dBm, and reduce the ADS-B Transmitter output by 43 dB so that the level at the ADS-B Receiver input is P_{RCVR} = –93 ± 0.5 dBm. For each equipment class, and for each frequency from 980 MHz to 985 MHz in 1 MHz steps, and from 990 MHz to, and including 1215 MHz in 50 MHz steps, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 99% Message Success Rate.

Step 6: Off Channel Pulsed Interference Tolerance Test (30 microsecond pulse spacing) – Greater than 1 MHz Offset (§2.2.8.2.4.a)

Reconfigure the DME source to produce pulse pairs spaced at 30 microseconds apart. For each equipment class, and for each frequency from 980 MHz to 985 MHz in 1 MHz steps, and from 990 MHz to, and including 1215 MHz in 50 MHz steps, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 99% Message Success Rate.

Reconfigure the DME source to produce pulse pairs spaced at 12 microseconds apart. For A0, A1L, A1H, and A2 equipment classes only: Execute steps 7a and 7b. For A3 equipment class only: Execute steps 8a and 8b.

Step 7a: Off Channel Pulsed Interference Tolerance Test – 1 MHz Offset (§2.2.8.2.4.b.1)

For A0, A1L, A1H, and A2 equipment classes only:

Decrease the attenuated DME output by 26 dB so that the DME level at the ADS-B Receiver input is P_{RCVR} = –59 ± 0.5 dBm, change the DME frequency to 979 MHz, decrease the Vector Signal Analyzer Range / ch[annel]1 range to –50 dBm, and increase the ADS-B Transmitter output by 3 dB so that the level at the ADS-B Receiver input is P_{RCVR} = –90 ± 0.5 dBm.

For each of the A0, A1L, A1H, and A2 equipment classes, make adjustments to the ADS-B Transmitter output so that the levels at the ADS-B Receiver input are P_{RCVR} = within ± 0.5 dBm of –90 dBm to -88 dBm in 1 dB steps, and –83 dBm to –13 dBm in 10 dB steps, and in each case, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 90% Message Success Rate.

Step 7b: On Channel Pulsed Interference Tolerance Test (§2.2.8.2.4.b.2)

For A0, A1L, A1S, A1H, and A2 equipment classes only:

Decrease the attenuated DME output by an additional 14 dB so that the DME level at the ADS-B Receiver input is P_{RCVR} = –73 ± 0.5 dBm, change the DME frequency to 978 MHz, and decrease the Vector Signal Analyzer Range / ch[annel]1 range to –50 dBm.

For each of the A0, A1L, A1S, A1H, and A2 equipment classes, make adjustments to the ADS-B Transmitter output so that the levels at the ADS-B Receiver input are P_{RCVR} = within ± 0.5 dBm of –89 dBm to -88 dBm in 1 dB steps, and –83 dBm to –13 dBm in 10 dB steps, and in each case, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 90% Message Success Rate.

Step 8a: Off Channel Pulsed Interference Tolerance Test – 1 MHz Offset (§2.2.8.2.4.c.1)

For A3 equipment class only:

Decrease the attenuated DME output by 16 dB so that the DME level at the ADS-B Receiver input is P_{RCVR} = –46 ± 0.5 dBm, change the DME frequency to 979 MHz, decrease the Vector Signal Analyzer Range / ch[annel]1 range to –45 dBm, and increase the ADS-B Transmitter output by 3 dB so that the level at the ADS-B Receiver input is P_{RCVR} = –90 ± 0.5 dBm.

For the A3 equipment class, make adjustments to the ADS-B Transmitter output so that the levels at the ADS-B Receiver input are P_{RCVR} = within ± 0.5 dBm of –90 dBm to –88 dBm in 1 dB steps, and –83 dBm to –13 dBm in 10 dB steps, and in each case, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 90% Message Success Rate.

Step 8b: On Channel Pulsed Interference Tolerance Test (§2.2.8.2.4.c.2)

For A3 equipment class only:

Decrease the attenuated DME output by an additional 36 dB so that the DME level at the ADS-B Receiver input is P_{RCVR} = –82 ± 0.5 dBm, and change the DME frequency to 978 MHz, and decrease the Vector Signal Analyzer Range / ch[annel]1 range to –50 dBm.

For the A3 equipment class, make adjustments to the ADS-B Transmitter output so that the levels at the ADS-B Receiver input are P_{RCVR} = within ± 0.5 dBm of –90 dBm to –88 dBm in 1 dB steps, and –83 dBm to –13 dBm in 10 dB steps, and in each case, count a total of at least 2500 test messages, count the number of good messages, and verify that the ADS-B Receiver is reporting good received test messages at a minimum of 90% Message Success Rate.

Step 9: 21 Microsecond Pulsed Interference Tolerance Test (§2.2.8.2.4.d)

Remove the DME source from the Four Terminal Hybrid Junction, and replace it with the Signal Generator. With "RF ON/OFF" set to "RF OFF," configure the Signal Generator to output a –3 dBm, 21 microsecond, 1090 MHz RF pulse, the beginning of which is positioned 33 microseconds prior to the first SYNCH bit of each Long ADS-B test message. Adjust the ADS-B Transmitting Equipment output attenuation to present a signal of –93 ± 0.5 dBm at the ADS-B Receiver input.

Change the Signal Generator "RF ON/OFF" to "RF ON," and verify that the ADS-B Receiver reports good received test messages at a minimum of 90% Message Success Rate.

2.4.8.2.5 Verification of Receiver Tolerance to Overlapping ADS-B Messages (Self Interference) (§2.2.8.2.5)

Purpose/Introduction:

A Successful Message Reception rate of 90% or better, for the stronger of two overlapping desired messages, **shall** result when the level of the stronger message is no weaker than -80 dBm and the stronger message is at least ***X*** dB above the weaker message, when the stronger message and weaker message are aligned in time.

Where the value of ***X*** is:

4 dB for Equipment Classes A0, A1L, A1S, A1H, and A2

9 dB for Equipment Class A3

Notes:

1. *The different values across equipment classes reflect the fact that Class A3 receivers will utilize a narrow filter that degrades demodulation performance slightly in order to gain added rejection from adjacent channel DME ground stations.*

2. *Signal values ensure both the desired and undesired signal levels are above the noise floor.*

This test verifies the compliance of the UAT receiver with the requirements for reception of overlapping Long ADS-B Messages.

Equipment Required:

Desired Message Signals:

Provide a method of supplying the UUT with two sources of desired Long ADS-B Messages that are aligned in time to within 5 microseconds, with the following characteristics:

Message Source 1

- RF Power Level: -80 dBm

Message Contents:
- Payload Type Code = 1
- Address Qualifier = 0
- ICAO address: 0x000001
- Fill remaining payload with pseudo-random payload data, and valid FEC Parity field per §2.2.3.1.3.
- Message Rate: 100 per second

Message Source 2

- RF Power Level: -68 dBm

Message Contents:
- Payload Type Code = 1
- Address Qualifier = 0
- ICAO address: 0x000002

- Fill remaining payload with pseudo-random payload data, and valid FEC Parity field per §2.2.3.1.3.
- Message Rate: 100 per second

Measurement Procedures:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply ADS-B Input Messages

Apply the **Desired Message Signals** at the UUT receiver input port. Observe that the UUT equipment reports reception of messages with ICAO address 0x000002 at the rate specified in §2.2.8.2.5.

Step 2: Measure the Receiver Tolerance to Overlapping Messages

Reduce the input signal level for Message Source 2 and determine the minimum level required to produce a 90% message reception rate of messages with ICAO Address 0x000002 by the UUT receiver. Verify that the measured performance is in compliance with the limits specified in §2.2.8.2.5 for the appropriate category of receiver equipment.

Set the signal level for Message Source 2 to –80 dBm.

Increase the input signal level for Message Source 1 and determine the minimum level required to produce a 90% message reception rate of messages with ICAO Address 0x000001 by the UUT receiver. Verify that the measured performance is in compliance with the limits specified in §2.2.8.2.5 for the appropriate category of receiver equipment.

Notes:

1. *This procedure demonstrates that the UUT can receive messages from both Message Sources, and that the control variable in this procedure is the input signal level.*

2. *Performing this procedure on all applicable receiver ports is not necessary, once the procedure of* §2.4.8.2.1 *(Receiver Sensitivity) has been executed and validated.*

2.4.8.2.6 Verification of Rate of False "Trigger" (§2.2.8.2.6)

Purpose/Introduction:

a. With no signal input, the ADS-B Receiver **shall** experience no more than 50 ADS-B Message triggers per second.

b. With no signal input, the ADS-B Receiver **shall** experience no more than 2 Ground Uplink Message triggers per minute.

Note: *Detection of either the ADS-B or Ground Uplink synchronization sequence is referred to as a "trigger."*

Measurement Procedure:

This test procedure requires monitoring the trigger signal from the receiver. This is an output that occurs upon detection of the synchronization sequence of an input message. Separate outputs are required for the synchronization trigger resulting from an ADS-B Basic or Long Message synchronization sequences and Ground Uplink Message synchronization sequences.

Step 1: ADS-B Message Trigger Rate Verification

Disconnect all connections to the receiver antenna port of the ADS-B Receiving System. If diversity receiving is implemented, disconnect all inputs to both antenna ports. For an interval of 5 minutes, count the number of ADS-B Message Triggers. Verify that the rate is 50 per second or less.

Step 2: Ground Uplink Message Trigger Rate Verification

Disconnect all connections to the receiver antenna port of the ADS-B Receiving System. If diversity receiving is implemented, disconnect all inputs to both antenna ports. For an interval of 10 minutes, count the number of Ground Uplink Message Triggers. Verify that the rate is 2 per minute or less.

2.4.8.2.7 Verification of Trigger Processing Rate (§2.2.8.2.7)

Purpose/Introduction:

Receiver trigger processing rate requirements are as follows:

a. Equipment Classes A3, A2 and A1H receivers **shall** be capable of successfully processing at least 1000 trigger events per second.

b. Equipment Classes A1S, A1L and A0 receivers **shall** be capable of successfully processing at least 900 trigger events per second.

Desired Message Signals:

Provide a method of supplying the UUT with two sources of desired Long ADS-B Messages. Each signal source generates messages according to a periodic schedule based on a 28 MSO period for Equipment Classes A3, A2 and A1H and a 24 MSO period for Equipment Classes A1S, A1L and A0. For each Equipment Class the period must be repeated exactly 101 times each second. The contents of the messages are as follows:

Message Contents for All Message Sources:

- Payload Type Code = 1
- Address Qualifier = 0
- ICAO Address = see below
- Payload is filled with pseudorandom data. The pseudorandom generator should have a long enough period so that no data is repeated during the course of this test.

Note: *It is acceptable to employ a limited set of "canned" messages based on pseudorandom number generator. The number of stored messages should be somewhat larger than the number of messages required for a second's worth of testing. If the number of each type of stored message is prime with respect to the number of messages needed each second, the overlap between two sources will be randomized on a second-by second basis.*

- Valid FEC Parity is provided.

Transmission Schedule and Power Level for Each Message Source:

For Equipment Classes A3, A2 and A1H

Table 2-102: Tx Schedule and Power Level for A3, A2 and A1H Message Sources

Message Source	Transmission Schedule (MSO within each 28 MSO period)	ICAO Address	Power Level (dBm)
1	0, 4, 8, 12, 16, 20, 24	0x000001	- 80
2	5, 13, 21	0x000002	- 65

For Equipment Classes A1S, A1L and A0

Table 2-103: Tx Schedule and Power Level for A1S, A1L and A0 Message Sources

Message Source	Transmission Schedule (MSO within each 28 MSO period)	ICAO Address	Power Level (dBm)
1	0, 4, 8, 12, 16, 20	0x000001	- 80
2	5, 13, 21	0x000002	- 65

Measurement Procedure:

In each case the beginning of the first transmission period is MSO = 752. (This causes all the ADS-B Messages to fall within the ADS-B segment of each second.)

For Equipment Classes A3, A2 and A1H verify that the UUT reports reception of at least 400 messages with ICAO address 0x000001 and at least 300 messages with ICAO address 0x000002 per second.

For Equipment Classes A1S, A1L and A0 verify that the UUT reports reception of at least 300 messages with ICAO address 0x000001 and at least 300 messages with ICAO address 0x000002 per second.

2.4.8.3 Verification of Receiver Message Processing (§2.2.8.3)

No specific test procedure is required to validate §2.2.8.3.

2.4.8.3.1 Verification of Criteria for Successful Message Reception (§2.2.8.3.1)

No specific test procedure is required to validate §2.2.8.3.1.

2.4.8.3.1.1 Verification of ADS-B Messages (§2.2.8.3.1.1)

Purpose/Introduction:

Upon detection of the ADS-B synchronization sequence, the receiver **shall** decode the ADS-B Message according to the procedure specified below:

a. The receiver **shall** attempt to decode the message in the Long format using hard decision decoding with no erasures allowed. The decoder **shall** correct no more than 7 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, then a Successful Message Reception **shall** be declared.

b. Otherwise, the receiver **shall** attempt to decode the message in the Basic format using hard decision decoding with no erasures allowed. The decoder **shall** correct no more than 6 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, AND the first 5 bits of the payload (the "PAYLOAD TYPE CODE" field) are ALL ZEROS, AND the Long decoding process fails, then a Successful Message Reception **shall** be declared.

c. Otherwise, no message reception **shall** be declared.

Notes:

1. *This procedure discriminates the Basic versus Long message format by using the characteristics of the RS code without an explicit length indicator.*

2. *To avoid misinterpreting the contents of Long Message reception declared to be successful, the receiver should discard any Message that has a "PAYLOAD TYPE CODE" field equal to ZERO. See Appendix M for the probability of such an event occurring (the probability is less than 10^{-9}).*

3. *Appendix M provides the analytic determination of the Undetected Message Error Rate (UMER) achieved through use of the RS coding. Due to the straightforward calculation of the UMER and the fact that the UMER is quite low, no explicit requirement/test is needed for a "False Message Reception Rate" test.*

The following test procedures will verify that the ADS-B UAT receiver system correctly declares the Successful Receipt of ADS-B Messages as defined in §2.2.8.3.1.1. The ADS-B UAT receiver system declares the Successful Message Reception when there are NO uncorrected errors indicated by the RS decoding process.

The Corrupted Messages (Erroneous Messages) provided in the Tables are designed as follows:

a. Table 2-104 has burst errors of three different sizes (50/42/12 consecutive erroneous bits) that are NOT perfectly lined up with the byte boundary of ADS-B Message symbols.

The errors in each message are at different BIT POSITIONS and the number of erroneous symbols induced into the ADS-B Messages largely depends on where the error burst resides in the ADS-B Message sequence.

b. Table 2-105 has random burst errors that are perfectly lined up with the byte boundary of the ADS-B Message symbols. The errors in each message are at different symbol positions and the number of erroneous symbols induced into the ADS-B Messages can be from 1 to 10 bytes.

Equipment Required:

Provide a method to supply controlled ADS-B Messages to the appropriate ADS-B UAT Receiver input.

Measurement Procedures:

Step 1: Establish the Initial Conditions

Configure the ADS-B UAT Receiver system to receive both Basic and Long ADS-B Messages and verify that the interface is providing the test data to the Receiver system.

Step 2: Verify Successful Message Reception of ADS-B Message (§2.2.8.3.1.1)

a. Load the set of test messages given in Table 2-104 and Table 2-105 into the Receiver input.

Notes:

1. This test procedure is designed based on the assumption that the RS decoder has the ability to sort (with very high probability) which of two possible types was actually sent.

2. The size of the provided stimulus given in column 2 of Table 2-104 and Table 2-105 is the same as the size of the long ADS-B Message. The decoder will first attempt to decode the incoming data sequence as a Long Message and if it fails, it will attempt to decode it as a Basic Message.

b. For each case of provided stimulus given in Table 2-104 and Table 2-105, verify that the ADS-B UAT Receiver system properly reports Successful Messages (Corrected Messages when errors induced in the Messages are correctable) and the associated Message Types as described in column numbers 5 and 4 of Table 2-104 and Table 2-105.

c. Verify that the Receiver system reports neither Message Type nor Payload Data other than "DATA NOT AVAILABLE (N/A)" in the cases where there are more errors than it is capable of correcting as described in column numbers 5 and 4 of Table 2-104 and Table 2-105.

CAUTION: *RS decoder shall use hard decision decoding to meet the proper Message Error Rate requirement.*

Table 2-104: ADS-B Message Reception – Set 1

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Succ-essful
1	FF8196782DD44238C1453855F89980C7524F5970940ED83A D89CE7A9BEF8761BBCD9FCC817D82E2D1ACF90CA78DA3C49	Basic	$^{1}P_{b42}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
2	007E6987D328BDC73EBA3955F89980C7524F5970940ED83A D89CE7A9BEF8BB7B190B2EA0EACC7237B7B01B036E07EE04	N/A	$^{1}F_{b42}$	N/A	N/A	N
3	007E6987D2D74238C146C7AA07667FC7524F5970940ED83A D89CE7A9BEF8DBE78F0C386EB860D64E9BA9E06B95BEB66A	Basic	$^{1}P_{b42}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
4	007E6987D2D74238C1453855F8998738ADB0A60F940ED83A D89CE7A9BEF8171F980B40C8B76AC0791254EE04AA73A982	Basic	$^{1}P_{b42}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
5	007E6987D2D74238C1453855F89980C7524F597F6BF127C5 E79CE7A9BEF8B22C710A46621200763F2DF70CBCBFCA1721	Basic	$^{1}P_{b42}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
6	5A8CAA4ABC7AEE2AD0929EB80DA044D556B452A7A73A5716 CD1DB40964F5BA105D9DAAD75342196DEBB63CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
7	A57355B5438412D52F6D61470CA044D556B452A7A73A5716 CD1DB40964F5BA105D9DAAD75342196DEBB63CC972994DEA	N/A	$^{1}F_{b50}$	N/A	N/A	N
8	A57355B54385ED2AD0929EBBF25FBB2AA94B52A7A73A5716 CD1DB40964F5BA105D9DAAD75342196DEBB63CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
9	A57355B54385ED2AD0929EB80DA044D556B3AD5858C5A869 CD1DB40964F5BA105D9DAAD75342196DEBB63CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
10	A57355B54385ED2AD0929EB80DA044D556B452A7A73A5719 32E24BF69BCABA105D9DAAD75342196DEBB63CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
11	A57355B54385ED2AD0929EB80DA044D556B452A7A73A5716 CD1DB40964EA45EFA26255C85342196DEBB63CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
12	A57355B54385ED2AD0929EB80DA044D556B452A7A73A5716 CD1DB40964F5BA105D9DAAE8ACBDE69214B93CC972994DEA	Long	$^{1}P_{b50}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
13	FFD7E73F83C10D2BF6B961410BEE0C2FD5A4C934E4972E7D 17C8495075B2F64260211F48524C5A5590A16E3EAF4068AB	Basic	$^{1}P_{b42}$	002818C07CC20D2BF6B961410BEE0C2FD5A4	Basic	Y
14	002818C07D3DF2D4094660410BEE0C2FD5A4C934E4972E7D 17C8495075B26DD7F172B5B56FF8F49067515A8A55D64D5E	N/A	$^{1}F_{b42}$	N/A	N/A	N
15	002818C07CC20D2BF6BA9EBEF411F32FD5A4C934E4972E7D 17C8495075B2C06F20916457C90BC47D261C8DEFE3ED74C5	Basic	$^{1}P_{b42}$	002818C07CC20D2BF6B961410BEE0C2FD5A4	Basic	Y
16	002818C07CC20D2BF6B961410BEE0BD02A5B364BE4972E7D 17C8495075B233CE68A8ABDCF663EAF24B3B2B1369D92C8D	Basic	$^{1}P_{b42}$	002818C07CC20D2BF6B961410BEE0C2FD5A4	Basic	Y
17	002818C07CC20D2BF6B961410BEE0C2FD5A4C93B1B68D182 28C8495075B215B194556A7E44E71C724666C96E55DEE72E	Basic	$^{1}P_{b42}$	002818C07CC20D2BF6B961410BEE0C2FD5A4	Basic	Y
18	FF6BD35D16B72B5A4521DB1F0697464369387A5F2C8C9E43 5F936F4912E17BD726E20847E1E69847CE7504CFE31ACE30	Basic	$^{1}P_{b42}$	00942CA2E9B42B5A4521DB1F069746436938	Basic	Y
19	00942CA2E84BD4A5BADEDA1F0697464369387A5F2C8C9E43 5F936F4912E1875A6F0477167558D0E3FCE8FC17F176AED4	N/A	$^{1}F_{b42}$	N/A	N/A	N

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Succ-essful
20	00942CA2E9B42B5A452224E0F968B94369387A5F2C8C9E43 5F936F4912E13773225FF83FE1D774B684BC1B474D55879A	Basic	$^{1}P_{b42}$	00942CA2E9B42B5A4521DB1F069746436938	Basic	Y
21	00942CA2E9B42B5A4521DB1F069741BC96C785202C8C9E43 5F936F4912E189CFFBB621E21E555CCC06495B619BDA4ABC	Basic	$^{1}P_{b42}$	00942CA2E9B42B5A4521DB1F069746436938	Basic	Y
22	00942CA2E9B42B5A4521DB1F0697464369387A50D37361BC 60936F4912E1263E0AD23CEC55487CDF1D60B972DE252D81	Basic	$^{1}P_{b42}$	00942CA2E9B42B5A4521DB1F069746436938	Basic	Y
23	29E66548CD3A0A4527AB422D6A14598C515810717B02C9C7 9B79F029CEEE6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	Long	$^{1}P_{b50}$	D6199AB732C5094527AB422D6A14598C51581071 7B02C9C79B79F029CEEE6B4DD1E8	Long	Y
24	D6199AB732C4F6BAD854BDD26B14598C515810717B02C9C7 9B79F029CEEE6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	N/A	$^{1}F_{50}$	N/A	N/A	N
25	D6199AB732C5094527AB422E95EBA673AEA710717B02C9C7 9B79F029CEEE6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	Long	$^{1}P_{b50}$	D6199AB732C5094527AB422D6A14598C51581071 7B02C9C79B79F029CEEE6B4DD1E8	Long	Y
26	D6199AB732C5094527AB422D6A14598C515FEF8E84FD36B8 9B79F029CEEE6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	Long	$^{1}P_{b50}$	D6199AB732C5094527AB422D6A14598C51581071 7B02C9C79B79F029CEEE6B4DD1E8	Long	Y
27	D6199AB732C5094527AB422D6A14598C515810717B02C9C8 64860FD631D16B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	Long	$^{1}P_{b50}$	D6199AB732C5094527AB422D6A14598C51581071 7B02C9C79B79F029CEEE6B4DD1E8	Long	Y
28	287F318C2A9FFF7F0784CA4036E252DEB0226A9F9E183CBB 933FA68DBF5E1F018F635195DE87894F16BDA55E42A64137	Basic	$^{1}P_{b42}$	D780CE73D59CFF7F0784CA4036E252DEB022	Long	N
29	D780CE73D4630080F87BCB4036E252DEB0226A9F9E183CBB 933FA68DBF5E161C9333D935A0C83220FC2799D84A139CAB	N/A	$^{1}F_{b42}$	N/A	N/A	N
30	157A70631C57176BA3073708854B66FF4083C2AF2D96F628 422CDA1A522295B85ED8C94A0DB164A4BEF4B3A402210E02	N/A	$^{1}F_{b50}$	N/A	N/A	N
31	773448BE613236BD3F0C53F45DCA5CC6F0B2C0A92F6B6DF3 072E0BEFFC8ADAA641EE602AC8B2DDE9A4429FAAB9AFD694	Long	$^{1}P_{b50}$	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A9 2F6B6DF3072E0BEFFC8ADAA641EE	Long	Y
32	88CBB7419ECCCA42C0F3AC0B5CCA5CC6F0B2C0A92F6B6DF3 072E0BEFFC8ADAA641EE602AC8B2DDE9A4429FAAB9AFD694	N/A	$^{1}F_{b50}$	N/A	N/A	N
33	88CBB7419ECD35BD3F0C53F7A235A3390F4DC0A92F6B6DF3 072E0BEFFC8ADAA641EE602AC8B2DDE9A4429FAAB9AFD694	Long	$^{1}P_{b50}$	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A9 2F6B6DF3072E0BEFFC8ADAA641EE	Long	Y
34	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A92F6B6DF3 072E0BEFFC8ADAA641EE6015374D22165B4D9FAAB9AFD694	Long	$^{1}P_{b50}$	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A9 2F6B6DF3072E0BEFFC8ADAA641EE	Long	Y
35	EE62BBECF66420F249ECF8FBC08F8FB3092B6EB4C61D6C26 4DB6F333BEA5570E0407693351FA9161858E6460DE629EFE	Long	$^{1}P_{b50}$	119D4413099B23F249ECF8FBC08F8FB3092B6EB4 C61D6C264DB6F333BEA5570E0407	Long	Y
36	119D4413099ADC0DB6130704C18F8FB3092B6EB4C61D6C26 4DB6F333BEA5570E0407693351FA9161858E6460DE629EFE	N/A	$^{1}F_{b50}$	N/A	N/A	N
37	119D4413099B23F249ECF8F83F70704CF6D46EB4C61D6C26 4DB6F333BEA5570E0407693351FA9161858E6460DE629EFE	Long	$^{1}P_{b50}$	119D4413099B23F249ECF8FBC08F8FB3092B6EB4 C61D6C264DB6F333BEA5570E0407	Long	Y
38	119D4413099B23F249ECF8FBC08F8FB3092C914B39E29359 4DB6F333BEA5570E0407693351FA9161858E6460DE629EFE	Long	$^{1}P_{b50}$	119D4413099B23F249ECF8FBC08F8FB3092B6EB4 C61D6C264DB6F333BEA5570E0407	Long	Y
39	DF784C02075C59B503CFF562E1A553E2B54F40092EF8C22D 0BFC643D3C5290867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{2}P_{b12}$	20884C02075C59B503CF0A92E1A553E2B54F	Long	N
40	5A8355B54385ED2AD0929EB80DA044D556B452A758CA5716 CD1DB40964F5BA10A26DAAD75342196DEBB63CC972994DEA	Long	$^{3}P_{b12}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Successful
41	D616654732C5094527AB422D65EBA98C515810717B02C9C7 94860029CEEE6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	N/A	$^{3}F_{b12}$	N/A	N/A	N
42	AC8857D3318447091F3244DB71A661C7CFC7C4D859F34BD3 05CED0F22A0FDBE78F0C386EB860D64E9BA9E06B95BEB66A	N/A	$^{3}F_{b12}$	N/A	N/A	N
43	F8A60931105731F486BCE2B75D2EBAB00C4FBFEC1C827BEB DDF3BABC5DFC90867BECAA1DB2EEC69474D7F594AC5738D8	Basic	$^{3}P_{b12}$	07560931105731F486BCE2B75D2EBA4FFC4F	Basic	Y
44	87AAEE174F86F7D6F81A6A5DFFE44BBE819127C89004918D 683D2DD3608523EFAC727A23A788A711FCA51139D874D5C8	Long	$^{3}P_{b12}$	87AAEE174F86F7D6F8E5955DFFE44BBE816ED8C8 9004918D683DD22C608523EFAC72	Long	Y
45	46D9B1EE2CE9216C8027CE5AE861E20BB742FF717C21B944 DED0B164595D7181B14C131EA2DCCDD5B86D46824464BE9A	Long	$^{3}P_{b12}$	46D9B1EE2C16DE6C8027CE5AE89E1D0BB742FF71 7C21B9BB21D0B164595D7181B14C	Long	Y
46	007F9667D2D74238C1453855076980C7524F5970940ED83A D89CE856BEF890867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{3}P_{b12}$	N/A	N/A	N

$^{1}P_{b50}$ - Long ADS-B Message corrupted with one 50 bits long burst error is Passed
$^{3}P_{b12}$ - ADS-B Message corrupted with three 12 bits long burst error is Passed
$^{2}P_{b12}$ - ADS-B Message corrupted with two 12 bits long burst error is Passed
$^{1}P_{b42}$ - Basic ADS-B Message corrupted with one 42 bits long burst error is Passed
$^{1}F_{b42}$ - Basic Message corrupted with one 42 bits long burst error is Failed
$^{1}F_{b50}$ - Long ADS-B Message corrupted with one 50 bits long burst error is Failed
$^{3}F_{b12}$ - ADS-B Message corrupted with three 12 bits long burst error is Failed

Table 2-105: ADS-B Message Reception – Set 2

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Succ-essful
1	007E6987D2D74238C1453855F89980C7524F5970940ED83A D89CE7A9BEF890867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{0}P_{R}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
2	A57355B54385ED2AD0929EB80DA044D556B452A7A73A5716 CD1DB4096465BA105D9DAAD75342196DEBB63CC972994DEA	Long	$^{1}P_{R}$	A57355B54385ED2AD0929EB80DA044D556B452A7 A73A5716CD1DB40964F5BA105D9D	Long	Y
3	002818C07CC20D2BF6B961410BEE0C2FD5B9C934E4972EED 17C8495075B290867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{2}P_{R}$	002818C07CC20D2BF6B961410BEE0C2FD5A4	Basic	Y
4	00942CA2E9B42B5A4521DB1F0697FE4369257A5F2C8C9ED3 5F936F4912E190867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{3}P_{R}$	00942CA2E9B42B5A4521DB1F069746436938	Basic	Y
5	8B199AB732C509459FAB422D6A14598C515810717B02C9DA 9B79F029CE7E6B4DD1E8F1F77F4CAB43AD74CBB01ECD155C	Long	$^{4}P_{R}$	D6199AB732C5094527AB422D6A14598C51581071 7B02C9C79B79F029CEEE6B4DD1E8	Long	Y
6	00879223318447F6E03244DB2CA6D93830DADB42E877E27C F095B704326590867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{5}P_{R}$	0087A823318447F6E03244DB71A6613830C7	Basic	Y
7	DAAAD4174F86F7D640E5955DFFE44BBE816ED86290049190 683DD22C601523EFAC727A23A788A711FCA51139D874D5C8	Long	$^{6}P_{R}$	87AAEE174F86F7D6F8E5955DFFE44BBE816ED8C8 9004918D683DD22C608523EFAC72	Long	Y
8	1BD98BEE5D16DE6C3827CE5AE89E1D0BB742FFDB7C21B9A6 21D0B16459CD7181B14C131EA2DCCDD5B86D46824464BE9A	Long	$^{7}P_{R}$	46D9B1EE2C16DE6C8027CE5AE89E1D0BB742FF71 7C21B9BB21D0B164595D7181B14C	Long	Y
9	D780F473A49C677F0784CA406BE2EADEB03F6A9F9E183C2B 9395A68DBF5E90867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{8}F_{R}$	N/A	N/A	N
10	487A4A636D56E894E4F8C8F7844B66FF4083C2052D96F635 DA2CDA1A52B295B85ED8C94A0DE064A4BEF4B3A402210E02	N/A	$^{9}F_{R}$	N/A	N/A	N
11	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A92F6B6DF3 072E0BEFFC8ADAA641EE602AC8B2DDE9A4429FAAB9AFD694	Long	$^{0}P_{R}$	88CBB7419ECD35BD3F0C53F45DCA5CC6F0B2C0A9 2F6B6DF3072E0BEFFC8ADAA641EE	Long	Y
12	3DC87150293C43E1218BBBB462F06CE1ABE77693C3C24648 277112B17B0EC4E774EED67F4A5C486E47E688B2FFA81FAD	Long	$^{5}P_{R}$	60C84B50293C43E1998BBBB462F06CE1ABE77693 C3C24655277112B17B9EC4E774EE	Long	Y
13	E4C735D67923E302D648F20F35C66F7027697BF77AE4F675 9F5106D592E19E48996C4008A98EC6178BB74D5E05380D73	Long	$^{6}P_{R}$	B9C70FD67923E3026E48F20F35C66F7027697B5D 7AE4F6689F5106D592719E48996C	Long	Y
14	53A810655AA6E68A2585D51E07F01003A662B66F98020986 F472BD563FD6D8CE9D354AB7E56F1871EF087F2C2DC5810F	N/A	$^{8}F_{R}$	N/A	N/A	N
15	294B0831CCD9B59FB2DB2078C6A796AC873977A0061D2AA5 FC057583D39AA1429DFBAC89A4F1A9D94D17D93FB5A982BA	Long	$^{2}P_{R}$	294B0831CCD9B59FB2DB2078C6A796AC873977A0 061D2AB8FC057583D30AA1429DFB	Long	Y
16	A30D2EF671D7A56136FCAAEEFA838793C58706661638720E 3E2539F280FD5B1CEC3255DB60BA866B7CD2E927188DAC0A	Long	$^{3}P_{R}$	A30D2EF671D7A5618EFCAAEEFA838793C5870666 163872133E2539F2806D5B1CEC32	Long	Y
17	1E9297DE55DDFDBC646A63E90E96784012A92DCE42660EC2 0BC9EC886EE60DC70D7E9B3FA52D17E62E90F4C69EDA07F6	Long	$^{5}P_{R}$	4392ADDE55DDFDBCDC6A63E90E96784012A92DCE 42660EDF0BC9EC886E760DC70D7E	Long	Y
18	FE767C70F15A99EE3FC77178FB1EED52BBBDBEFAB8C0F0EC 0C1FB1350D363A24A24DEA5F5E955696C56858C093594BF1	Long	$^{7}P_{R}$	A3764670805A99EE87C77178FB1EED52BBBDBE50 B8C0F0F10C1FB1350DA63A24A24D	Long	Y
19	62A76B1293A13428872CF1A006431013E1E25D045594026A B07440F966277040AF3B9FD2701B68113F6BCABB38B1AB7C	N/A	$^{8}F_{R}$	N/A	N/A	N

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Succ-essful
20	00CB83BC39C90101CD97F84751E2D679CD3ADE7EE8D98C88 24BE9F7565B690867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{9}F_{R}$	N/A	N/A	N
21	BEF0F217696E4652DE8CB92BEC089CFA688E91363C4C627E EDC50B2B3621CD80A407357B9646CF133CDE92807BDE083A	Long	$^{1}P_{R}$	BEF0F217696E4652DE8CB92BEC089CFA688E9136 3C4C627EEDC50B2B36B1CD80A407	Long	Y
22	25F2846879F474085AD651F61011A07E55B92EF8412B72ED 889CCBABD43BE51C2CECE97C250E4F5FAB16CEDAFA5CE238	Long	$^{2}P_{R}$	25F2846879F474085AD651F61011A07E55B92EF8 412B72F0889CCBABD4ABE51C2CEC	Long	Y
23	FE8BBEFA469671700F1B9BCE491CE2E7C61DCB0266805440 1B2D129FBBA808A0C4F18A2B7847A35F56BFE897BFF31E71	Long	$^{6}P_{R}$	A38B84FA46967170B71B9BCE491CE2E7C61DCBA8 6680545D1B2D129FBB3808A0C4F1	Long	Y
24	B026C4F405E0F6DAF7EEA90134AD7F4C79CC105115F779A6 96B6FF79665B7D30DA7B0E12E49705C2EFBF64726AF41A65	Long	$^{7}P_{R}$	ED26FEF474E0F6DA4FEEA90134AD7F4C79CC10FB 15F779BB96B6FF7966CB7D30DA7B	Long	Y
25	B2F0B85427A6B9B30ADE959C9A3597E429B4C7DB15DDD9C8 E9DC9CADC4FBBDB6B7BD2446C0391DA4ACB7D62FF4DE4448	N/A	$^{8}F_{R}$	N/A	N/A	N
26	6B9AC92CCE70667C6FD5D4B316DA46E4B5322A4B4151F651 DEDBE85633E19768DE42F879B6BCB73C308D85D5E6EC2834	N/A	$^{9}F_{R}$	N/A	N/A	N
27	07560931105731F486BCE2B75D2EBA4FFC4FBFEC1C827BEB DDF3BABC5DFC90867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{0}P_{R}$	07560931105731F486BCE2B75D2EBA4FFC4F	Basic	Y
28	8D264F73C42014181D475A812755061B88B784F2D7E57866 DAF007EA4A420D7B5829E103C0E3DF069015893738D26FC1	Long	$^{1}P_{R}$	8D264F73C42014181D475A812755061B88B784F2 D7E57866DAF007EA4AD20D7B5829	Long	Y
29	0511EE3AFD5356739D80545F1D978A8E75FFBA8D349CFBD3 C19D1852B06690867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{2}P_{R}$	0511EE3AFD5356739D80545F1D978A8E75E2	Basic	Y
30	077B559BEFA8DA4D43A0ED6253FA096926C1EBE0899BC38D 3A8415367D64756997DB0F53F54227A14229F3654F5FB489	Long	$^{5}P_{R}$	5A7B6F9BEFA8DA4DFBA0ED6253FA096926C1EBE0 899BC3903A8415367DF4756997DB	Long	Y
31	14A61CC7D8766A511C98CAF387403156AFB78E35C0840FB8 2D6A1C4A9EEB8D3493E567AFA9EDDF7B6713935817587985	Long	$^{6}P_{R}$	49A626C7D8766A51A498CAF387403156AFB78E9F C0840FA52D6A1C4A9E7B8D3493E5	Long	Y
32	94032D84D22B86C1E1E2A18859083B9737E7F48C1F477D29 51D333795CB75CA801BEFFF271349F7665D670AD62AF2FF3	Long	$^{7}P_{R}$	C9031784A32B86C159E2A18859083B9737E7F426 1F477D3451D333795C275CA801BE	Long	Y
33	105B5212705BBE0DE89A8033898EFBA25AA41F9D4880BA06 6C874BD4AA7B90867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{8}F_{R}$	N/A	N/A	N
34	0C646844862595EAA54DAD2F2DA5D1481D0DE3828C22F4E2 A4D9D15D795D570AE9320018B985B188C1192A60300F0A37	Long	$^{0}P_{R}$	0C646844862595EAA54DAD2F2DA5D1481D0DE382 8C22F4E2A4D9D15D795D570AE932	Long	Y
35	71219DC30B25D77EB24D25A1E38811FDEB9C303F0329C26F 0DA358E86C327A3EAEBE2D88F3C31EC323F20D43109D7BFF	Long	$^{2}P_{R}$	71219DC30B25D77EB24D25A1E38811FDEB9C303F 0329C2720DA358E86CA27A3EAEBE	Long	Y
36	20884C02075C59B503CF0A92E1A5EBE2B55240092EF8C22D 0BFC643D3C5290867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{3}P_{R}$	20884C02075C59B503CF0A92E1A553E2B54F	Long	N
37	041FAD506C2ACF832E6E709A64393C100253641E26C3D92D 0F2AA4C38AF490867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{5}P_{R}$	041F97506C2ACF832E6E709A39398410024E	Basic	Y
38	00117E82A1E6F9F487423BD32B0765CFC70A65332A820C1B 34702487811990867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{7}P_{R}$	N/A	N/A	N
39	7C69D795C15C7E322415505445A1588476473FF6928382FD 43173F9B56A96BACBBF0B5C3868CAEB2856C8AD0E4F31A95	Long	$^{2}P_{R}$	7C69D795C15C7E322415505445A1588476473FF6 928382E043173F9B56396BACBBF0	Long	Y
40	E4D3C31F1B25232D4E43F6C3F8368596C5346C919C0960B2 EE40492BEEDA77934474F26191E4D8048AB87CA49EE0BE29	Long	$^{6}P_{R}$	B9D3F91F1B25232DF643F6C3F8368596C5346C3B 9C0960AFEE40492BEE4A77934474	Long	Y

No.	Corrupted	Type (RS)	Error	RS Decoded Messages	Payload Type	Succ-essful
41	FE69CC228E786E996CCC8318C9C90F25C6B68F566C74316C B5FDAFCA226E7A19EA66AD963A6327B8A2F49291C22A656C	Long	$^{7}P_{R}$	A369F622FF786E99D4CC8318C9C90F25C6B68FFC 6C743171B5FDAFCA22FE7A19EA66	Long	Y
42	008B74BC393401BE9D6A11D93C62435F127541E5D17C2397 CCFF49EE043890867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{8}F_{R}$	N/A	N/A	N
43	00FAE34A81BF609DACB0388BDC818EAAD028684EF3F7A68A 856C9BD8CA0F90867B135A1DB2EEC69474D7F594AC5738D8	N/A	$^{9}F_{R}$	N/A	N/A	N
44	0004E865A9FCC6E11D03557BAC9C64852F69D3174482AD91 06856918E6D790867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{0}P_{R}$	0004E865A9FCC6E11D03557BAC9C64852F69	Basic	Y
45	B509125D72B9D0CDC67016287921F01E0DD52193C1BD8B50 DD2A6BBECDEF7A50DDDC73D996CFD227032EB4A1EC746E4C	Long	$^{1}P_{R}$	B509125D72B9D0CDC67016287921F01E0DD52193 C1BD8B50DD2A6BBECD7F7A50DDDC	Long	Y
46	E5A6D7BE57EBB83BFA867DA7B6978BB7161F778B63B098D7 2EE880885E48E6F3240528F8F1230C5537F5EA030243537A	Long	$^{2}P_{R}$	E5A6D7BE57EBB83BFA867DA7B6978BB7161F778B 63B098CA2EE880885ED8E6F32405	Long	Y
47	00E7B451B11DAE9750011F73723404D39A5DE2647484ABC7 890F0800969890867B135A1DB2EEC69474D7F594AC5738D8	Basic	$^{3}P_{R}$	00E7B451B11DAE9750011F737234BCD39A40	Basic	Y
48	FD24A99E20ECC8E347D4D46D141FCCC52A6AC35E5CE4B693 38BE22E0ECB72F702E49D0EF7142D6675A4E79E2590865AF	Long	$^{5}P_{R}$	A024939E20ECC8E3FFD4D46D141FCCC52A6AC35E 5CE4B68E38BE22E0EC272F702E49	Long	Y
49	1F83699AD2D74238C1453855F89980C7524F5C70390ED83A D89CE7A947F8BA105D9D83DADD3FC8DC9842693A4E9D7E63	Basic	$^{8*}P_{R}$	007E6987D2D74238C1453855F89980C7524F	Basic	Y
50	20884C02075C59B503CFC353E1A553E2B54F4009EAF8C20E 0BFC64C93C52D0AA219E83E952864A5EE34E5C06B43ED570	Basic	$^{9*}P_{R}$	20884C02075C59B503CF0A92E1A553E2B54F	Long	N
51	1F83699AD2D74238C1453855F89980C7524F5C70390ED83A D89CE7A9BEF8BA105D9D83DADD3FC8DC9842693A4E9D7E63	Long	$^{7}P_{R}$	097E6987D2D74238C1453855F89980C7524F5970 940ED83AD89CE7A9BEF8BA105D9D	Long	Y
52	20884C02075C59B503CFC392E1A553E2B54F4009EAF8C20E 0BFC64C93C52D0AA219E83E952864A5EE34E5C06B43ED58B	Long	$^{7}P_{R}$	20884C02075C59B503CF0A92E1A553E2B54F4009 2EF8C2BD0BFC643D3C52D6AA219E	Long	Y

$^{0}P_{R}$ - ADS-B Message without an error symbol is Passed
$^{2}P_{R}$ - ADS-B Message with two error symbols is Passed
$^{6}P_{R}$ - ADS-B Message with six error symbols is Passed
$^{8}F_{R}$ - ADS-B Message with eight error symbols is Failed
$^{9}F_{R}$ - ADS-B Message with nine error symbols is Failed
$^{8*}P_{R}$ - ADS-B Message with eight error symbols is Failed as Long and Passed as Basic
$^{9*}P_{R}$ - ADS-B Message with nine error symbols is Failed as Long and Passed as Basic

Note: *The "**Payload Type**" column in the above tables shows the Payload Type of the ADS-B Message as it is read from the ADS-B Message PAYLOAD TYPE CODE (after it comes out from the RS decoder). N/A is listed when the message is uncorrectable as either "Long" or "Basic." The receiver will declare successful message reception status as the "FAIL" condition if there is a mismatch in declaration of Payload Type between the two message Type discrimination methods.*

2.4.8.3.1.2 Verification of Ground Uplink Messages (§2.2.8.3.1.2)

Purpose/Introduction:

The receiver **shall** determine Successful Message Receipt for a Ground Uplink Message according to the following procedure:

a. Each de-interleaved RS block of the Ground Uplink Message shall be individually examined for errors. Each RS block shall be declared as valid only if it contains NO uncorrected errors after RS decoding. The decoding process shall use hard decision decoding with no erasures allowed.

b. Successful Message reception shall be declared for a Ground Uplink Message when all six constituent RS blocks are declared valid from (a) above.

Note: *Appendix M provides the analytic determination of the Undetected Message Error Rate achieved though use of the RS coding. Due to the straightforward calculation of the UMER and the fact that the UMER is quite low, no explicit requirement/test is needed for a "False Message Reception Rate" test.*

The following test procedure will verify that the UAT receiver system correctly declares the Successful Receipt of Ground Uplink Messages as defined in §2.2.8.3.1.2. The receiver system must declare the Successful Message Reception only when there is NO uncorrected error indicated in all six constituent de-interleaved RS blocks after the RS decoding processes.

The Corrupted Messages (Erroneous Messages) provided in the Tables are designed as follows:

a. Table 2-106 through Table 2-114 have random burst errors that are perfectly lined up with the byte boundary of ADS-B Message symbols. The errors in each message are at different symbol positions and the number of erroneous symbols that are induced into the ADS-B Messages can be from 1 to 14 bytes.

Equipment Required:

Provide a method to supply controlled De-Interleaved RS blocks of Ground Uplink Messages to the appropriate ADS-B UAT Receiver interface.

Measurement Procedures:

Step 1: Establish the Initial Conditions

Configure the UAT Receiver system to receive Ground Uplink Messages and verify that the interface is providing the test data to the UUT.

Step 2: Verify Successful Reception of each De-Interleaved RS Blocks

a. Load the set of test messages provided in Table 2-106 through Table 2-114 into the Receiver Interface.

b. For each case of provided stimulus given in Table 2-106 through Table 2-114, verify that each de-interleaved RS block of Ground Uplink Messages properly reports the Successful RS block (Corrected Messages when errors induced in each RS block are correctable) as described in column 5 of Table 2-106 through Table 2-114.

c. Verify that each de-interleaved RS block of Ground Uplink Messages report "DATA NOT AVAILABLE (N/A)" if there exist more errors than it can correct as described in column 5 of Table 2-106 through Table 2-114.

Step 3: Verify Successful Reception of Ground Uplink Messages

a. Verify that the UAT receiver system declares Successful Ground Uplink Messages Reception only when all six constituent RS blocks are declared valid as described in column 6 of Table 2-106 through Table 2-114.

b. Verify that the UAT receiver system FAILs to report Successful Ground Uplink Messages Reception when one or more failed/invalid RS blocks exists in any of six constituent RS blocks as described in column 6 of Table 2-106 through Table 2-114.

CAUTION: *RS decoder shall use hard decision decoding to meet the proper Message Error Rate requirement.*

Table 2-106: **Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 1**

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	FA1F424AD9F4B06814BBC1401975CCBA86A6D96E DAD21985672C1CDB815E69F44231D9A6EA90FC8F 24A059BE3F67419BB140A9F5569924D1D3BDFA54 2090FFDFF19A15CAB23B0CBDC45C27312D923281 BC99E458FB2B4A7E74D2439A	^{0}Pass$_R$	Grd$_1$	FA1F424AD9F4B06814BBC1401975CCBA86A6D96E DAD21985672C1CDB815E69F44231D9A6EA90FC8F 24A059BE3F67419BB140A9F5569924D1D3BDFA54 2090FFDFF19A15CAB23B0CBD	Report successful ground message.
2	3862CAA751ADE24FF1B60B6A910F9AD9779D8257 91DA66C41F31C2F8AFEE4FB1CE14040164EBF659 91B8718820E3704642F884B43E5BA2D143FE76BF 83163FFC4BF9BBE235BBC611DAA44D72EBA30337 4103DE72612A5773565DE276	^{1}Pass$_R$	Grd$_2$	3862CAA751ADE24FF1B60B6A910F9AD9779D8257 91DA66C41F31C267AFEE4FB1CE14040164EBF659 91B8718820E3704642F884B43E5BA2D143FE76BF 83163FFC4BF9BBE235BBC611	
3	3BA98F9BB43FA0920AB017CDB2A540083DC1862E 7613D60774916766A32A9DA17EA2610727B9A890 075A149BA2414DBB4FEA0F9CEFB8960AF4074688 B1B8CC0CCFED20BFF46309641ACFCCBE12ED6388 2C9F28FD348A02708DBA40ED	^{2}Pass$_R$	Grd$_3$	3BA98F9BB43FA0920AB017CDB2A540083DC1862E 7613D607749167F9A32A9DA17EA2610727B9A890 075A149BA2414DBB4FEA0F9CEFB8960AF4074688 B1B8CC0CCFED20BFF4630964	
4	57BD9AA761A7DA179D9FEE0B804F01945C3ED461 07DC28A1868BD04E3D3E4786F9578B11694B8298 B33BC88E5A929E891C4ED97070FE890BDE2FFCD8 453FEEC3D4D80E8B570CDC11CAC31C6016FC08A5 FC5E3E6EFD036FC319D281D3	^{3}Pass$_R$	Grd$_4$	57BD9AA761A7DA179D9FEE0B804F01945C3ED461 07DC28A1868BD0D13D3E4786F9578B11694B8298 B33BC88E5A929E891C4ED97070FE890BDE2F35D8 453FEEC3D4D80E8B570CDC11	
5	FECA03CE5334F99E0D825CAF5C7D4CC2F7C15908 F45E0BBA31268CC3ED430926508E4A87E4D6A3DD 6757A832DCA8521A575D0825D854AFE13A58FA61 10BB29CFDD7E0D872F94AFA686D235AC7B9B408A DC46E613FB6AEC35A427863A	^{4}Pass$_R$	Grd$_5$	FECA03CE5334F99E0D825CAF5C7D4CC2F7C15908 F4510BBA31268C5CED430926508E4A87E4D6A3DD 6757A832DCA8521A575D0825D854AFE13A583361 10BB29CFDD7E0D872F94AFA6	
6	4C81CE1C2B457E33E253D28A2117EF0182FAF486 48BCE45D42C2FD2B7378B42BBCE623A5228DBA86 E6A610A52362E7B47D5189D0446065707B39DC06 18024E7221A23C1E402FF3DD1640FCFCDD5360E0 39814E3D046C198D2ECA6B5E	^{5}Pass$_R$	Grd$_6$	4C81CE1C2B457E33E253D28A2117EF01823BF486 48B3E45D42C2FDB47378B42BBCE623A5228DBA86 E6A610A52362E7B47D5189D0446065707B391506 18024E7221A23C1E402FF3DD	

Table 2-107: Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 2

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	150ED7F7556FB36D06CDE756D5E65AFB69B5F687 A7291C564483F87CA9CA9959FDF50798D46D74EF D61BD1C2F06375CCD4B964D9CFCD4284D20BBE6D A574216D9C7E3FB0637DD1D3868E736E3D45F5F1 7E0F47D77062F7016F1B6C07	[6]Pass$_R$	Grd$_1$	150ED7F7556FB36D06CDE756D5E65AFB69740D87 A7261C564483F8E3A9CA9959FDF50798D46D74EF D61BD1C2F06375CCD4B964D9CFCD4284D20B776D A574216D9C7E3FB0637DD1D3	Fail to report successful ground message.
2	7154C5D330656E7EE4835EAFE4D3670162316743 1F3802604AFA65E1E2367206BB4A0DDCCF6F7F82 29FC82D1DA89B721E8208F03A58E3A4F49737BD4 5EA106473D81AFC532F8E61E5BC86AA16F2267EC 27579EA5BC03B4AFC8F07C41	[7]Pass$_R$	Grd$_2$	1254C5D330656E7EE4835EAFE4D3670162F09C43 1F3702604AFA657EE2367206BB4A0DDCCF6F7F82 29FC82D1DA89B721E8208F03A58E3A4F4973A2D4 5EA106473D81AFC532F8E61E	
3	708A1C1C4DB1E39040373DDB6CEC49A7BB629897 FF313E2CE2347B965CED67EBF741B9FEF9079DCC A8095515CAB734ADA9FA5A43197E509B5E4E5C31 F5AC47D891E9AEFDC3B49D282B069D3D37B579AB C15072CBC4084653B1EE53F4	[8]Pass$_R$	Grd$_3$	138A1C1C4DB1E39040373DDB6CEC49A7BBA36397 FF3E3E2CE2347B095CED67EBF741B9FEF9079DCC A8095515CAB734ADA9FA5A43197E509B5E4E85B5 F5AC47D891E9AEFDC3B49D28	
4	A09A4C06BCC684787F9C7B631DC775D443AE64EE 4F87D1267E0391AFB1D81F8D1929591CE16945F4 8BE1FF9BA5756AE58B6EE76A5849D4E8C0BE6747 EB8A612C94A2F9D87B5E086110949546549AA6F7 0485633C289B6E84DEAB6839	[9]Pass$_R$	Grd$_4$	C39A4C06BCC684787F9C7B631DC775D4436F9FEE 4F88D1267E039130B1D81F4A1929591CE16945F4 8BE1FF9BA5756AE58B6EE76A5849D4E8C0BEBEC3 EB8A612C94A2F9D87B5E0861	
5	67D4E3A06ED472349352B8742628A30BCA40A876 435FA81D0228ED5073DC609680366B3ED7285378 1DD7B76BF158154A3EE5341DA7A73CBE9612E12F D28DE72C7A789850E5A6D43E825D3F8DFCB41937 2C0F325864E6270AA0354677	[10]Pass$_R$	Grd$_5$	04D4E3A06ED472349352B8742628A30B3D815376 4350A81D0228EDCF73DC605180366B3ED7285378 1DD7B76BF158154A3EE5341DA7A73CBE961238AB D28DE72C7A789850E5A6D43E	
6	2871C8C299788238F1398820B1FFE6099E2AD928 4B83BA2ED34535D4C17946A0A78895811E234A3A 6A7EB97A99BCF945F371B696AE6CF9664FF69636 B7BE77A620A20E4126E1D088353A3DD47AD2320C D14E5DE716A19E00D319EB05	[11]Fail$_R$	Grd$_6$	N/A	

<u>Table 2-108:</u> Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 3

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	7F6878BD4037C893161847DC7332C83762DF4DA0 B605BF0683A04DADF834FBF461AD370C26BB29E2 1185E67137D6D259B2FD814554DFF761097C5213 840EB698790EAC1EF10A787D0A8209FB70A4EE9C DE9C9346F10B7E49AD58E5EB	$^{12}\text{Fail}_R$	Grd_1	N/A	Fail to report successful ground message.
2	6D15EDE4B7C7C058150E09DF483B7D69BF6BBAC7 5B596D701CB7FADFEDD515BB961D79D45965C513 92796949EF0A33A1BD53812EB0E695C20966B4D5 0949E3CC9886E7F7A28516BD4E56E0B3B564E88D CDCB70A112BE57DC15E1AF78	$^{13}\text{Fail}_R$	Grd_2	N/A	
3	83A184694AAFFC644AD48FC86091246E871200C7 D4714B34F0227008BEF1E9999D507EBDFC01455C 333EEF2C651793A30AEEC4A8088637C53D531D0B FDE6FD51C7A7415A5049790B30E9485F3065DE24 92CC42234048632CBF656299	$^{14}\text{Fail}_R$	Grd_3	N/A	
4	A1D5EE7D6330646806D8D3917CE598EC31F647D0 D217134642C97964AE460B44229219F81D871696 F966F932B194606942215562D4266D41572E9894 AAA9EF3025A2C0ECFD3CB15B8DC13ED5D9EFEA63 EB04D816D82E968C3D82469C	$^{0}\text{Pass}_R$	Grd_4	A1D5EE7D6330646806D8D3917CE598EC31F647D0 D217134642C97964AE460B44229219F81D871696 F966F932B194606942215562D4266D41572E9894 AAA9EF3025A2C0ECFD3CB15B	
5	E1A2C74EC8FD084D5417245A40ADD49831B8543A 7799A1CCFF667CA313E1C138994A96BD89038BFD 2F54AA67F2BA1777DF822437EDB11DE8EB72A55F 0D7F5402644F7F6CDC7868B6A1531A95D6B3D813 9A46A602C5C75E7A5F33D2AE	$^{1}\text{Pass}_R$	Grd_5	E1A2C74EC8FD084D5417245A40ADD49831B8543A 7799A1CCFF667C3C13E1C138994A96BD89038BFD 2F54AA67F2BA1777DF822437EDB11DE8EB72A55F 0D7F5402644F7F6CDC7868B6	
6	FA09264A714F855F575546010A7EE4A9840E5B5F C18FFAE2E65862C3D1A5A486481516D6E1DFF221 6FB13B21EB837E084B39FDDBA983CC582B3E629E 1A4846CE09113E7891D5B86677E27B2E4407681D 51D71D68067BD0AAE0E5D9B4	$^{2}\text{Pass}_R$	Grd_6	FA09264A714F855F575546010A7EE4A9840E5B5F C18FFAE2E658625CD1A5A486481516D6E1DFF221 6FB13B21EB837E084B39FDDBA983CC582B3E629E 1A4846CE09113E7891D5B866	

Table 2-109: Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 4

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	E34CC8B7D8B6F24FA521B508E2BB65B39F0E675B 0D0FD8C59647A736EC0FB3A9540AF6743881D0A1 DA2D6BAAAE11639A960A1B51A31EEC772837D47C 8ADBC339458A149D96C228F1321F8DBFF8AF80E5 34CBF4D0B9F49D67BE0417D6	[3]Pass$_R$	Grd$_1$	E34CC8B7D8B6F24FA521B508E2BB65B39F0E675B 0D0FD8C59647A7A9EC0FB3A9540AF6743881D0A1 DA2D6BAAAE11639A960A1B51A31EEC7728371D7C 8ADBC339458A149D96C228F1	Report successful ground message.
2	1A754D1F72CEE785C329ED4D7E8D9541DF12AF16 9F0D4FBA9E1AAF12A44D8F09F1C4CCD338339AC3 C29391B4DD6B6A55BD3FB22E07B93CA52BBEEB33 37E42184D81EA14CABF225F4ACC68A74DC316130 284DCC4C7D550439F24A7AD1	[4]Pass$_R$	Grd$_2$	1A754D1F72CEE785C329ED4D7E8D9541DF12AF16 9F024FBA9E1AAF8DA44D8F09F1C4CCD338339AC3 C29391B4DD6B6A55BD3FB22E07B93CA52BBE2233 37E42184D81EA14CABF225F4	
3	91287EFFA836873BAA5A3F14C2B178431CEEFF8F C4C87953A53545809EB3B78F90F6EDBA69620BCB F0B031A6F38AF4340456A9386B20B93A18F33C76 089103DB87C761054ED89A38CF91726E491B7AB4 8962C1B7C618ACDC8341B083	[5]Pass$_R$	Grd$_3$	91287EFFA836873BAA5A3F14C2B178431C2FFF8F C4C77953A535451F9EB3B78F90F6EDBA69620BCB F0B031A6F38AF4340456A9386B20B93A18F3F576 089103DB87C761054ED89A38	
4	3F4528DB62D926ECDBD53FD76B1388534FB54813 FE943FF91E92990EA9F45BFFA7CE883CF9280434 7D8025ACA7351088CF0BC7C642552758648669 2A F1877BFA2239F96549F20CA4EDAA8D8DEB37812E F20D84FF4AD6CA34502D0DB1	[6]Pass$_R$	Grd$_4$	3F4528DB62D926ECDBD53FD76B1388534F74B313 FE9B3FF91E929991A9F45BFFA7CE883CF9280434 7D8025ACA7351088CF0BC7C6425527586486A02A F1877BFA2239F96549F20CA4	
5	C8DC85072A91FB1C83B83A783335773E4BC5C5A9 415A28D38922699804AABE2E8829CDCE1F25FF21 36B85924D5A77445272103FF561518081CDB5CE7 82369F151BD2ADFCD5E3CF027A883E4D5086AD72 45F0965241DD5ABE5B69C41D	[7]Pass$_R$	Grd$_5$	ABDC85072A91FB1C83B83A783335773E4B043EA9 415528D38922690704AABE2E8829CDCE1F25FF21 36B85924D5A77445272103FF561518081CDB85E7 82369F151BD2ADFCD5E3CF02	
6	7AF639D7558AE3D934A8C23113F37FEBFDAF385F 3E62B76FD07E1A0042B3267941932C37FD31903E 0F169356FE129B24B3935BDAD69E14AA790414DD FDEDC099A7E44FF74164C807DFC41D48E1C9CA2F 79C214551BEBA37F22F82C67	[8]Pass$_R$	Grd$_6$	19F639D7558AE3D934A8C23113F37FEBFD6EC35F 3E6DB76FD07E1A9F42B3267941932C37FD31903E 0F169356FE129B24B3935BDAD69E14AA7904CD59 FDEDC099A7E44FF74164C807	

Table 2-110: **Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 5**

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	75E817FB19AFF01239C9EB777B965C5488FA2027 22168304BE212B15B6882DFE5FECCD147E1684DC 0779B0DD8F773D385E688B78110551BCA8E5EB77 0F143B8C5967FC02D8A954771886AB2E1BFD9FC5 51CF49244725401FB51499C0	^{0}Pass$_{R}$	Grd$_1$	75E817FB19AFF01239C9EB777B965C5488FA2027 22168304BE212B15B6882DFE5FECCD147E1684DC 0779B0DD8F773D385E688B78110551BCA8E5EB77 0F143B8C5967FC02D8A95477	Report successful ground message.
2	40C66535F27735F7C1A935499DAA2D0B2037E40E DC0F48D157226123A37AE38581FC2A0AFC9054BD D7657C97D6CE99FEB3F8952F496CA720B01D7B4D FE8A38FF4D18DEF9A5B4B10714899D8A9781DB9C 0A2916295DFCE8D6676D2F60	^{1}Pass$_{R}$	Grd$_2$	40C66535F27735F7C1A935499DAA2D0B2037E40E DC0F48D1572261BCA37AE38581FC2A0AFC9054BD D7657C97D6CE99FEB3F8952F496CA720B01D7B4D FE8A38FF4D18DEF9A5B4B107	
3	2B7583F8ED2E1F7A5741C0429D16B2A0210D11D0 B04E5A3306C72BA80B446825296631943BF9C935 605A7046CAE9C44E49D8ABFA9FB1583F75F1F88B 6D18973EA3FBB126375528B785C0272EECF34CC7 E15915233E6B06073CFF2189	^{2}Pass$_{R}$	Grd$_3$	2B7583F8ED2E1F7A5741C0429D16B2A0210D11D0 B04E5A3306C72B370B446825296631943BF9C935 605A7046CAE9C44E49D8ABFA9FB1583F75F1F88B 6D18973EA3FBB126375528B7	
4	8AC36FC963B840772C1C16905893439949AEF5CF 32FA60C9D1A8F36181D84DE173AFCEF11F470942 3326E3EC0C43B10911CB937463AB6A18CB996381 5C8FD1E5200561F9D9CE07A3E167041449DFBC5D F90AB05E34735F4DAE0A70E0	^{3}Pass$_{R}$	Grd$_4$	8AC36FC963B840772C1C16905893439949AEF5CF 32FA60C9D1A8F3FE81D84DE173AFCEF11F470942 3326E3EC0C43B10911CB937463AB6A18CB99AA81 5C8FD1E5200561F9D9CE07A3	
5	A77C69FB8F0ABB2BC248097A2E5EDFC88F2BCCA6 2D73D1CA74DD40B212FD27683B55BFC1D82080EF 37D9507AE4B96F51FFEE95F9FE906BE9BE0A0E6C EA745B2F029D43D28535219C9CA2F653AACEF83B 89173E3704A0B2F41B9DA2FF	^{4}Pass$_{R}$	Grd$_5$	A77C69FB8F0ABB2BC248097A2E5EDFC88F2BCCA6 2D7CD1CA74DD402D12FD27683B55BFC1D82080EF 37D9507AE4B96F51FFEE95F9FE906BE9BE0AC76C EA745B2F029D43D28535219C	
6	2AE8271E7AD84C7AE1AA041B8036C3F12B4A172D ACC7156BF1F21546576AC2C83C1310268ACBAB64 60575C3F03C80265CD1A1378C182D066E8AAD594 31568F61F3A7D0E3D094C8FDB309B7CD3720EC1F AB0C2CABFAB29AF8E6C91930	^{5}Pass$_{R}$	Grd$_6$	2AE8271E7AD84C7AE1AA041B8036C3F12B8B172D ACC8156BF1F215D9576AC2C83C1310268ACBAB64 60575C3F03C80265CD1A1378C182D066E8AA1C94 31568F61F3A7D0E3D094C8FD	

Table 2-111: Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 6

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	8824242DFC18D01C1D9FE2EA3A208739268C0455 9A8D3427B92D7321AFAA620ECAF127418968DFBD F33A7335C8913D544C932D80C16EE3AE595A8C32 ACF9BBAD7F56F36BE673E3CB37B6C81F20DEE364 A7E3673F34FEDBEB6A5E02DD	[6]Pass$_R$	Grd$_1$	8824242DFC18D01C1D9FE2EA3A208739264DFF55 9A823427B92D73BEAFAA620ECAF127418968DFBD F33A7335C8913D544C932D80C16EE3AE595A4532 ACF9BBAD7F56F36BE673E3CB	Fail to report successful ground message.
2	72BCF39C45BDF37BE4EF5612768BD15F84DC224D 706E9A4A5F1C5EAF76651417972FD9FBABFCB446 5B86EF182BBF3AF5CF1507B147B3C9A508BF2526 C0DBABC58D4B5C3D991D0D1F7AE07E4138AC4674 E188F3280A705200B6721CDA	[7]Pass$_R$	Grd$_2$	11BCF39C45BDF37BE4EF5612768BD15F841DD94D 70619A4A5F1C5E3076651417972FD9FBABFCB446 5B86EF182BBF3AF5CF1507B147B3C9A508BFFC26 C0DBABC58D4B5C3D991D0D1F	
3	9DABB232FA665883B419661825B817547B33D07A 6D626A53DE7F777E535D8DC5046E9B98214DEF6C 0FAF564A9DAA56C09F9C07EDCCA1938DD9EFB585 C075C9CE818CEC15FDB545690BF93277F7B73333 B82FF7AD4D3DCCAC04C519B9	[8]Pass$_R$	Grd$_3$	FEABB232FA665883B419661825B817547BF22B7A 6D6D6A53DE7F77E1535D8DC5046E9B98214DEF6C 0FAF564A9DAA56C09F9C07EDCCA1938DD9EF6C01 C075C9CE818CEC15FDB54569	
4	FC16F8A76ABA5E283E5475D2CFF4EE9732304641 EB01DA21747BA99B95D622C18C3EB223E80A889B 056B1D100ED549E6FC90B4E106C25DF73C6144DC 10DA5423DCCAB0431A31348154AE671CA3AB4090 2E67739330E6AABB23276CAE	[9]Pass$_R$	Grd$_4$	9F16F8A76ABA5E283E5475D2CFF4EE9732F1BD41 EB0EDA21747BA90495D622068C3EB223E80A889B 056B1D100ED549E6FC90B4E106C25DF73C619D58 10DA5423DCCAB0431A313481	
5	65DFE725402C7047370B5CB16126F1E2EA5BAF98 BB502DF47F17DEBB25BA43D53869061FC64C38D5 BD538595F33DBDC4BD361EDD06770384432DA9F7 50A59C5CF2F0E9232305F80631E370B7DF7BA79F 4CE4E66B8CF63DD976C336EC	[10]Pass$_R$	Grd$_5$	06DFE725402C7047370B5CB16126F1E21D9A5498 BB5F2DF47F17DE2425BA43123869061FC64C38D5 BD538595F33DBDC4BD361EDD06770384432D7073 50A59C5CF2F0E9232305F806	
6	B790C3095B8168D5AA79915784A8AEAEA90EA174 8AEA2B40F515CA777B958ED9A254EF17D5DF1EA1 545A07C4F06D8D23E8F2D7FE66625D73E226FD38 99B1573731082660C6399187FF77DCD2870C4285 9F9FD883BB7585606C7EEC2C	[11]Fail$_R$	Grd$_6$	N/A	

Grd$_{10}$ – De-Interleaved RS Block number 10 of the Ground Uplink Message

Table 2-112: **Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 7**

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	EE861CFD253381E6603FE57D96F5A57F49EA4F7E EC0C384271146B84B5E2F4FC0F9331ECA2DDEFD0 A591C76EF6F07A4374DDFFA1072418FFB4B8AA0B CD2703C273EDEB8E8E42C30F2CDE8DE7AE2B38FB EC4D2883DF11105E8C1A98BA	$^{12}Fail_R$	Grd_1	N/A	Fail to report successful ground message.
2	9FF982E50315D76E51AA4C2F1E26E107C55E6D1A DECE757A24869B6A31ABE8E50FF4E0895D9A3A88 06B425C18D0E07428427DBAD5B6590934C1FE043 7457D1DD69D57115CAACA567DC911BC57BEAC439 1745324DA6079F3128CE4C90	$^{13}Fail_R$	Grd_2	N/A	
3	C951DA0A5252F8EF2B62B2CC5CB5160E1C2911BF EBF873E9646EABC9B36A20FBB7407D4B10DFB123 089850139ACC4FC446C7FE2A4AB248459D686BB7 A7E534878B1B675F0D172A41146399C158CCB437 9613571072B9795D6250A8DC	$^{14}Fail_R$	Grd_3	N/A	
4	E244AB2AF6378A616AD1EC69E7244EBD8459531F 56A8701D677932AF32CC6485E593025675779563 4ED3F37341580579CE090727952BE7A771C73C3E 1048E17EA06AD26BBB02461EBD517D5A3B0C1439 DAE5BADBFCC0A9782E76E64D	$^{0}Pass_R$	Grd_4	E244AB2AF6378A616AD1EC69E7244EBD8459531F 56A8701D677932AF32CC6485E593025675779563 4ED3F37341580579CE090727952BE7A771C73C3E 1048E17EA06AD26BBB02461E	
5	C9CD135376D1F2EF7E73AD6A5E5FB02633E12A1E 56C6AB0E055EE14F963F763A177311A54C08A3ED 764BEE9A4E26E6661B5462F7DD774C6A6A3A3885 F30E8132D5AB759C2B6421945091121BB5EC3B3F 2FBC259FEBA3E128B87D3E6A	$^{1}Pass_R$	Grd_5	C9CD135376D1F2EF7E73AD6A5E5FB02633E12A1E 56C6AB0E055EE1D0963F763A177311A54C08A3ED 764BEE9A4E26E6661B5462F7DD774C6A6A3A3885 F30E8132D5AB759C2B642194	
6	80F3B3FF275826117AE18F079E7E54200CFDA099 69BEC6550B920F619EC40157C806AC744DC0131F 87FEA01B3974570B87D92C322C162D489E776D26 D7FBD5FE61CF48E7CB9DD45CC294165AC8BEACEF D98FF05F06C787180D1E736D	$^{2}Pass_R$	Grd_6	80F3B3FF275826117AE18F079E7E54200CFDA099 69BEC6550B920FFE9EC40157C806AC744DC0131F 87FEA01B3974570B87D92C322C162D489E776D26 D7FBD5FE61CF48E7CB9DD45C	

Grd_8 – De-Interleaved RS Block number 8 of the Ground Uplink Message

Table 2-113: Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 8

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	DCD5CA18EEE56CDE61B72E8897CD1C015C5FE680 ABCE39A83DCEBEC3CDA3146B76C381F626D22F22 FF2F3FE8AC93014CF201940F11FACA44B7BBC368 26790142B75B04C3692F3F2EF1D07C4696B9851B AC3EFE9FC1D806672B251CFA	[3]$Pass_R$	Grd_1	DCD5CA18EEE56CDE61B72E8897CD1C015C5FE680 ABCE39A83DCEBE5CCDA3146B76C381F626D22F22 FF2F3FE8AC93014CF201940F11FACA44B7BB0A68 26790142B75B04C3692F3F2E	Report successful ground message.
2	2C913CB58D87CAC8F7C85268A52A2A958BFB6739 C9B64EA965624E8266E3C0B3976044E102C0EE69 61D542B7A702FEB6DAAE5A0C5174313EAA51EDB7 EF4CD93353D23B77F44667F715784CA08EE3C737 488E7EF13CEDBDE07968A8D7	[4]$Pass_R$	Grd_2	2C913CB58D87CAC8F7C85268A52A2A958BFB6739 C9B94EA965624E1D66E3C0B3976044E102C0EE69 61D542B7A702FEB6DAAE5A0C5174313EAA5124B7 EF4CD93353D23B77F44667F7	
3	0D7BC8B77E977092A9A228B3FBAC64F213968D5B 7CB7B78357D1C98C7696AE0D39418FBD2FF42F6A DF5DDA18A9D8A78D935555E3266E0ACF7D7E1266 B9224699896403AE6997E8D296D6F242846C091E 8693A357A535CFE9B6475394	[5]$Pass_R$	Grd_3	0D7BC8B77E977092A9A228B3FBAC64F213578D5B 7CB8B78357D1C9137696AE0D39418FBD2FF42F6A DF5DDA18A9D8A78D935555E3266E0ACF7D7EDB66 B9224699896403AE6997E8D2	
4	CC98BFB3DEE53D26FFE00A422BA4039605EADAB5 1540B26187D3551C7B73D633213F6A9547316B2A 92C4FEF96E075BA8115D8E5A84F57C7B1EB2B2CA D86E304A6FF3B0602E0F7C5CE91FE29DA52575FA 4F46BD46D34033DBBDE2E56D	[6]$Pass_R$	Grd_4	CC98BFB3DEE53D26FFE00A422BA40396052B21B5 154FB26187D355837B73D633213F6A9547316B2A 92C4FEF96E075BA8115D8E5A84F57C7B1EB27BCA D86E304A6FF3B0602E0F7C5C	
5	8B7D4BA276B7CD2EA750DA4127E4B1D21D19D627 1C6E332631092B5486C6C05105BC4AE76C499A22 B4F283EBC1DADF2738D2E8CD019B222C4409E322 64910873CCE91B0A20448451CB78D69583ADC02E 7017F1079F099E13A1EAAF76	[7]$Pass_R$	Grd_5	E87D4BA276B7CD2EA750DA4127E4B1D21DD82D27 1C61332631092BCB86C6C05105BC4AE76C499A22 B4F283EBC1DADF2738D2E8CD019B222C44093A22 64910873CCE91B0A20448451	
6	64E7C86E398F9D8D07E0EE88675E4215E8F006C2 812DAA7E8A9C204202A4545ECF06AD719B2C046B 0674C4B553E1DCEB45EFDD203B980384EAA326CE AADBD4412857FAB2164B2F7BC7A727F865A9CD59 EE2F862A9E3F9E5DD915FA4C	[8]$Pass_R$	Grd_6	07E7C86E398F9D8D07E0EE88675E4215E831FDC2 8122AA7E8A9C20DD02A4545ECF06AD719B2C046B 0674C4B553E1DCEB45EFDD203B980384EAA3FF4A AADBD4412857FAB2164B2F7B	

Grd_6 – De-Interleaved RS Block number 6 of the Ground Uplink Message

Table 2-114: Six consecutive De-Interleaved RS Block Values of a Ground Uplink Message – Set 9

No.	De-Interleaved six constituent erroneous RS Blocks	Status (RS Blk)	Type	De-Interleaved six constituent RS Decoded Blocks	Status (Grd Msg)
1	763733C8ED4DBF145FEB8341130EEF6C013E5CCA D142D542099A3C9C7C01BE977704C7450442BB3F 277CDC422E8C536EC1E8C571D850AB81D2441843 C65057CA566B534504CF28777453237FB4F0DC73 E0D1675E7A8B759E4A2ADD89	[9]Pass$_R$	Grd$_1$	153733C8ED4DBF145FEB8341130EEF6C01FFA7CA D14DD542099A3C037C01BE507704C7450442BB3F 277CDC422E8C536EC1E8C571D850AB81D244C1C7 C65057CA566B534504CF2877	Fail to report successful ground message.
2	09301CD0D514141888C6CB604033AC71B1396479 10BBA2233B2FEA67037E5C5F6146373078979CCA 1138F2502EB435D70D152E24971A4D6598C8BE1B 3BC73853223368B7A57E5C3CA2233FDD7F14A16E 8D0C15B75A4BB555C76EB524	[10]Pass$_R$	Grd$_2$	6A301CD0D514141888C6CB604033AC7146F89F79 10B4A2233B2FEAF8037E5C986146373078979CCA 1138F2502EB435D70D152E24971A4D6598C8679F 3BC73853223368B7A57E5C3C	
3	9D8EB50DED0A24CF30A60A6BC06186F048A51E92 06151C2B2A21ADCD9423C4325607D1F5ECD8DDC6 9D6F1281925F84786A60C838E5D6ED7A5BEA9079 1C564DD482B24B803E4049FFE5220D7D42F51BC6 31B01B88E250CA9DED03F0AA	[11]Fail$_R$	Grd$_3$	N/A	
4	C9E6E930385F7E8333D03390FDD417EB8E633BCE 3C55F00B5029C72D1850D2D58CF17C54029CB1EE 1B7D8F2C97DD8401AD8D5F6C14E5AC9EF253EEAE 540BE9675EC17260624A5EE813DF26EAA544065C A814364890A9D330D434CD70	[12]Fail$_R$	Grd$_4$	N/A	
5	65628B331E31290D05A3B20FEA2584E709477896 71E5813E071710C8718B4AB3396616DDA28079BA 70900C8829B6FD93EE4D62BB125A9028B17CCDD7 697A3D69E3C6657AD9F1EF04F7247971CE5D6470 D0D1DEB3EEC2B6949CFB8A6D	[13]Fail$_R$	Grd$_5$	N/A	
6	27B5033B5C2EA4A5A0E429707DBB950E2B2F9281 ABAC03F48C42DCF41B9E097C3A60EF9CB51306F0 D43E74A29B618C284C1DFC223989EC14BE6BA222 E296C784ED32F1B80A5E36A18ABC263A6A8461EA A24857393D9A264D45D734CF	[14]Fail$_R$	Grd$_6$	N/A	

Grd$_2$–De-Interleaved RS Block number 2 of the Ground Uplink Message

2.4.8.3.2 Verification of Receiver Discrimination Between ADS-B and Ground Uplink Message Types (§2.2.8.3.2)

Purpose/Introduction:

The receiver **shall** determine the message type by means of the correlation between the received bits, and the synchronization sequences given in §2.2.3.1.1 and §2.2.3.2.1.

Note: *Specifically, the receiver should not attempt to distinguish ADS-B Messages from Ground Uplink Messages by their position in the UAT frame.*

The following test procedure verifies that the UAT receiver system correctly differentiates ADS-B Messages from Ground Uplink Message Types regardless of their position in the UAT frame as defined in §2.2.8.3.2.

Equipment Required:

Provide a method such that controlled Ground Uplink Message Data can be supplied to the appropriate ADS-B UAT Receiver at any given time of UAT frame with a resolution of at least 100 nanoseconds. Also provide a method such that an ADS-B Message can be supplied to the appropriate ADS-B UAT Receiver at any given time of UAT frame with a resolution of at least 100 nanoseconds.

Measurement Procedures:

a. Apply a valid Ground Uplink Message to the Receiver Interface 250 milliseconds away from the UTC Time mark such that the first bit of the synchronization sequence of the transmitted Ground Uplink Message is 250 milliseconds offset from UTC Time Mark.

b. Verify that the UAT receiver declares the Successful Message Reception of a Ground Uplink Message.

c. Apply a valid ADS-B Message to the Receiver Interface 100 milliseconds away from the UTC Time mark such that the first bit of the synchronization sequence of the transmitted ADS-B Message is 100 milliseconds offset from UTC Time Mark.

d. Verify that the UAT receiver declares the Successful Message Reception of an ADS-B Message.

2.4.8.3.3 Verification of Receiver Processing of ADS-B Synchronization "Trigger" (§2.2.8.3.3)

Purpose/Introduction:

Receivers **shall** meet the following message processing requirements:

a. When an initial ADS-B trigger occurs (no message decode in progress), the decode process associated with this trigger **shall** be completed regardless of other trigger activity subsequently detected.

b. The decode process associated with a second, subsequent ADS-B trigger event that occurs during the Message Reception process of an initial ADS-B trigger event **shall** also be completed regardless of other trigger activity subsequently detected.

c. The decode process associated with a third ADS-B trigger event that occurs during the simultaneous decoding of an initial and second ADS-B trigger **shall** also be completed regardless of other trigger activity subsequently detected.

d. The decode process associated with a fourth ADS-B trigger event that occurs during the simultaneous decoding of the second and third ADS-B trigger **shall** also be completed, provided that the fourth trigger event begins not earlier than 28 bit periods after the completion of the reception of the message associated with the initial ADS-B trigger event.

Notes:

1. *Detection of the ADS-B synchronization sequence is referred to as a "trigger."*

2. *These requirements ensure that the receiver "re-trigger" procedure does not abandon the initial trigger when a close match to the sync pattern appears in the payload, and that the transmitter need not preclude the sync pattern from occurring in the payload.*

3. *From simulation, this three-level decoding depth also assures that — in the highest self interference environments — the receiver will be >99.5% efficient in decoding of all ADS-B Messages that appear at the receiver with an adequate SIR for Successful Message Reception.*

4. *See Appendix H for one potential method to implement a "re-trigger" capability of the synchronization mechanism, and for a recommended synchronization threshold value for ADS-B.*

5. *During decoding of an ADS-B trigger, it is acceptable for the receiver to be "locked out" to Ground Uplink triggers.*

This test verifies the compliance of the UAT receiver with the requirements for detection and processing of ADS-B Synchronization trigger events.

Equipment Required:

Provide a method of supplying the UUT with a single source of desired bit patterns, each of which contains at least one complete valid Long ADS-B message. The content of the messages shall be selected from among the following three Data Sets, as specified in the test procedure Steps. The rate of message generation should be selected to allow for convenient measurement.

These Data Sets define what may be considered the entire time span of up to three overlapping Long ADS-B Messages. Each Data Set begins with the ADS-B Sync pattern (right-justified to 5 bytes as 0x0EACDDA4E2), and ends with a valid FEC encoding parity field that is calculated over only the final 34 payload bytes immediately preceding it. Data Sets 2, 3, 4 and 5 contain at least one additional embedded Sync pattern. Bytes labeled 'PN' may be filled with pseudo-random data as necessary. The Parity bytes are labeled 'P1' through 'P14.'

Data Set 1 consists of a Long ADS-B Message whose payload content includes the ADS-B Sync pattern. One such pattern is listed below.

Byte #	Data							
1-8	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
9-16	PN	PN	PN	PN	PN	PN	PN	PN
17-24	PN	PN	PN	PN	PN	PN	PN	PN
25-32	PN	PN	PN	PN	PN	PN	PN	PN
33-40	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	P1
41-48	P2	P3	P4	P5	P6	P7	P8	P9
49-53	P10	P11	P12	P13	P14			

Data Set 2 consists of an ADS-B Sync pattern, followed by 11 bytes of PN data, followed by a valid Long ADS-B Message. One such pattern is listed below. The Parity field is computed over Bytes 22 through 55.

Byte #	Data							
1-8	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
9-16	PN	PN	PN	PN	PN	PN	PN	PN
17-24	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
25-32	PN	PN	PN	PN	PN	PN	PN	PN
33-40	PN	PN	PN	PN	PN	PN	PN	PN
41-48	PN	PN	PN	PN	PN	PN	PN	PN
49-56	PN	PN	PN	PN	PN	PN	PN	P1
57-64	P2	P3	P4	P5	P6	P7	P8	P9
65-69	P10	P11	P12	P13	P14			

Data Set 3 consists of an ADS-B Sync pattern, followed by 11 bytes of data, followed by a second ADS-B Sync pattern, followed by 11 bytes of data, followed by a valid Long ADS-B Message. One such pattern is listed below. The Parity field is computed over Bytes 38 through 71.

Byte #	Data							
1-8	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
9-16	PN	PN	PN	PN	PN	PN	PN	PN
17-24	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
25-32	PN	PN	PN	PN	PN	PN	PN	PN
33-40	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
41-48	PN	PN	PN	PN	PN	PN	PN	PN
49-56	PN	PN	PN	PN	PN	PN	PN	PN
57-64	PN	PN	PN	PN	PN	PN	PN	PN
65-72	PN	PN	PN	PN	PN	PN	PN	P1
73-80	P2	P3	P4	P5	P6	P7	P8	P9
81-85	P10	P11	P12	P13	P14			

Data Set 4 consists of an ADS-B Sync pattern, followed by 11 bytes of data, followed by a second ADS-B Sync pattern, followed by 11 bytes of data, followed by a third Sync pattern, followed by 19 bytes of data, followed by a fourth Sync pattern and a valid Long ADS-B Message corresponding to the third Sync pattern. One such pattern is listed below. The Parity field is computed over Bytes 38 through 71.

Byte #	**Data**							
1-8	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
9-16	PN	PN	PN	PN	PN	PN	PN	PN
17-24	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
25-32	PN	PN	PN	PN	PN	PN	PN	PN
33-40	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
41-48	PN	PN	PN	PN	PN	PN	PN	PN
49-56	PN	PN	PN	PN	PN	PN	PN	PN
57-64	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
65-72	PN	PN	PN	PN	PN	PN	PN	P1
73-80	P2	P3	P4	P5	P6	P7	P8	P9
81-88	P10	P11	P12	P13	P14	PN	PN	PN

Data Set 5 consists of an ADS-B Sync pattern, followed by 11 bytes of data, followed by a second ADS-B Sync pattern, followed by 11 bytes of data, followed by a third Sync pattern, followed by 19 bytes of data, followed by a fourth Sync pattern, and a valid Long ADS-B Message corresponding to the fourth Sync pattern. One such pattern is listed below. The Parity field is computed over Bytes 62 through 95.

Byte #	Data							
1-8	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
9-16	PN	PN	PN	PN	PN	PN	PN	PN
17-24	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
25-32	PN	PN	PN	PN	PN	PN	PN	PN
33-40	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
41-48	PN	PN	PN	PN	PN	PN	PN	PN
49-56	PN	PN	PN	PN	PN	PN	PN	PN
57-64	0x0E	0xAC	0xDD	0xA4	0xE2	PN	PN	PN
65-72	PN	PN	PN	PN	PN	PN	PN	PN
73-80	PN	PN	PN	PN	PN	PN	PN	PN
81-88	PN	PN	PN	PN	PN	PN	PN	PN
89-96	PN	PN	PN	PN	PN	PN	PN	P1
97-104	P2	P3	P4	P5	P6	P7	P8	P9
105-112	P10	P11	P12	P13	P14	PN	PN	PN

Measurement Procedures:

Step 1: Verification of §2.2.8.3.3.a (Initial Trigger Processing Completed)

Configure the message source to generate Data Set 1.

Verify that at least 10 messages from Data Set 1 are successfully received.

Step 2: Verification of §2.2.8.3.3.b (Second Trigger Processing Completed)

Configure the message source to generate Data Set 2.

Verify that at least 10 messages from Data Set 2 are successfully received.

Step 3: Verification of §2.2.8.3.3.c (Third Trigger Processing Completed)

Configure the message source to generate Data Set 3.

Verify that at least 10 messages from Data Set 3 are successfully received.

Step 4: Verification of §2.2.8.3.3.c (Third Trigger Processing Completed)

Configure the message source to generate Data Set 4.

Verify that at least 10 messages from Data Set 4 are successfully received.

Step 5: Verification of §2.2.8.3.3.c (Third Trigger Processing Completed)

Configure the message source to generate Data Set 5.

Verify that at least 10 messages from Data Set 5 are successfully received.

2.4.8.3.4 Verification of Receiver Processing of Ground Uplink Synchronization "Trigger" (§2.2.8.3.4)

Purpose/Introduction:

Receivers **shall** meet the following message processing requirements:

a. When an initial Ground Uplink trigger occurs (no message decode in progress), the decode process associated with this trigger shall be completed regardless of other trigger activity subsequently detected.

b. A second, subsequent Ground Uplink trigger event that occurs during the decode process of an initial Ground Uplink trigger event shall also be completed regardless of other trigger activity subsequently detected.

Notes:

1. *This two-level decoding depth assures that a strong Ground Uplink Message will be decoded when a distant (>200 NM) station on the preceding time slot triggers the receiver. This minimizes planning constraints when assigning slot resources to ground stations.*

2. *See Appendix H for one potential method to implement a "re-trigger" capability of the synchronization mechanism.*

3. *During reception of a Ground Uplink Message, it is acceptable for the receiver to be "locked out" to ADS-B triggers.*

This test procedure verifies the compliance of the UAT receiver with the requirements for detection and processing of Ground Uplink Synchronization trigger events.

Equipment Required:

Desired Message Signals:

Provide a method of supplying the UUT with two sources of desired Ground Uplink Messages. The center of the first bit of the Ground Uplink Synchronization pattern of the 1st message source is the timing reference T_0. The 2nd message source transmits at a time offset from the reference time T_0. The RF signal level and time offset of each message source is set per the specific procedure step. The data contents and rates for the message sources are:

Message Contents for all Message Sources:

- TIS-B Site ID (bits 1 through 4 of byte 8): Message Source 1 = 0x1, Message Source 2 = 0x2.
- Bit 1 of byte 25 through bit 4 of byte 29 (36 bits): Fill these bits with data corresponding to the Ground Uplink Synchronization Pattern (see §2.2.3.2.1). This is referred to as the "embedded sync pattern."
- Fill remaining payload (bit 1 of byte 1 through bit 8 of byte 7, bit 5 of byte 8 through bit 8 of byte 24, and bit 5 of byte 29 through bit 8 of byte 432) with pseudo-random payload data, with interleaving and FEC Parity field per §2.2.3.2.3.
- Message Rate: 1 per second for each message source.

Measurement Procedure:

The signal power level specified in this procedure is relative to the message source end of the transmission line used to interface the UUT receiver port to the message source. The specified RF power level applied to the UUT shall be compensated for the maximum line loss for which the UUT receiver has been designed. For example, if the line loss is 3 dB, then each of the RF message power levels specified in the test procedures shall be lowered by 3 dB.

Step 1: Apply Ground Uplink Input Messages and test for non-overlapping reception

Apply the **Desired Message Signals** at the UUT receiver input port. Set the RF signal levels and time offset so that:

Message Source 1: -85 dBm	Time Offset: 0.0 milliseconds.
Message Source 2: -70 dBm	Time Offset: 5.5 milliseconds.

Observe that the UUT equipment reports reception of messages with both TIS-B site IDs 0x1 and 0x2 at a success rate of 99% or greater.

Note: *This procedure verifies the requirements of §2.2.8.3.4.a, in that the embedded Synchronization pattern in the Message Source 1 data does not prevent the reception of that message, nor does it prevent the reception of the non-overlapping message supplied by Message Source 2.*

Step 2: Apply ADS-B Input Messages and test for one overlapping reception

Apply the **Desired Message Signals** at the UUT receiver input port. Set the RF signal levels and time offset so that:

Message Source 1: -85 dBm	Time Offset: 0.0 milliseconds.
Message Source 2: -70 dBm	Time Offset: 1.0 milliseconds.

Observe that the UUT equipment reports reception of only messages with TIS-B Site ID = 0x2, at a success rate of 99% or greater.

Note: *This procedure verifies the requirements of §2.2.8.3.4.b, in that the louder overlapping message is properly detected and reported.*

2.4.8.3.5 Verification of Receiver Time of Message Receipt (§2.2.8.3.5)

Purpose/Introduction:

The receiver **shall** declare a Time of Message Receipt (TOMR) and include this as part of the report issued to the on-board application systems. The TOMR value **shall** be reported to within the parameters listed below:

a. Range of at least 25 seconds expressed as seconds since UTC midnight modulo the range.

b. Resolution of 100 nanoseconds or less.

c. Accuracy of ±500 nanoseconds relative to the optimum sample point of the first bit of the synchronization sequence applied at the receiver terminals for UAT equipment using either an internal, or external UTC coupled time source.

d. The reported TOMR will be equal to the following quantity: seconds since the previous UTC midnight modulo the specified TOMR range.

Note: *TOMR is required to support ADS-B Time of Applicability (TOA) and range validation by a receiving application. See Appendix I for a discussion of UAT Timing Considerations. ADS-B applications derive the TOA from the TOMR as follows:*

1. *If the report indicates UTC Coupled, and is in the Non-Precision Condition, the TOA is the TOMR truncated to the start of the UTC second.*

2. *If the report indicates UTC Coupled, and is in the Precision Condition, the TOA is the TOMR truncated to the start of the 0.20 second UTC epoch containing the TOMR.*

3. *If the report indicates Non-UTC Coupled, the TOA is the TOMR minus one (1) second.*

The purpose of this test procedure is to verify that the Time of Message Receipt is declared by the receiver as a part of the report issued to the on-board application systems according to the parameters outlined in §2.2.8.3.5.

Equipment Required:

Provide equipment capable of supplying valid ADS-B and Ground Uplink Messages to the ADS-B Receiving Subsystem being tested. Provide an Elapse Timer with a resolution of at least 100 nanoseconds.

Measurement Procedure:

Step 1: Apply messages to the receiver and verify the TOMR output

Apply a valid ADS-B Message to the receiver with the optimum sampling point of the first bit of the synchronization sequence, applied at the receiver terminals, arriving at 900 milliseconds ±100 nanoseconds after the leading edge of the UTC Time Mark. Verify that the TOMR reported at the output of the ADS-B Receiving Subsystem for the ADS-B Message has a value of 900 milliseconds ±600 nanoseconds relative to the time of the UTC Time Mark.

Apply a valid Ground Uplink Message to the receiver with the optimum sampling point of the first bit of the synchronization sequence, applied at the receiver terminals, arriving at 100 milliseconds ±100 nanoseconds after the leading edge of the UTC Time Mark. Verify that the TOMR reported at the output of the ADS-B Receiving Subsystem for the Ground Uplink Message has a value of 100 milliseconds ±600 nanoseconds relative to the time of the UTC Time Mark.

2.4.9 Verification of Report Assembly Requirements (§2.2.9)

Appropriate test procedures required to validate the requirements of §2.2.9 are included in §2.4.9.1 and §2.4.9.2.

2.4.9.1 Verification of Report Assembly on Receipt of ADS-B Message (§2.2.9.1)

Purpose/Introduction:

Reports **shall** contain the following information:

a. All elements of the received message payload applicable to the ADS-B report type with range, resolution and units of each payload field preserved.

b. The Time of Message Receipt value measured by the receiver.

Note: *Time of Applicability may be derived by the receiving application from the TOMR.*

Equipment Required:

Use the equipment required for the test procedure in §2.4.10.3.

Measurement Procedures:

This test procedure verifies the requirements of §2.2.9.1. Note that verification of requirements for the Time of Message Receipt value is covered in §2.4.8.3.5, and is not further verified here.

Note: *This test procedure can be performed simultaneously with the procedure of §2.4.10.3.*

Step 1: Perform Applicable Message Reception.

Perform the test procedure provided in §2.4.10.3, Steps 1 through 3.

Step 2: Verify Report Assembly

For all Applicable ADS-B Messages, verify that each Report delivered to the external interface contains a Time of Message Reception value. Verify that the range, resolution, and units of each report element are preserved from their value that was transmitted by the RF test signal source.

2.4.9.2 Verification of Report Assembly on Receipt of Ground Uplink Message (§2.2.9.2)

Purpose/Introduction:

Reports **shall** contain the following information:

a. The 432 byte received message payload unaltered.

b. The Time of Message Receipt value measured by the receiver.

Note: *Time of Applicability may be derived by the receiving application from the TOMR.*

Equipment Required:

Use the equipment required for the test procedure in §2.4.10.3.

Measurement Procedures:

This test procedure verifies the requirements of §2.2.9.2. Note that verification of requirements for the Time of Message Receipt value is covered in §2.4.8.3.5, and is not further verified here.

Note: *This test procedure can be performed simultaneously with the procedure of §2.4.10.3.*

Step 1: Perform Applicable Message reception.

Perform the test procedure provided in §2.4.10.3, Steps 1 through 3.

Step 2: Verify Report Assembly

For all Applicable Ground Uplink Messages, verify that each Report delivered to the external interface contains a Time of Message Reception value. Verify that Uplink Header and Application Data contained in the Report are preserved from their value that was transmitted by the RF test signal source.

2.4.10 Verification of Receiver Subsystem Capacity and Throughput Requirements (§2.2.10)

Appropriate test procedures required to validate the requirements in §2.2.10 are included in §2.4.10.2, §2.4.10.3 and §2.4.10.4.

2.4.10.1 Verification of Fundamental Principals of Report Assembly (§2.2.10.1)

No specific test procedure is required to validate §2.2.10.1.

2.4.10.2 Verification of Capacity for Successful Message Reception (§2.2.10.2)

Purpose/Introduction:

Receiving subsystems shall demonstrate the ability to perform Successful Message Reception at the message input rates specified in Table 2-66.

Equipment Required:

Provide a means to generate an RF test signal consisting of the appropriate number and proportion of unique, valid Long and Basic ADS-B Messages, and Ground Uplink Messages, for the equipment class, with the following characteristics:

a. Number of messages:

   The messages consist of 32 Ground Uplink Messages per second, and **either** 600 ADS-B Messages per second (for equipment classes A0, A1S and A1L), **or** 700 ADS-B Messages per second (for equipment classes A1H, A2, and A3).

b. Proportion of ADS-B Messages:

   The ADS-B Messages should be proportioned such that 80% are Long messages (approximately 10% each for Payload Type Codes 1 through 6, and 5% each for Payload Type Codes 7 through 10), and 20% are Basic messages (Payload Type Code 0).

c. Message Spacing:

   One Uplink message is placed in each Uplink time slot.

   During each 1-second interval, 20 of the ADS-B Messages should be uniformly spaced without overlap over a 10 millisecond "peak" interval. The remaining portion of the ADS-B Messages should be uniformly spaced over the remainder of the ADS-B Segment of each second. The start time of the peak interval in the first second of the test is 200 milliseconds after the UTC time mark signal. In each subsequent second, the start time of the peak interval is delayed by an additional 100 milliseconds. The start time of the peak interval is reset to 200 milliseconds after every 8^{th} second.

Measurement Procedures:

The equipment under test must provide a means to confirm the reception of each of the messages contained in the RF test signal. Suitable means could include the delivery of each message to the equipment's external report interface, internal data recording which can be reviewed post-test to verify equipment performance, or other suitable means.

If the equipment under test is designed for the transmit function to be placed into a "standby" mode, it is permissible to do so during the performance of this test. If the equipment does not support a "standby" function, care should be taken to prevent the transmitted signals from damaging the RF test generator.

Step 1: Equipment Setup

Apply the RF test signal to the equipment under test, with a signal strength of –80 dBm at the equipment antenna port. Supply the equipment under test and the test signal generator with a suitable UTC time reference signal.

Step 2: Perform Message Receptions

Allow the equipment under test to receive the test messages for a minimum of 8 seconds.

Step 3: Verify Reception Performance

Using the means provided by the equipment, verify that all test messages contain the intended payload data that was provided in each test message, for both ADS-B and Ground Uplink Messages.

Step 4: Repeat Test for Each Antenna Port

Perform Steps 1 through 3 for each antenna port that the equipment provides. This verifies the requirements of §2.2.10.2.

2.4.10.3 Verification of Applicable Messages (§2.2.10.3)

Purpose/Introduction:

Applicable Messages are defined as those requiring Report Assembly. Successful Messages are deemed to be Applicable Messages according to the criteria below:

a. For Successful Message Reception of ADS-B Messages of PAYLOAD TYPE ZERO (binary 0 0000) through TEN (binary 0 1010), one of the following two criteria **shall** apply:

   1. All Successful Message Receptions are Applicable Messages, OR

   2. All Successful Message Receptions are from targets within the "Range Limit" (in NM) for up to the "Target Limit" number of targets, where "Range Limit" and "Target Limit" are listed in Table 2-67 by equipment class. If the "Target Limit" number of targets is exceeded within the "Range Limit," such that ADS-B Messages are discarded, then all such discarded ADS-B Messages shall be at greater range than any reported ADS-B Messages.

b. For Successful Message Reception of Ground Uplink Messages, one of the following two criteria **shall** apply:

   1. All Successful Message Receptions, OR

   2. Only those Successful Message Receptions from ground stations within the range criteria from Table 2-68.

Equipment Required:

Use the RF test signal set as defined in §2.4.10.2, with the addition that the geographic locations contained in the message payloads for ADS-B and Uplink messages should conform with the range limitations of Table 2-67 and Table 2-68 for the equipment class under test.

Measurement Procedures:

The equipment under test must provide a means to confirm the Report Assembly for each Applicable Message. For equipment that complies with §2.2.10.3.a.1, the "Equipment Required" and "Measurement Procedure" given in §2.4.10.2 is appropriate. The method of verifying Report Assembly for Successful Message Reception could include delivery of each message to the equipment's external report interface, an internal data recording which can be reviewed post-test to verify equipment performance, or other appropriate means.

The following procedure applies to equipment that complies with §2.2.10.3.a.2. (i.e., Applicable Messages are only those Successful Messages that meet the range filter criteria). Note that this procedure need be performed on only one of the equipment's antenna ports.

Step 1: Equipment Setup

Apply the RF test signal to the equipment under test, with a signal strength of –80 dBm at the equipment antenna port. Supply the equipment under test and the test signal generator with a suitable UTC time reference signal. Supply the equipment under test with a suitable position reference.

Step 2: Perform Message Receptions

Allow the equipment under test to receive the test messages for a minimum of 8 seconds.

Step 3: Verify All Applicable Messages

Using an appropriate means (as discussed above), verify that the equipment under test assembles a report for all messages that meet the range criteria.

Step 4: Increase the number of test targets that are within the range criteria

Modify the geographic position contained in the ADS-B and Ground Uplink test messages, such that the number of targets that are within the range criteria of Table 2-67 and Table 2-68 is increased by ten (10) percent.

Step 5: Perform Message Receptions

Allow the equipment under test to receive the test messages for a minimum of 8 seconds.

Step 6: Verify All Applicable Messages

Using an appropriate means (as discussed above), verify that the equipment under test assembles a report for the number of targets and Ground Stations shown in Table 2-67 and Table 2-68, which are most proximate to the position reference given to the equipment under test in Step 1.

2.4.10.4 Verification of Message Reception-to-Report Completion Time (§2.2.10.4)

Purpose/Introduction:

All ADS-B Applicable Messages **shall** be output from the Report Assembly Function within 200 milliseconds of message input.

All Ground Uplink Applicable Messages **shall** be output from the Report Assembly Function within 500 milliseconds of message input.

Equipment Required:

Use the RF test signal set as defined in §2.4.10.3.

Measurement Procedures:

The time delay between Message Reception and Report Completion can be measured by utilizing an internal time-stamp that is recorded at the instant of that Report Completion has occurred. These time stamps can be provided by the equipment under test, such as an internal data log, or through use of an external device that applies time stamps to reports that appear at the equipment's external interface. Other suitable means may be provided by the manufacturer.

Step 1: Equipment Setup and Test Conduct

Perform Steps 1 through 3 of §2.4.10.2.

Step 2: Measure the Reception-to-Report Completion Time

For each message that results in an Applicable Message, and therefore results in report delivery to the external interface, compute the difference between the time the message was transmitted by the RF test signal generator, and the Report Completion time. Verify that the Message-to-Report Completion time does not exceed 200 milliseconds for ADS-B Messages, and 500 milliseconds for Ground Uplink Messages.

2.4.11 Verification of Special Requirements for Transceiver Implementations (§2.2.11)

No specific test procedure is required to validate §2.2.11.

2.4.11.1 Verification of Transmit-Receive Turnaround Time (§2.2.11.1)

Purpose/Introduction:

A transceiver **shall** be capable of switching from transmission to reception within 2 milliseconds.

Note: *Transmit to receive switching time is defined as the time between the optimum sampling point of the last information bit of one transmit message and the optimum sampling point of the first bit of the synchronization sequence of the subsequent receive message.*

Equipment Required:

Provide a means to generate an RF test signal that contains two valid Long ADS-B Messages, separated in time such that the time interval between the middle of the last parity bit of the first message (A), and the middle of the first symbol of the synchronization pattern of the second message (B), is 4,402.24 ±0.25 microseconds. This represents the sum of 2 milliseconds for receive-to-transmit delay, 2 milliseconds for transmit-to-receive delay, and the duration of a Long ADS-B Message between the middle of the first and last bits.

Provide the RF test signal generator with an appropriate UTC time mark reference.

With reference to the UTC time mark signal, message (A) above should begin at the time specified in Step 1 below.

Provide a means to verify reception of ADS-B Messages by the equipment under test.

Measurement Procedures:

This test procedure verifies the requirements of both §2.2.11.1 and §2.2.11.2.

Step 1: Equipment Setup

Configure the equipment under test to transmit one valid Long ADS-B Message per second using a fixed Tx MSO value. Configure the RF test signal generator such that message (A) begins 2,402.24 ±0.25 microseconds prior to the selected Tx MSO.

Step 2: Perform message reception and transmission

Allow the equipment under test to receive messages from the RF test signal generator, and to transmit one ADS-B Message per second.

Step 3: Verify performance

Verify that the equipment under test receives both messages (A) and (B), while transmitting one ADS-B Message per second.

2.4.11.2 Verification of Receive-Transmit Turnaround Time (§2.2.11.2)

Appropriate test procedures required to validate the requirements of §2.2.11.2 are included in §2.4.11.1.

2.4.12 Verification of Mutual Suppression Pulses (§2.2.12)

Purpose/Introduction:

UAT equipment **shall** provide an output signal suitable for sending suppression signals. The UAT equipment **shall** provide a mutual suppression signal whenever the transmitter output power exceeds –20 dBm. In addition, the suppression signal **shall not** become active prior to 5 microseconds before the start of the ADS-B Message Transmission Interval defined in §2.2.2.5, and the suppression signal **shall not** remain active later than 5 microseconds after the end of the ADS-B Message Transmission Interval defined in §2.2.2.5.

UAT equipment **shall not** respond to suppression signals.

Note: *UAT equipment is not to inhibit or delay its transmissions based on suppression signals. There is no need to desensitize the UAT Receiver based on suppression signals.*

Equipment:

Provide an oscilloscope, an RF detector that provides a trigger output when the input level exceeds –20 dBm, and a load for the suppression output signal that is characteristic of the intended application.

Measurement Procedures:

Step 1: ADS-B Basic Message Suppression Interval

Configure the UAT equipment to transmit valid ADS-B Basic Messages. Connect the suppression output signal to the load. Connect the oscilloscope to the RF detector (trigger input) and the suppression signal (scope Channel A). Verify that the rising and falling edges of the suppression output signal occur within 5 microseconds of the RF detector trigger points.

Step 2: ADS-B Long Message Suppression Interval

Configure the UAT equipment to transmit valid ADS-B Long Messages. Verify that the rising and falling edges of the suppression output signal occur within 5 microseconds of the RF detector trigger points.

2.4.13 Verification of Self Test and Monitors (§2.2.13)

No specific test procedure is required to validate §2.2.13.

2.4.13.1 Verification of Self Test (§2.2.13.1)

Purpose/Introduction:

If the equipment transmits special UAT Messages for self test:

a. The device which radiates test UAT Messages or prevents messages from being broadcast during the test period **shall** be limited to no longer than that required to determine the status of the system.

b. The self-test message signal level at the antenna end of the transmission line **shall** not exceed -40 dBm.

c. If provision is made for automatic periodic self-test procedure, such self-testing **shall** not radiate UAT Messages at a rate exceeding one broadcast every ten seconds.

Equipment Required:

Provide a method of loading valid data for ADS-B broadcast messages into the UAT equipment under test. Provide a Wide Band Dual Channel Oscilloscope (HP 1710, or equivalent). Provide a method of detecting and monitoring UAT Broadcast Messages.

Measurement Procedures:

Load valid data into the UAT Transmitting Subsystem and verify that the appropriate message is transmitted. Monitor all UAT Broadcast Messages for the occurrence of the provided test message.

Verify that the power of the test message does not exceed –40 dBm.

Verify that the average rate of the provided test message occurrences does not exceed one in a 10 second interval.

2.4.13.2 Verification of Broadcast Monitoring (§2.2.13.2)

Purpose/Introduction:

A monitor **shall** be provided to verify that UAT Message transmissions are generated per the schedule defined in §2.2.6.1. If any of the UAT Message types for which the equipment is certified is not transmitted, then the equipment **shall** be considered as failed and the appropriate "Fail/Warn" indicators **shall** be set to the "Fail/Warn" state.

Measurement Procedure:

Step 1: Verification of Device Failure Declaration

Provide a method of transmitting UAT Messages such that they are missing one or more of the message types defined in §2.2.6.1. Transmit such a message and verify that the equipment declares a device failure.

2.4.13.3 Verification of Address Verification (§2.2.13.3)

Purpose/Introduction:

The UAT transmission device **shall** declare a device failure in the event that it's own ICAO 24-bit Address (if required to have a ICAO 24 bit address) is set to all "ZEROs" or all "ONEs."

Measurement Procedure:

Step 1: Verification of Transmitter Device Failure Declaration

Set up the UAT Transmitting Subsystem for the transmission of UAT Messages. Input a message with the address field set to all ZEROs (hex 00 00 00) and verify that the UAT Transmitting Subsystem declares a device failure. Repeat this step with the address field set to all ONEs (hex FF FF FF) and again verify that the UAT Transmitting Subsystem declares a device failure.

2.4.13.4 Verification of Receiver Self-Test Capability (§2.2.13.4)

Purpose/Introduction:

UAT Receiving Subsystems **shall** be designed to provide sufficient self-test capability to detect a loss of capability to receive UAT Messages, structure appropriate ADS-B reports, and make such reports available to the intended user interface. Should the receiving device detect that any of these basic functions cannot be performed properly, then the receiving device **shall** be considered as failed and the appropriate "Fail/Warn" indicators **shall** be set to the "Fail/Warn" state.

Equipment Required:

Provide a method of supplying the Receiving function under test with UAT Broadcast Messages. Provide a method of receiving and storing all Output Messages or Reports generated by the receiving function under test. Provide a method of analyzing the Output Messages or Reports generated by the Receiving function under test.

Provide a method of inducing a fault condition into the Receiving function such that it can no longer properly receive and process UAT Broadcast messages.

Note: *The manufacturer shall provide a method of inducing or simulating failure of the ADS-B Broadcast Message reception capability. This may be done by appropriate Software Test provisions or may require that the unit under test be opened in order to provide access to the internal circuitry.*

Measurement Procedure:

Step 1: Establish the UAT Broadcast Message Stimulus

Configure the UAT Broadcast Message simulation function to provide the UAT Receiving Subsystem under test with UAT Broadcast messages for at least 10 Airborne participants.

Verify that the UAT Receiving Subsystem under test is generating the appropriate Reports that are expected for the UAT Broadcast Messages being provided by the simulation function.

Step 2: Induce Receiver Failure

Induce a failure into the UAT Receiving Subsystem under test such that UAT Broadcast Messages can no longer be received.

Verify that the UAT Receiving Subsystem properly annunciates the “Fail/Warn” state for as long as the failure is induced.

Step3: Remove Induced Receiver Failure

Remove the induced failure and allow the UAT Receiving Subsystem under test to return to normal operation.

Verify that the UAT Receiving Subsystem does not annunciate the “Fail/Warn” state 2.0 seconds after removing the induced failure.

2.4.13.5 Verification of Failure Annunciation (§2.2.13.5)

No specific test procedure is required to validate §2.2.13.5.

2.4.13.5.1 Verification of UAT Transmitting Device Failure Annunciation (§2.2.13.5.1)

Purpose/Introduction:

An output **shall** be provided to indicate the validity/non-validity of the ADS-B transmission device. Failure to generate UAT Messages at a nominal rate, a failure detected by self-test or the monitoring function, or failure of the address verification **shall** cause the output to assume the invalid state. Momentary power interrupts **shall** not cause the output to assume the invalid state. The status of the UAT transmission device **shall** be enunciated to the flight crew where applicable.

Measurement Procedure:

Step 1: Verification of UAT Transmission Device Failure Annunciation – Too Fast

Set up the UAT Transmitting Subsystem to simulate a transmission rate that exceeds 1.364 messages per second.

Verify that the UAT transmission monitoring function properly annunciates the “Fail/Warn” state within 2.3 seconds of the UTC Time Mark.

Note: *The transmission rate determination is based on the minimum/maximum MSO times (i.e., the 0.2 to 2.0 second interval) for three consecutive transmissions, +/− 100 milliseconds, referenced to the UTC time mark when the rate change is induced.*

Step 2: Verification of UAT Transmission Device Failure Annunciation – Too Slow

Set up the UAT Transmitting Subsystem to simulate a transmission rate that does not exceed 0.789 messages per second.

Verify that the UAT transmission monitoring function properly annunciates the “Fail/Warn” state within 3.9 seconds of the UTC Time Mark.

2.4.13.5.2 Verification of UAT Receiving Subsystem Failure Annunciation (§2.2.13.5.2)

Appropriate test procedures required to validate the requirements of §2.2.13.5.2 are included in §2.4.13.4.

2.4.13.5.3 Verification of Co-Located UAT Transmitting and Receiving Device Failure Annunciation (§2.2.13.5.3)

Appropriate test procedures required to validate the requirements of §2.2.13.5.3 are included in §2.4.13.5.1, §2.4.13.5.2 and §2.4.13.4.

2.4.14 Verification of Antenna System (§2.2.14)

No specific test procedure is required to validate §2.2.14.

2.4.14.1 Verification of Polarization (§2.2.14.1)

Appropriate test procedures required to validate the requirements of §2.2.14.1 are included in §3.4.1.7.

2.4.14.2 Verification of Antenna Voltage Standing Wave Ratio (VSWR) (§2.2.14.2)

Purpose/Introduction:

The Voltage Standing Wave Ratio (VSWR) produced on the antenna transmission line by the antenna **shall** not exceed 1.7:1 at 978 MHz when the antenna is mounted at the center of a 1.2 meter (4 foot) diameter (or larger) flat circular ground plane. The transmission line impedance **shall** be that as specified by the UAT equipment manufacturer.

Equipment Required:

Provide appropriate Couplers and Connectors as required. Provide Coaxial Connection of known attenuation. Provide appropriate Attenuators as required. Provide an HP 8562e Network Analyzer (or equivalent capability).

Measurement Procedure:

Step 1: Install Network Analyzer

For A UAT Transmitting installations, disconnect the UAT Transmitting Subsystem to Antenna connection at the UAT Transmitting Subsystem unit connector.

For UAT Receiving installations, disconnect the UAT Receiving Subsystem to Antenna connection at the UAT Receiving Subsystem unit connector.

Using appropriate attenuators, connectors, and coaxial cable of known attenuation and impedance, connect the Network Analyzer to the cable end of the Antenna connection (i.e., the connector just removed from the UAT Transmitting or Receiving device).

Note: *The use of attenuators is strongly recommended such that the RF front end of the Network Analyzer is not destroyed.*

Step 2: Perform the VSWR Measurement

Using the Network Analyzer, measure the Voltage Standing Wave Ratio (VSWR) of the antenna installation at a frequency of 978 MHz. Verify that the VSWR does not exceed 1.7:1.

Note: *This measurement will also verify that the impedance is within the UAT equipment manufacturers' tolerances.*

2.4.14.3 Verification of Requirements for Optional Passive Diplexer (§2.2.14.3)

No specific test procedure is required to validate §2.2.14.3.

2.4.14.3.1 Verification of Diplexer RF Requirements (§2.2.14.3.1)

No specific test procedure is required to validate §2.2.14.3.1.

2.4.14.3.1.1 Verification of The UAT Channel (§2.2.14.3.1.1)

Purpose/Introduction:

The Diplexer **shall** include a UAT Channel that conveys UAT signals without distortion of the waveform. The UAT Channel **shall** convey UAT Basic, Long and Ground Uplink Messages while maintaining the modulation accuracy of the input UAT signals as specified in §2.2.2.4 and produce no more than 0.5 dB amplitude attenuation and no more than 30 nanoseconds in propagation delay. Additionally, the variation in delay **shall** be no more than 10 nanoseconds over the frequency band of 977 MHz to 979 MHz. The UAT Channel **shall** provide a passband from no greater than 977 MHz to no less than 979 MHz (2.0 MHz minimum) and a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband **shall** be different by no greater than 0.20 dB. The UAT port of the Diplexer **shall** be capable of peak power transmissions according to the appropriate aircraft equipage class given by Table 2-1. The VSWR produced by the Diplexer at the UAT port, when the other two ports are terminated in a 50 ohm load, **shall** not exceed 1.3:1 for frequencies within the passband.

Equipment Required:

The tests performed in this subparagraph require the Diplexer under test, equipment as described in §2.4.8.2.3.a and §2.4.8.2.3.b, two lengths of 50 ohm cable of known loss and connector adaptors, as necessary, a 50 ohm termination, 20 to 30 dB of power attenuation, and a High Power UAT message source that meets the maximum RF power requirements of the equipage class under test. Provide a means for measurement of

VSWR. Additionally, provide a means for measurement of Group Delay variation, an Agilent 8753 Network Analyzer, or the equivalent.

Measurement Procedure:

Step 1: Equipment Setup

Connect both cables in series directly between the Signal Generator and the Vector Signal Analyzer temporarily bypassing the Diplexer. Configure the Signal Generator to sweep CW RF with a sweep range of 3 MHz centered at 978 MHz. Configure the Vector Signal Analyzer to display the continuous peak hold of a RF spectrum 3 MHz wide centered at 978 MHz and signal levels between –29.9 and –31.9 dBm.

Step 2: Test Setup

Adjust the Signal Generator so that the Vector Signal Analyzer measures a level of –30 dBm, and insure that the difference between the maximum and minimum level across the 3 MHz band is less than 0.05 dB. Insert the Diplexer between the two cables at the UAT and Antenna ports, and terminate the Transponder port in 50 ohms.

Step 3: Maximum UAT Channel Passband Attenuation and Ripple

Allow the Vector Signal Analyzer to record the results of a number of sweeps sufficient to show smooth results, and verify 1) that the minimum signal level in the 978 MHz ±1 MHz range is no less than –30.5 dBm, and 2) that the maximum minus minimum level in the 3 MHz band is no greater than 0.2 dB.

Step 4: UAT Signal Verification

Get ready to replace the Signal Generator with the UAT message source, place attenuation between the Diplexer and the Vector Signal Analyzer to limit the power into the Vector Signal Analyzer to less than +25 dBm, replace the Signal Generator with the UAT message source, set it to the maximum power for the equipage class under test.

Setup the Vector Signal Analyzer as described in §2.4.2.4 except adjust for the signal levels specified above in this test, and verify that the measured "Eye Diagram" is similar to the one measured in §2.4.2.4, Step 2, and that it shows no distortion of the UAT waveform.

Step 5: UAT Signal Verification - Loss and Delay

Determine the power loss of the pulse from the UAT port to the Antenna port, and verify that the loss is no more than 0.5 dB.

Determine the pulse delay measured from the lead edge time of the pulse at the UAT port to the lead edge of the pulse at the Antenna port, and verify that the delay introduced by the Diplexer is no more than 30 nanoseconds.

Step 6: Delay Variation Verification

Set up the Network Analyzer to measure Group Delay Variation. Set the start and stop frequencies to 977 MHz and 979 MHz, respectively. Set the RF power level to 0 dBm. Set the markers at the start, stop and center frequencies. Calibrate the delay measurement by using a through line between the RF IN and OUT ports of the analyzer.

Remove the through line and connect the Diplexer antenna port to the RF IN port of the analyzer and the Diplexer UAT port to the RF OUT port of the analyzer. Terminate the Transponder port of the Diplexer with a 50 ohm load. Measure the absolute Group Delay and verify that the delay is less than 30 nanoseconds. Measure the delay at 978 MHz and read the difference between the delays at 977 MHz and 979 MHz respectively. Verify that the difference is less than 10 nanoseconds.

Step 7: VSWR at 978 MHz

Verify that the VSWR at the UAT port, with the other two ports terminated in 50 ohms, is no more than 1.3:1 at 978 1030 MHz.

2.4.14.3.1.2 Verification of The Transponder Channel (§2.2.14.3.1.2)

Purpose/Introduction:

The Diplexer **shall** include a Transponder Channel that conveys received 1030 MHz interrogation and 1090 MHz reply signals without distortion of the waveform. The Transponder Channel **shall** convey pulses that are amplitude modulated on either 1030 MHz or 1090 MHz and having rise and fall times of 50 nanoseconds or more and produce no more than 0.5 dB amplitude attenuation and no more than 10 nanoseconds delay while retaining the pulse rise and fall times and pulse width of the input pulses. Additionally, the variation in delay **shall** be no more than 5 nanoseconds over the frequency band of 1015 MHz to 1105 MHz. The Transponder Channel **shall** provide a passband from no greater than 1015 MHz to no less than 1105 MHz (90 MHz minimum) and a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband **shall** be different by no greater than 0.20 dB. The Transponder port **shall** be capable of handling 1000 Watts instantaneous power. The VSWR produced by the Diplexer at the Transponder port, when the other two ports are terminated in a 50 ohm load, **shall** not exceed 1.3:1 for frequencies within the passband. If required by the transponder installation, the Diplexer **shall** support DC coupling from the Transponder port to the antenna port as required by the electrical characteristics of the installed equipment.

Equipment Required:

The tests performed in this subparagraph require the Diplexer under test, equipment as described in §2.4.8.2.3.a and §2.4.8.2.3.b, two lengths of 50 ohm cable with connector adaptors, a 50 ohm termination, at least 35 dB of power attenuation, and an RF Signal Source with Pulse Amplitude Modulation at both 1030 and 1090 MHz Carrier Frequencies and at least 1000 Watts of power output. Also, provide a means for measurement of VSWR. Additionally, provide a means for measurement of Group Delay variation, an Agilent 8753 Network Analyzer, or the equivalent.

Measurement Procedures:

Step 1: Equipment Setup

Connect both cables in series directly between the Signal Generator and the Vector Signal Analyzer temporarily bypassing the Diplexer. Configure the Signal Generator to sweep CW RF with a sweep range of 100 MHz centered at 1060 MHz. Configure the Vector Signal Analyzer to display the continuous peak hold of a RF spectrum 100 MHz wide centered at 1060 MHz and signal levels between –29.9 and –31.9 dBm.

Step 2: Test Setup

Adjust the Signal Generator so that the Vector Signal Analyzer measures a level of –30 dBm, and insure that the difference between the maximum and minimum level across the 100 MHz band is less than 0.05 dB. Insert the Diplexer between the two cables at the Transponder and Antenna ports, and terminate the UAT port in 50 ohms.

Step 3: Maximum Transponder Channel Passband Attenuation and Ripple

Allow the Vector Signal Analyzer to record the results of a number of sweeps sufficient to show smooth results, and verify 1) that the minimum signal level in the 1015 to 1105 MHz (central 90 MHz) range is no less than –30.5 dBm, and 2) that the maximum minus minimum level in the central 90 MHz band is no greater than 0.2 dB.

Step 4: Pulse Input Verification

Get ready to replace the Signal Generator with the RF source providing a 450 nanosecond pulse with 50 nanosecond rise and fall times pulse modulated at 1030 MHz. Place attenuation between the Diplexer and the Vector Signal Analyzer to limit the power into the Vector Signal Analyzer to less than +25 dBm, and replace the Signal Generator with the RF source.

Setup the Vector Signal Analyzer in vector mode in order to measure the envelope of the RF pulse, and verify that the measured pulse has a 450 nanosecond pulse width and 50 nanosecond rise and fall times.

Step 5: RF Pulse Input Verification – Loss and Delay

Determine the power loss of the pulse from the Transponder port to the Antenna port, and verify that the loss is no more than 0.5 dB.

Determine the pulse delay measured from the lead edge time of the pulse at the Transponder port to the lead edge of the pulse at the Antenna port, and verify that the delay introduced by the Diplexer is no more than 10 nanoseconds.

Step 6: RF Pulse Input Verification at 1090 MHz

Repeat Steps 4 and 5 above with the input RF signal source set at 1090 MHz.

Step 7: Delay Variation Verification

Set up the Network Analyzer to measure Group Delay Variation. Set the start and stop frequencies to 1015 MHz and 1105 MHz, respectively. Set the RF power level to 0 dBm. Set the markers at the start and stop frequencies, and at the 1060 MHz center frequency. Calibrate the delay measurement by using a through line between the RF IN and OUT ports of the analyzer.

Remove the through line and connect the Diplexer antenna port to the RF IN port of the analyzer and the Diplexer Transponder port to the RF OUT port of the analyzer. Terminate the UAT port of the Diplexer with a 50 ohm load. Measure the absolute Group Delay and verify that the delay is less than 10 nanoseconds. Measure the delay at 1060 MHz and read the difference between the delays at 1015 MHz and 1105 MHz, respectively. Verify that the difference is less than 5 nanoseconds.

Step 8: VSWR at 1030 MHz and 1090 MHz

Verify that the VSWR at the Transponder port, with the other two ports terminated in 50 ohms, is no more than 1.3:1 for both 1030 MHz and 1090 MHz.

2.4.14.3.1.3 Verification of Channel to Channel Isolation (§2.2.14.3.1.3)

Purpose/Introduction:

The Diplexer **shall** provide RF isolation between the UAT Channel and the Transponder Channel. The Diplexer **shall** provide a minimum of 50 dB of isolation between these ports at 1090 MHz. Additionally, the Diplexer **shall** provide a minimum isolation of 30 dB between the UAT and Transponder ports of the Diplexer at 1030 MHz. The Diplexer **shall** provide a minimum of 20 dB of isolation between the ports at 978 MHz.

Equipment Required:

The tests performed in this subparagraph require the Diplexer under test, equipment as described in §2.4.8.2.3.a and §2.4.8.2.3.b, two lengths of 50 ohm cable with connector adaptors, and a 50 ohm termination.

Measurement Procedures:

Step 1: Equipment Setup

Connect both cables in series directly between the Signal Generator and the Vector Signal Analyzer temporarily bypassing the Diplexer. Configure the Signal Generator to sweep CW RF with a sweep range of 150 MHz centered at 1035 MHz. Configure the Vector Signal Analyzer to display the continuous peak hold of a RF spectrum 150 MHz wide centered at 1035 MHz and signal levels between –29.9 and –31.9 dBm.

Step 2: Test Setup

Adjust the Signal Generator so that the Vector Signal Analyzer measures a level of –30 dBm, and insure that the difference between the maximum and minimum level across the 150 MHz band is less than 0.05 dB. Insert the

Diplexer between the two cables at the UAT and Transponder ports, and terminate the Antenna port in 50 ohms.

Step 3: Minimum UAT and Transponder Channel Isolation

Allow the Vector Signal Analyzer to record the results of a number of sweeps sufficient to show smooth results, and verify (1) that the maximum signal level at 978 MHz is no greater than –55.0 dBm, (2) that the maximum signal level at 1030 MHz is no greater than –70.0 dBm, and (3) that the maximum signal level at 1090 MHz is no greater than –85.0 dBm.

2.4.15 Verification of Interfaces (§2.2.15)

No specific test procedure is required to validate §2.2.15.

2.4.15.1 Verification of UAT Transmitting Subsystem Interfaces (§2.2.15.1)

No specific test procedure is required to validate §2.2.15.1.

2.4.15.1.1 Verification of UAT Transmitting Subsystem Input Interfaces (§2.2.15.1.1)

Appropriate test procedures required to validate the requirements of §2.2.15.1.1 are included in §2.4.15.1.1.1 through §2.4.15.1.1.3.

2.4.15.1.1.1 Verification of Discrete Input Interfaces (§2.2.15.1.1.1)

Purpose/Introduction:

Appropriate discrete inputs may be used to provide the UAT Transmitting Subsystem with configuration and control information. When implemented, all discrete inputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

Measurement Procedure:

Appropriate verification of discrete input interfaces to the UAT Transmission function was demonstrated during testing of the entire transmission function performed in §2.4.2 and §2.4.3 of this document.

Note: *The manufacturer is required to document all intended data to be input via discrete inputs and ensure full and correct functioning of the UAT Transmission function for all inputs at these interfaces. The manufacturer should also demonstrate that appropriate protection, such as diode isolation, is provided for each input interface. Such demonstration can be done by formal documentation of the design such as schematics and Bill of Materials (BOM).*

2.4.15.1.1.2 Verification of Digital Communication Input Interfaces (§2.2.15.1.1.2)

Purpose/Introduction:

Approved Avionics Digital Communication interfaces **shall** be used to provide all digital data parameters (including control information) to the UAT Transmitting Subsystem. Such input interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to the UAT Transmitting Subsystem control and message generation functions.

Measurement Procedure:

Appropriate verification of digital communication input interfaces to the UAT Transmission function was demonstrated during testing of the entire transmission function performed in §2.4.2 and §2.4.3 of this document.

Note: *The manufacturer is required to disclose the interface protocols and error control techniques used with these interfaces and to demonstrate correct functioning of these interfaces in such regards. Traditionally, analysis and established knowledge of the interface have been sufficient to satisfy these interface integrity requirements.*

2.4.15.1.1.3 Verification of Processing Efficiency (§2.2.15.1.1.3)

Purpose/Introduction:

The UAT Transmitting Subsystem input processing function **shall** be capable of efficiently processing all data input interfaces in a manner that ensures that the most recent update received for all required data parameters is made available to the message generation function to support the rates identified in §2.2.6.1.

Measurement Procedure:

Appropriate verification of processing efficiency of interfaces to the UAT Transmission function was demonstrated during testing of the entire transmission function performed in §2.4.2 and §2.4.3 of this document.

2.4.15.1.2 Verification of UAT Transmitting Subsystem Output Interfaces (§2.2.15.1.2)

No specific test procedure is required to validate §2.2.15.1.2.

2.4.15.1.2.1 Verification of Discrete Output Interfaces (§2.2.15.1.2.1)

Purpose/Introduction:

Appropriate discrete outputs may be used by the UAT Transmitting Subsystem to provide Mode Status and Failure Monitoring information to other users or monitoring equipment. When implemented, all discrete outputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

Measurement Procedure:

Appropriate verification of discrete output interfaces from the UAT Transmission function was demonstrated during testing of the entire transmission function performed in §2.4.2 and §2.4.3 of this document.

Note: *The manufacturer is required to document all intended data to be output via discrete interfaces and ensure full and correct functioning of the UAT Transmission function for all outputs at these interfaces. The manufacturer shall also demonstrate that appropriate protection, such as diode isolation, is provided* *for each output interface. Such demonstration can be done by formal documentation of the design such as schematics and Bill of Materials (BOM).*

2.4.15.1.2.2 Verification of Digital Communication Output Interfaces (§2.2.15.1.2.2)

Purpose/Introduction:

Appropriate Avionics Digital Communication output interfaces **shall** be implemented by the UAT Transmitting Subsystem to provide status and data communication to other user or monitoring equipment. Such output interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to other user or monitoring equipment.

Measurement Procedure:

Appropriate verification of digital communication output interfaces from the UAT Transmission function was demonstrated during testing of the entire transmission function performed in §2.4.2 and §2.4.3 of this document.

Note: *The manufacturer is required to disclose the interface protocols and error control techniques used with these interfaces and to demonstrate correct functioning of these interfaces in such regards. Traditionally, analysis and established knowledge of the interface have been sufficient to satisfy these interface integrity requirements.*

2.4.15.2 Verification of UAT Receiving Subsystem Interfaces (§2.2.15.2)

No specific test procedure is required to validate §2.2.15.2.

2.4.15.2.1 Verification of UAT Receiving Subsystem Input Interfaces (§2.2.15.2.1)

No specific test procedure is required to validate §2.2.15.2.1.

2.4.15.2.1.1 Verification of Discrete Input Interfaces (§2.2.15.2.1.1)

Purpose/Introduction:

Appropriate discrete inputs may be used to provide the UAT Receiving Subsystem with configuration and control information. When implemented, all discrete inputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

Measurement Procedure:

Appropriate verification of discrete input interfaces to the UAT Receiving function was demonstrated during testing of the entire receiving function performed in §2.4.8 through §2.4.13 of this document.

Note: *The manufacturer is required to document all intended data to be input via discrete inputs and ensure full and correct functioning of the UAT Transmission function for all inputs at these interfaces. The manufacturer shall also demonstrate that appropriate protection, such as diode isolation, is provided for each input interface. Such demonstration can be done by formal documentation of the design such as schematics and Bill of Materials (BOM).*

2.4.15.2.1.2 Verification of Digital Communication Input Interfaces (§2.2.15.2.1.2)

Purpose/Introduction:

Appropriate Avionics Digital Communication interfaces **shall** be used to provide all digital data parameters (including control information) to the UAT Receiving Subsystem. Such input interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to the UAT Receiving Subsystem control and Report Assembly functions.

Measurement Procedure:

Appropriate verification of digital communication input interfaces to the UAT Receiving function was demonstrated during testing of the entire receiving function performed in §2.4.8 through §2.4.13 of this document.

Note: *The manufacturer is required to disclose the interface protocols and error control techniques used with these interfaces and to demonstrate correct functioning of these interfaces in such regards. Traditionally, analysis and established knowledge of the interface have been sufficient to satisfy these interface integrity requirements.*

2.4.15.2.1.3 Verification of Processing Efficiency (§2.2.15.2.1.3)

Purpose/Introduction:

The UAT Receiving Subsystem input processing function **shall** be capable of efficiently processing all necessary interfaces as required for Receiver Message Processing and Report Assembly, as defined in §2.2.8.3, §2.2.9 and §2.2.10.

Measurement Procedure:

Appropriate verification of processing efficiency of interfaces to the UAT Receiving function was demonstrated during testing of the entire receiving function performed in §2.4.8 through §2.4.13 of this document.

2.4.15.2.2 Verification of UAT Receiving Subsystem Output Interfaces (§2.2.15.2.2)

No specific test procedure is required to validate §2.2.15.2.2.

2.4.15.2.2.1 Verification of Discrete Output Interfaces (§2.2.15.2.2.1)

Purpose/Introduction:

Appropriate discrete outputs may be used by the UAT Receiving Subsystem to provide Mode Status and Failure Monitoring information to other users or monitoring equipment. When implemented, all discrete outputs **shall** provide appropriate protection, such as diode isolation, to prevent sneak current paths.

Measurement Procedure:

Appropriate verification of discrete output interfaces to the UAT Receiving function was demonstrated during testing of the entire receiving function performed in §2.4.8 through §2.4.13 of this document.

Note: *The manufacturer is required to document all intended data to be output via discrete interfaces and ensure full and correct functioning of the UAT Receiving function for all outputs at these interfaces. The manufacturer shall also demonstrate that appropriate protection, such as diode isolation, is provided for each output interface. Such demonstration can be done by formal documentation of the design such as schematics and Bill of Materials (BOM)*

2.4.15.2.2.2 Verification of Digital Communication Output Interfaces (§2.2.15.2.2.2)

Purpose/Introduction:

Appropriate Avionics Digital Communication output interfaces **shall** be implemented by the UAT Receiving Subsystem to provide status and data communication to other user or monitoring equipment. Such output interfaces **shall** implement appropriate error control techniques (i.e., parity as a minimum) to ensure that data is properly delivered to other user or monitoring equipment.

Measurement Procedure:

Appropriate verification of digital communication output interfaces to the ADS-B Receiving function was demonstrated during testing of the entire receiving function performed in §2.4.8 through §2.4.13 of this document.

Note: *The manufacturer is required to disclose the interface protocols and error control techniques used with these interfaces and to demonstrate correct functioning of these interfaces in such regards. Traditionally, analysis and established knowledge of the interface have been sufficient to satisfy these interface integrity requirements.*

2.4.16 Verification of Power Interruption (§2.2.16)

Appropriate test procedures required to validate the requirements of §2.2.16 are included in §2.4.16.1 and §2.4.16.2.

2.4.16.1 Verification of Power Interruption to UAT Transmitting Functions (§2.2.16)

Purpose/Introduction:

The UAT Transmitting Subsystem **shall** regain operational capability to within its operational limits within two seconds after the restoration of power following a momentary power interruption.

Note: *The UAT Transmitting and/or Receiving Subsystems are not required to continue operation during momentary power interruptions.*

Equipment Required:

Supply equipment capable of loading valid data for UAT broadcast messages into the UAT Transmitting equipment under test through the operational interface.

Measurement Procedure:

Step 1: Enable Transmission of UAT Messages

Supply the UAT Transmission function with the appropriate data necessary to establish UAT Messages.

Verify that the UAT Transmission function generates appropriate ADS-B Messages at the nominal rate.

Step 2: Apply Momentary Power Interrupts

Apply momentary power interrupts to the UAT Transmission function under test in accordance with RTCA Document DO-160D section 16 (EUROCAE ED-14D, section 16). Then restore the power to normal operating conditions.

Verify that the UAT Transmission function resumes generation of appropriate UAT Messages no later than 2.0 seconds after the restoration of nominal power.

2.4.16.2 Verification of Power Interruption to UAT Receiving Functions (§2.2.16)

Purpose/Introduction:

The UAT Receiving Subsystem **shall** regain operational capability to within its operational limits within two seconds after the restoration of power following a momentary power interruption.

Note: *The UAT Transmitting and/or Receiving Subsystems are not required to continue operation during momentary power interruptions.*

Equipment Required:

Supply equipment capable of supplying valid UAT broadcast messages to the UAT Receiving equipment under test via the appropriate interface.

Measurement Procedure:

Step 1: Enable Reception of UAT Messages

Via the appropriate interface and in the absence of interference, apply valid 978 MHz UAT Messages at a uniform rate of one per second and at a signal level that is at least 15 dB above the minimum sensitivity of the UAT Receiving Subsystem.

Verify that the UAT Receiving Subsystem delivers appropriate Output Messages to the user interface or the Report Assembly function for all messages received.

Step 2: Apply Momentary Power Interrupts

Apply momentary power interrupts to the UAT Receiving Subsystem under test in accordance with RTCA Document DO-160D section 16 (EUROCAE ED-14D, section 16). Then restore the power to normal operating conditions.

Verify that the UAT Receiving Subsystem resumes generation of appropriate Output messages to the user interface or to the Report Assembly function no later than 2.0 seconds after the restoration of power.

Then verify that the UAT Receiving Subsystem continues to deliver appropriate Output Messages to the user interface or to the Report Assembly function for all messages received.

2.4.17 Verification of Compatibility with Other Systems (§2.2.17)

No specific test procedure is required to validate §2.2.17.

2.4.17.1 Verification of EMI Compatibility (§2.2.17.1)

Purpose/Introduction:

The UAT Transmitting and/or Receiving Subsystems **shall** not compromise the operation of any co-located communication or navigation equipment, or ATCRBS and/or Mode-S transponders. Likewise, the UAT antenna **shall** be mounted such that it does not compromise the operation of any other proximate antenna.

Measurement Procedure:

Verification of EMI/EMC/HIRF/LIGHTNING compatibility is performed during Environmental testing in accordance with RTCA Document DO-160D (EUROCAE ED-14D) with the test procedures provided in §2.3 of this document.

2.4.17.2 Verification of Compatibility with GPS Receivers (§2.2.17.2)

Purpose/Introduction:

The UAT Transmitting and/or Receiving Subsystem **shall** not compromise the operation of a co-located proximate GPS receiver.

Measurement Procedure:

Verification of compatibility with GPS Receivers is demonstrated during verification of EMI/EMC/HIRF/LIGHTNING compatibility performed during Environmental testing in accordance with RTCA Document DO-160D (EUROCAE ED-14D) with the test procedures provided in §2.3 of this document.

2.4.17.3 Verification of Compatibility with Other Navigation Receivers and ATC Transponders (§2.2.17.3)

Purpose/Introduction:

The UAT Transmitting and/or Receiving Subsystem **shall** not compromise the operation of VOR, DME, ADF, LORAN, ATCRBS or Mode-S equipment installed in a proximate location.

In addition, the UAT Receiving Subsystem must be fully operational when located in close proximity of an ATCRBS or Mode-S transponder.

<u>Measurement Procedure:</u>

Verification of compatibility with Other Navigation Receivers and ATC Transponders is demonstrated during verification of EMI/EMC/HIRF/LIGHTNING compatibility performed during Environmental testing in accordance with RTCA Document DO-160D (EUROCAE ED-14D) with the test procedures provided in §2.3 of this document.

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3 Equipment Performance Characteristics

This section states the minimum acceptable level of performance for the equipment when installed in the aircraft. Installed performance requirements are the same as contained in §2.2, which are verified through bench and environmental testing. Some system attributes and performance aspects may be affected by the physical installation (e.g., antenna patterns can affect system transmit and receive performance). System integrators might have several options when connecting to aircraft sensors or data sources. Some sources might lack the necessary range, resolution or accuracy to support the desired applications. This section identifies system attributes which installation techniques and choices might affect, beyond the equipment manufacturer's ability to compensate.

3.1 Equipment Installation

Equipment selection and installation characteristics must be appropriate for the airframe and location in which it is installed.

3.1.1 Installed Equipment Considerations

A complete UAT ADS-B system consists of five (5) functional elements:

1. Data sources for aircraft position, velocity, flight plan, status, etc.
2. UAT ADS-B Transmitter
3. UAT ADS-B Receiver
4. Report Assembly
5. Applications

Each of these elements must meet the minimum requirements for an application in order for operational approval to be granted for that application. Additional guidance for determining requirements is contained in §3.1.1.1 through §3.1.1.5.

3.1.1.1 Data Sources

Data sources necessary to support an application shall meet the requirements of the operational environment. See §3.5 for requirements on Flight Mode Data Sources.

3.1.1.2 ADS-B Transmitter

Transmitter RF power categories are defined in §2.1.12. All configurations of UAT ADS-B Transmitting Subsystems may be used for VFR and IFR applications. Some applications may require support for other specific message content. The transmitter antenna feed line loss shall not exceed 3dB over the full environmental range of operation.

The equipment shall be capable of placing the Transmitter into a Standby mode.

3.1.1.3 ADS-B Receiver

The UAT receiver shall be capable of supporting the message types and reports required by the application. The receiver antenna feed line loss shall not exceed 3dB over the full environmental range of operation.

3.1.1.4 Report Assembly

The Report Assembly function shall be capable of accepting all message types and generating all reports appropriate to the intended applications.

3.1.1.5 Applications

Applications comprise any use of ADS-B data. Applications shall be developed in accordance with approved standards if standards exist. If approved standards do not exist, the developer shall propose a standard early in the development process to support approval of the operational concept and identify operational limitations.

First time operational approval for the use of installed ADS-B equipment in a given application will be accomplished via the Type Certificate (TC) or Supplemental Type Certificate (STC) approval process. Subsequent installations may be approved via the TC, STC, or field approval process. It is incumbent upon the developer to show that the system meets the requirements of the application. Operating limits of the system shall be included in an approved aircraft/rotorcraft flight manual supplement (AFMS/RFMS).

3.1.2 Aircraft Environment

Equipment shall be installed such that environmental conditions do not exceed the manufacturer’s specifications during normal operations.

3.1.3 Aircraft Power Source

The supply voltage and allowable variation shall not exceed the ADS-B equipment manufacturer’s specifications during normal operations. Equipment voltage and frequency tolerance characteristics shall be compatible with an aircraft power source of appropriate category as specified in RTCA DO-160D.

3.1.3.1 Power Fluctuation

The equipment shall retain memory of variable data through aircraft power transfer, which occurs during normal operation. Typical power transfer involves switching from external power to internal power, either battery or APU generator, or to engine driven generator(s). The equipment shall not require re-initialization for power transfer (i.e., power loss) for a period up to 0.5 second maximum. Power transfer shall not latch a failure indication. Momentary failure indications, during switching, are allowed.

3.1.4 Accessibility

Controls, indicators, and displays provided for in-flight use shall be readily accessible and/or readable from the pilot’s normal seated position. If two pilots are required to operate the aircraft, the controls must be readily accessible from each pilot’s seated position. Adequate protection must be provided to prevent inadvertent turnoff of the equipment.

3.1.5 Display Visibility

If there is a control panel display, then appropriate flight crew member(s) must have an unobstructed view of displayed data when in the seated position. The brightness of any display must be adjustable to levels suitable for data interpretation under all cockpit ambient lighting conditions ranging from total darkness to reflected sunlight.

Note: *Visors, glare shields or filters may be an acceptable means of obtaining daylight visibility.*

3.1.6 Indicators

If visual indicators are installed, they shall be visible and readable from the pilot's normal seated position. If two pilots are required to operate the aircraft, indicators shall be visible from each pilot's seated position. The brightness of any indicator must be adjustable to levels suitable under all cockpit ambient lighting conditions ranging from total darkness to reflected sunlight. If an indication is distracting, a means to cancel it should be provided.

3.1.7 Alerts

If appropriate to an application, a means to alert the crew shall be provided. Aural alerts shall provide a mechanism by which they can be prioritized with respect to other aircraft system alerts (e.g., audio inhibit input and output discretes). Aural alerts shall include a means by which they can be silenced.

3.1.8 Failure Protection

Probable failures of the ADS-B equipment must not degrade the normal operation of equipment or systems connected to it. The failure of connected equipment or systems must not degrade normal operation of the ADS-B equipment except for loss of functions directly dependent upon the failed equipment.

3.1.9 Failure Indication

The ADS-B system operational status shall be available to the crew. Failures of the ADS-B Transmitting Subsystem shall be annunciated to the crew. Failures of the ADS-B Receiving Subsystem shall be annunciated to the crew. Though acceptable, dedicated ADS-B Transmitting and Receiving Subsystem failure indicators are not required. Text messages, displayed to the crew until acknowledged, are acceptable. Systems which combine transmit and receive functions in a common unit may use a single annunciation to indicate a failure.

3.1.10 Interference Effects

The equipment shall not be the source of objectionable conducted or radiated interference nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

Note: *Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. The installing facility is* *responsible for resolving incompatibilities between the ADS-B equipment and previously installed equipment in the aircraft.*

3.1.11 Mutual Suppression

UAT ADS-B equipment **shall** interface to the mutual suppression bus. The UAT **shall** drive the mutual suppression bus during UAT transmissions so that other L Band systems installed in the aircraft can desensitize their receivers during UAT transmissions. Installations with ATCRBS or Mode S transponders **shall** insure that the transponder is connected to the mutual suppression bus to prevent unsolicited replies from being generated by the transponder during UAT transmissions. UAT equipment **shall** not receive from the mutual suppression bus.

3.2 Installed Equipment Performance Requirements

The installed equipment shall meet the requirements of §2.1 and §2.2 in addition to, or as modified by, the requirements stated below.

3.2.1 Antenna Installation

3.2.1.1 General Considerations

Antenna gain and pattern characteristics are major contributors to the system data link performance. The location and number of antennas required for aircraft ADS-B systems is determined by the equipage class. Classes A1L, A1H, A2, and A3 require antenna diversity and must have transmit and receiving capability on both the top and bottom of the aircraft. Exceptions may be made for installations on radio-transparent airframes. Class A0 and A1S installations do not require antenna diversity. Compliance of the installed antennas with the requirements of §2.1.11 may be demonstrated by analysis.

If the ADS-B Transceiver shares antennas with a Mode S or ATCRBS transponder, the antennas **shall** additionally comply with the requirements of the applicable transponder standards (currently for Mode S – RTCA Document Number DO-181C, and for ATCRBS, TSO-C74C), and the Diplexer **shall** comply with the requirements of §2.2.14.3 of this document.

3.2.1.2 Transmission Lines

Transmission lines between the equipment and the antennas shall have impedance, power handling, and loss characteristics in accordance with the equipment manufacturer's specifications. The VSWR at 978 MHz, as seen through the transmission lines to the antenna(s), shall not exceed 1.7:1.

All minimum installed system performance requirements stated in §2.2, must be met with the transmission line installed. Test results provided by the equipment manufacturer may be accepted in lieu of tests performed by the equipment installer.

3.2.1.3 Antenna Polarization

The ADS-B Transmit and Receive antennas shall be predominantly vertically polarized.

3.2.1.4 Antenna Location

Antennas shall be mounted as near as practical to the centerline of the fuselage. Antennas shall be located to minimize obstruction to their fields in the horizontal plane. Antenna locations should be selected such that, with the aircraft configured in a level-flight attitude, at least one antenna should be visible at all times over the full range of 360 degrees of azimuth, to the fullest extent possible. Viewing distance for this action should be appropriate for the airframe, and clear of all aircraft extremities, such as twice the wingspan. For Class A1S/B1S equipment the antenna shall be located on the bottom of the fuselage, or shall have an antenna pattern at least equivalent to that of a quarter-wave resonant antenna mounted on the fuselage bottom surface.

Note: *The potential of UAT sharing existing transponder antennas is discussed in Appendix E of this document.*

3.2.1.5 Minimum Distance from Other Antennas

The spacing between any ADS-B antenna and any DME antenna shall be sufficient to provide a minimum of 20dB of isolation between the two antennas.

Note: *If both antennas are conventional omni-directional matched quarter-wave stubs, 20 dB of isolation is obtained by providing a spacing of at least 51 cm (20 in.) between the centers of the two antennas. If either antenna is other than a conventional stub, the minimum spacing must be determined by measurement.*

3.2.1.6 Minimum Reception Range

Antenna(s) shall be located such that a receiving system reliably receives data from the transmitting aircraft at the minimum range appropriate to the equipage category, as stated in Table 3-1. If a traffic display is installed, reliable data reception is indicated by traffic target acquisition range and smooth movement of traffic targets, without excessive “pop-up,” “drop-out,” or position “jumps.”

Note: *Typical ADS-B antennas have areas of reduced gain, directly above or below the antenna, such that signals from transmitters in these areas are substantially reduced. Reliable data reception from these areas is not required.*

Table 3-1: Minimum Ranges for Receiving Capability

Equipage		Required Range (NM)
Class	Type	
A0	Minimum	10
A1L, A1S, A1H	Basic	20
A2	Enhanced	40
A3	Extended	90 (120 desired)

Note: *The range values shown in Table 3-1 correspond to encounters between like-equipped aircraft. See RTCA DO-242A Table 3-2(b) for range values between other combinations of equipment classes. The Class A3 required range is for head-to-head encounters. A3 equipment is allowed to have reduced range at other encounter angles. See RTCA DO-242A Table 3-2(a) for allowed range reductions.*

3.2.1.7 Transmit Pattern Gain

The gain of the transmit antenna subsystem **shall** not be less than the gain of a matched quarter-wave stub minus 3 dB, under the following conditions:

a. Over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane,

b. When installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane,

c. Measured at an operating frequency of 978 MHz.

3.2.1.8 Receive Pattern Gain

The gain of the receive antenna subsystem **shall** not be less than the gain of a matched quarter-wave stub minus 3 dB, under the following conditions:

a. Over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane,

b. When installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane,

c. Measured at an operating frequency of 978 MHz.

3.2.1.9 Dynamic Response

The antenna(s) shall be located such that operation of the equipment is not adversely affected by aircraft maneuvering or changes in attitude encountered in normal flight operations.

Note: *Class A0 installations are not required to install multiple (e.g., top fuselage and bottom fuselage) antennas.*

3.2.1.10 Antenna Diplexer

An antenna Diplexer may be utilized in installations with SSR ATCRBS transponders or Mode S transponders to allow antenna sharing of the UAT equipment and the transponder. The use of a Diplexer may be considered in all classes of UAT equipage classes. When installed with the Diplexer, the ATCRBS or Mode S transponder **shall** continue to conform to the appropriate standards. The installation of a Diplexer must consider the impact to the transponder and UAT equipment. The loss of signal power through the Diplexer must be included in the cable loss allocation between the antenna and the transponder, and the antenna and the UAT equipment. The signal delay through the Diplexer must also be considered and if diversity is supported, the use of a Diplexer on the Top, Bottom or both antennas must insure that the diversity delay tolerances between Top and Bottom antenna are met for both the transponder and UAT equipment.

Note: *The characteristics of the Diplexer contained in these MOPS should insure proper operation of UAT equipment with the majority of existing models of ATCRBS and Mode S transponders. Extensive testing was performed with current representative ATCRBS and Mode S transponders and prototype Diplexers to verify proper operation of the transponders and UAT equipment* *with the use of a Diplexer. Results of these tests were utilized to produce and validate the Diplexer requirements contained in this document. The assumptions used to derive Diplexer characteristics have taken into consideration existing installations of ATCRBS and Mode S transponders; installation manuals for such existing transponder installations should be consulted to calculate acceptable cable loss. The loss budget for cable loss between the antenna and equipment in most installations should readily absorb the loss allocated to the Diplexer.*

Variation in Diplexer characteristics from the requirements contained in this document must insure that the transponder and UAT equipment meet the requirements of the appropriate applicable standards. Verification that the isolation requirements of the transponder are satisfied and receiver tolerance to high power off frequency signals need to be factors in consideration of use of a Diplexer in installations.

3.2.2 Mutual Suppression Bus

This test verifies that the UAT equipment and the on-board SSR transponder and TCAS, if applicable, operate properly on the mutual suppression bus.

Demonstrate that the UAT transmission does not cause the SSR transponder to generate spurious signals during a UAT transmission, as defined by the ADS-B Message Transmission Interval in §2.2.2.5.

Demonstrate that the UAT transmission does not cause TCAS to generate spurious signals during a UAT transmission, as defined by the ADS-B Message Transmission Interval in §2.2.2.5.

3.3 Conditions of Test

The following subparagraphs define conditions under which tests, specified in §3.4, shall be conducted.

3.3.1 Safety Precautions

Comply with any specific safety precautions that are recommended by the equipment manufacturer.

3.3.2 Power Input

Unless otherwise specified, all aircraft electrically operated equipment and systems shall be turned ON before conducting interference testing.

3.3.3 Environment

During testing, the equipment shall not be subjected to environmental conditions that exceed those specified by the equipment manufacturer.

3.3.4 Adjustment of Equipment

Circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

3.3.5 Warm-up Period

Unless otherwise specified, tests shall be conducted after a warm-up (stabilization) period of not more than fifteen (15) minutes.

3.4 Test Procedures for Installed Equipment Performance

The following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred by the installing activity. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures. The equipment shall be tested to determine compliance with the minimum requirements stated in §2.2. In order to meet this requirement, test results supplied by the equipment manufacturer or other proof of conformity may be accepted in lieu of bench tests performed by the installing activity.

3.4.1 Verification of Antenna Installation (§3.2.1)

No specific test procedure is required to verify compliance with §3.2.1.

3.4.1.1 Verification of General Considerations (§3.2.1.1)

No specific test procedures are required for §3.2.1.1.

3.4.1.2 Verification of Transmission Lines (§3.2.1.2)

Purpose/Introduction:

The purpose of this procedure is to verify that the VSWR produced by the antenna when terminated in a 50 ohm transmission line does not exceed 1.7:1 at 978 MHz.

Equipment Required:

Appropriate Couplers and Connectors as required. Coaxial Connection of known attenuation (shown in Figure 3-1 and Figure 3-2 as Coax #2). Appropriate Attenuators as required. HP 8562E Network Analyzer (or equivalent capability)

Measurement Procedure:

Step 1: Install Network Analyzer

For ADS-B Transmitting Subsystem installations, disconnect the ADS-B Transmitting Subsystem to Antenna connection at the ADS-B Transmitting Subsystem unit connector.

For ADS-B Receiving Subsystems, disconnect the ADS-B Receiving Subsystem to Antenna connection at the ADS-B Receiving Subsystem unit connector.

Using appropriate attenuators, connectors, and coaxial cable of known attenuation and impedance, connect the Network Analyzer to the cable end of the Antenna connection (i.e., the connector just removed from the ADS-B Transmitting or Receiving Subsystem).

Note: *The use of attenuators is strongly recommended such that the RF front end of the Network Analyzer is not damaged.*

Step 2: Perform Impedance and VSWR Measurements

Using the Network Analyzer, measure the impedance of the antenna installation at a frequency of 978 MHz.

Verify that the impedance does not exceed 50 ohms.

Using the Network Analyzer, measure the Voltage Standing Wave Ratio (VSWR) of the antenna installation at a frequency of 978 MHz.

Verify that the VSWR does not exceed 1.7:1.

3.4.1.3 Verification of Antenna Polarization (§3.2.1.3)

Procedures to verify that the ADS-B Transmitting antenna is vertically polarized are contained within §3.4.1.7 through §3.4.1.7.3.

Procedures to verify that the ADS-B Receiving antenna is vertically polarized are contained within §3.4.1.8.

Data supplied by the antenna manufacturer can be used to verify the antenna polarization, in place of performing the test procedure.

3.4.1.4 Verification of Antenna Location (§3.2.1.4)

No specific test procedures are required for §3.2.1.4. Requirements for §3.2.1.4 can be verified by measurements of the final installed equipment, or by reference to the manufacturer's installation guide for the equipment.

3.4.1.5 Verification of Minimum Distance from Other Antennas (§3.2.1.5)

No specific test procedures are required for §3.2.1.5. Requirements for §3.2.1.5 can be verified by measurements of the final installed equipment, or by reference to the manufacturer's installation guide for the equipment.

3.4.1.6 Verification of Minimum Reception Range (§3.2.1.6)

Requirements for §3.2.1.6 can be verified during the flight test procedures (see §3.7).

3.4.1.7 Verification of Transmit Pattern Gain (§3.2.1.7)

Transmit pattern gain can be verified using data provided by the antenna manufacturer, or by any of the procedures provided in §3.4.1.7.1. If the manufacturer does not provide antenna gain pattern data, the procedure in §3.4.1.7.3 can be used to verify the antenna gain performance.

3.4.1.7.1 Background Material on Gain Performance Verification

Gain performance can be verified using one or a combination of the following procedures:

a. Full scale antenna range measurements, see §3.4.1.7.1.1.

b. Scaled model measurements, see §3.4.1.7.1.2.

c. Theoretical calculations, see §3.4.1.7.1.4.

d. Distance-area calculations, to ensure that the location of the antenna on the aircraft does not unduly degrade its gain performance, see §3.4.1.7.1.5.

The validation procedure, or combination of procedures, shall be performed using the configuration of the final installed equipment with all appropriate connections and antenna, in order to demonstrate proper operation of the final installation.

3.4.1.7.1.1 Full Scale Anechoic Antenna Range Measurements of Gain

The gain characteristics of the antenna as mounted on the actual airframe may be measured directly in a calibrated anechoic antenna test range using standard controlled procedures for such measurements. Gain characteristics determined in this way require no further validation.

Note: *Anechoic range measurements are generally impractical for determining full antenna gain patterns for large aircraft. However, such techniques may be practical for qualifying certain sub-regions of the coverage pattern or for validating model measurements or theoretical calculations.*

3.4.1.7.1.2 Scaled Model Measurements of Gain

Aircraft models for antenna measurements are normally 1/10 to 1/40 scale. Scale selection is dependent upon considerations such as availability of equipment, and antenna scaling, with larger models resulting in greater accuracy.

Only the major structural features of the airframe need be constructed. Details such as windows, doors, turbines, etc., are not required. The outside skin should be of conductive material. Typically, the fuselage and engine nacelles are modeled from metal tubing and/or shaped metal screening; wings and stabilizers can be modeled from flat metal plates. Movable control surfaces are not required unless they will have significant effects upon the antenna pattern.

Notes:

1. *In general, obstructions that subtend angles at the antenna of less than a few degrees in elevation or azimuth need not be modeled. However, smaller obstructions such as other antennas, that are located within a few wavelengths of the antenna under test, may have to be modeled because they can act as resonant scatterers and could have a significant effect on the radiation pattern.*

2. *If the swept area of propeller blades exceeds the limits given in (1) above, the blades can be worst-case modeled by a flat metal disk of radius proportional to blade length. If the radiation pattern using disks for propellers satisfies the success criteria, it can be assumed that the pattern modulation caused by the rotating blades will not significantly degrade the ADS-B system performance.*

3.4.1.7.1.3 Model Tests

Mount the scaled model antenna in the center of a ground plane whose radius is equal in wavelengths to the ground plane used for testing the full-scale antenna.

Using a calibrated anechoic antenna test range, confirm that the gain of the scaled antenna (including possible multiple radiating elements, splitting or combining networks, impedance, and mutual coupling effects) is within 2 dB of the full-scale antenna gain, for all azimuth and elevation angles for which the gain of the full-scale antenna is within 6 dB of the peak gain.

Mount the scaled model antenna on the aircraft model at the intended installation location.

Measure the antenna gain for all azimuth angles (for Top and Bottom antennas).

Confirm that the scaled antenna meets the success criteria of §3.4.1.7.2.

3.4.1.7.1.4 Theoretical Calculations of Antenna Gain

The gain characteristics of the antenna as mounted on the actual airframe may be determined by a combination of radiation pattern calculations, and measurements designed to validate those calculations. When using such techniques to determine the gain of a multi-element antenna, it is necessary to show that the calculations include the inherent characteristics of the antenna elements and their drivers, splitters, or combining networks and any effects due to mutual coupling between those elements.

3.4.1.7.1.4.1 Validation of Theoretical Calculations

If radiation pattern calculations are used to prove the success criteria of §3.4.1.7.2, the manufacturer of the antenna must provide corroborating data demonstrating the success of the calculation technique in predicting the antenna gain on an airframe roughly similar in size and complexity to the airframe under qualification. Such data must be obtained by comparison with selected gain measurements made (a) on a full-size airframe using a calibrated ramp test antenna range (see §3.4.1.7.1.1) or (b) on a scaled model airframe (see §3.4.1.7.1.2).

3.4.1.7.1.5 Distance Area Calculations

The extent to which the antenna installation minimizes obstructions in the horizontal plane and minimizes effects of reflecting objects, may be judged by the distance to such objects and their sizes. If the distances and sizes satisfy the condition given here, then the antenna installation may be considered validated with regard to antenna gain. The condition is: For target aircraft at zero degree elevation angle and at azimuth bearing between –90 degrees and +90 degrees,

$$\frac{A_1^2}{\lambda^2 D_1^2}+\sum\frac{A_2^2 G_2^{'}}{\lambda^2 D_2^2 G_2}+\sum\frac{A_3 G_3^{'}}{4\pi D_3^2 G_3}<0.02$$

where $\lambda = 1.006$ feet is the free space wavelength at 978 MHz. The first term is applicable only if there is a metallic obstruction between the target and the ADS-B antenna. The distance in feet to the obstruction is denoted D_1 and the area in ft^2 of the obstruction projected in the direction of the ADS-B antenna is denoted A_1. The second term is a summation over flat metallic reflectors, if any, that are oriented so as to cause a specular reflection between the ADS-B antenna and the target. The distance to the reflector, in feet, is denoted D_2, the area, in square feet, of the reflector, projected in the direction of the ADS-B antenna is denoted A_2, the antenna gain in the direction of the reflector is denoted G'_2 and is dimensionless (i.e., gain in dB = 10 log G'_2), and the antenna gain in the direction of the target is denoted G_2 and is dimensionless. The third term is a summation over all other metallic objects that may cause reflections between the ADS-B antenna and the target. The parameters D_3, A_3, G'_3, and G_3 have the same meanings as in the second term. In the case of other aircraft antennas in view of the ADS-B antenna, a minimum value for $A_x = 0.06$ square feet is to be used if the actual area of the antenna is less than 0.06 square feet. This value represents the maximum cross-sectional area of a typical L-band antenna.

3.4.1.7.2 Success Criteria

At an elevation angle of zero degrees relative to the fuselage reference plane, the gain of the forward ±45 degree azimuth sector of both the Top and Bottom antennas shall be no more than one dB below the gain of the antenna when installed on a 4-foot diameter ground plane. The radiation pattern gain, at zero degrees elevation, shall be within 3 dB of the gain of the ground-plane-installed antenna over 90% of the remainder of its azimuth coverage. The verification procedures of §3.4.1.7.3 shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

Note: *Antenna system performance tests are specified to accommodate the most stringent envisioned applications. Operational approval of proposed applications must consider installed antenna system performance. Installations that do not fully comply with the above requirements may be approved for particular operations based on the safety implications of the application.*

3.4.1.7.3 Verification Procedure for Transmit Pattern Gain

Purpose/Introduction:

The purpose of this procedure is to verify that the gain of an omni-directional transmit antenna is not less than the gain of a matched quarter-wave stub minus 3 dB over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane when installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane.

This procedure should be performed in the laboratory environment to demonstrate that the ADS-B Transmitting Subsystem properly delivers RF ADS-B Messages to the free space medium via the expected installation connections and radiating antenna.

This procedure shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

Equipment Required:

Provide a method of generating ADS-B Airborne Position Broadcast.

Calibrated quarter-wave stub Sense Antenna of known gain. (See Figure 3-1)

Appropriate Couplers and Connectors as required.

Coaxial Connection of known attenuation (shown in Figure 3-1 as Coax #2).

Appropriate Attenuators as required.

HP 8753E Spectrum Analyzer (or equivalent capability).

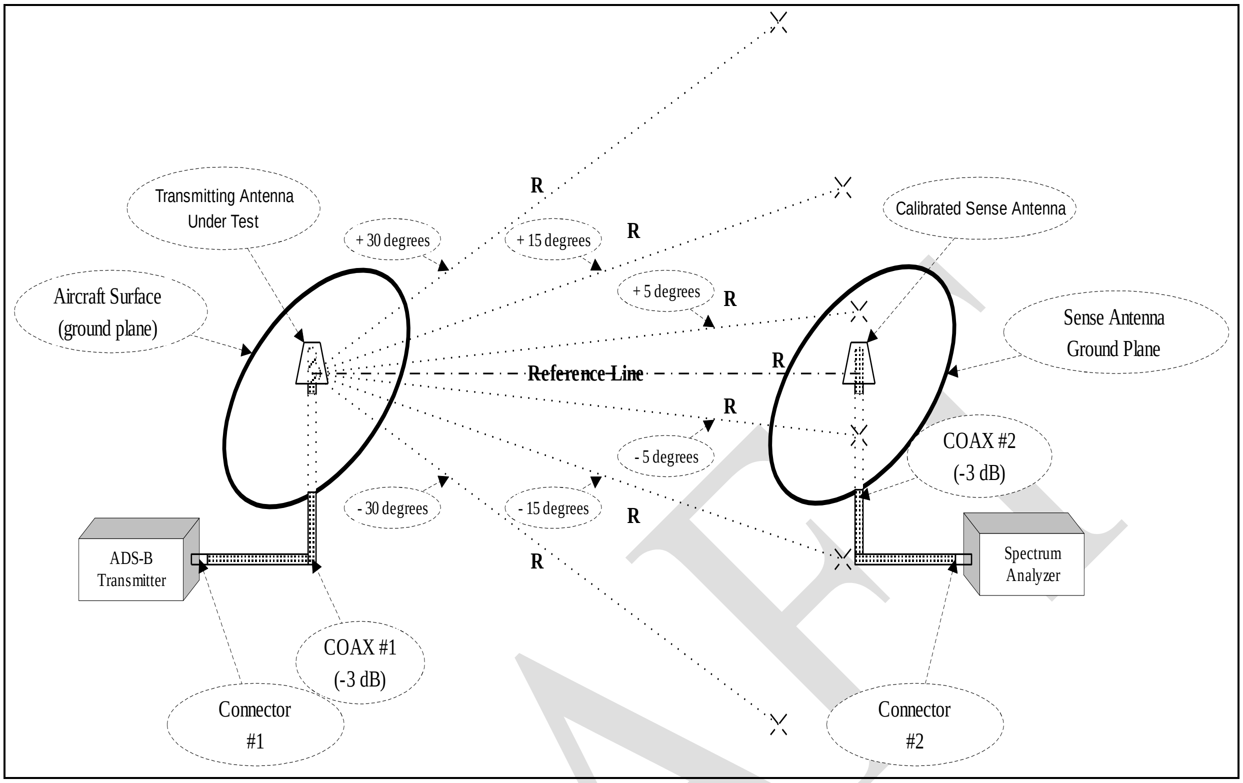


Figure 3-1: Antenna Test Configuration

Measurement Procedure:

Step 1: Understand the Equation

Define:

P_out = Transmitted Power (**in watts**) Measured at the ADS-B Broadcast Message Generator output connector in watts

Loss_TX = **attenuation** (**in dB**) provided by connection of the ADS-B Broadcast Message Generator to the Transmitting Antenna. This includes the cable (i.e., Coax #1 in Figure 3-1) and connectors

G_tx = gain (**in dB**) of the transmitting antenna

R = Distance between the transmitting antenna and the receiving antenna in meters

Path_Loss = attenuation (**in -dB**) of a 978 MHz signal in free space for distance = R

$= [\lambda/(4\pi R)]^2 = [(300/978)/(4\pi R)]^2 = [(2.44 \times 10^{-2})/R]^2$

$= 20*\log(2.44 \times 10^{-2}) - 20*\log(R)$

$= -32.25 - 20*\log(R)$

G_rx = gain (**in dB**) of the receiving or Calibrated Sense Antenna

Loss_RX = **attenuation** (**in dB**) provided by connection of the Calibrated Sense Antenna to the Spectrum Analyzer. This includes the cable (i.e., Coax #2 in Figure 3-1) and connectors and should be calibrated to 3 dB

P_rx_dBw = Power (in **dBw**) received at the Spectrum Analyzer

P_rx_dBm = P_rx_dBw - 30 = Power (in **dBm**) received at the Spectrum Analyzer

Then the expected power of the 978 MHz signal received at the Spectrum Analyzer is given by the following equation.

EQUATION 1:

P_rx_dBw = 10*log(P_out) - Loss_TX + G_tx + Path_Loss + G_rx - Loss_RX

= 10*log(P_out) - Loss_TX + G_tx –32.25 -20*log(R) + G_rx - Loss_RX

Specifying a Range of 3 meters (i.e., the distance between the antennas along the reference line shown in Figure 3-1) to be used as the Range in the following procedure provides the following Equation 2.

P_rx_dBw = 10*log(P_out) - Loss_TX + G_tx – 32.25 - 9.54 + G_rx - Loss_RX

EQUATION 2:

P_rx_dBw = 10*log(P_out) - Loss_TX + G_tx – 41.79 + G_rx - Loss_RX

Note: *If the measurement distance, R, is different from 3 meters, then Equation 2 must be recomputed for the new R and the recomputation must be based on Equation 1. Equation 1 is based on the fact that there are 1852 meters in one nautical mile. Also, there are 6076.1 feet in one nautical mile. Therefore, for the purpose of these computations, there are 3.28 feet per meter.*

The Effective Radiated Power (ERP) emitted from the Transmitting Antenna is then given by Equation 3 as follows:

EQUATION 3:

ERP_dBw = P_rx_dBw + 41.79 - G_rx + Loss_RX

Note: *Whenever the need to measure radiated RF power is established, the question arises in regards to the permissible level of radiation that can be sustained by personnel making the measurements. This document addresses such concerns in the following paragraph of this note.*

Assume that the maximum Effective Radiated Power from the UAT ADS-B Transmitting Subsystem is 250 W (24.0 dBW) as specified in §2.1.12 of this document. Then, using portions of equation 2 or 3 from above, the radiated power at 3 meters is given as follows:

P_3m_dBW = ERP – 41.791

= 24.0 dBW –41.79

P_3m_dBW = -17.79 dBW

then the power at 3 meters in watts is as follows:

$$10*log(P\_3m\_W) = -17.79$$

$$P\_3m\_W = 10^{-1.779}$$

$$= 0.0166\ W$$

$$= 16.6\ mW$$

This would appear to be a minimum amount of power: however, it does not readily translate into Maximum Permissible Exposure ***(MPE)*** *limits that are typically used to determine hazard levels.*

Consulting FCC OET Bulletin 65, Edition 97-01, August, 1997, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," provides information as provided in the following paragraphs.

Section 2, equation 3, page 19 of the bulletin provides the following equation for the prediction of RF fields:

$$S = \frac{EIRP}{4\pi R^2}$$

where:

S	=	*power density (in appropriate units, e.g., mW/cm²)*
EIRP	=	*equivalent (or effective) isotropically radiated power (in appropriate units, e.g .mW)*
R	=	*distance to the center of radiation of the antenna (appropriate units, e.g., cm)*

Applying this equation at 3 meters to the maximum radiated power (e.g., 250 W) allowed for UAT ADS-B Transmitting Subsystems provides the following results:

$$S = \frac{(250\ W)(1000\ mW/W)}{4\pi(300\ cm)^2}$$

$$= 0.221\ mW/cm^2$$

Appendix A, Table 1(A) of the bulletin then provides MPE limits for Occupational/Controlled Exposure as follows:

Frequency Range (MHz)	=	*300 - 1500*
Electric Field Strength (E) (V/m)	=	*Not Applicable*
Magnetic Field Strength (H) (A/M)	=	*Not Applicable*
Power Density (S) (mW/cm^2)	=	*f/300*
Averaging Time, S ***(minutes)***	=	*6*

Therefore, the MPE exposure for an average of 6 minutes at 978 MHz is:

$$S\_MPE\_978 = (978)/300 = 3.26\ mW/cm^2$$

Note that this limit value is over 14 times greater than the power density at 3 meters computed above as 0.221 mW/cm^2.

Next, the time of exposure must be considered. Page 11 of the bulletin addresses this concern with the equation:

$$\Sigma S_{exp} t_{exp} = S_{limit} t_{avg}$$

where:

S_{exp} = power density of exposure (mW/cm^2)
S_{limit} = appropriate power density MPE limit (mW/cm^2)
t_{exp} = allowable time of exposure for S_{exp}
t_{avg} = appropriate MPE averaging time

Taking into the consideration that the ADS-B Transmitting Subsystem will never exceed a transmitting duty cycle of .05% (one message per second, which does not exceed 500 microseconds duration), the allowable time of exposure is computed from the above equation as follows:

$$(0.221 \text{ mW/cm}^2)*X*(0.0005) = (978/300 \text{ mw/cm}^2)(6 \text{ minutes})$$

$$X = \frac{(978/300 \text{ mw/cm}^2)(6 \text{ minutes})}{(0.221 \text{ mW/cm}^2)(0.0005)}$$

$$X = 177 \times 10^3 \text{ minutes}$$

or

$$X = \mathbf{2{,}950 \text{ hours}}$$

These calculations have demonstrated that the expected power density of the ADS-B Transmitting Subsystem at 3 meters is well within the allowable MPE.

Step 2: Measure the Output Power of the ADS-B Transmitting Subsystem

On the Aircraft (or other applicable installation), disconnect the ADS-B Transmitting Subsystem to Antenna connection at the ADS-B Transmitting Subsystem unit connector.

Using appropriate attenuators, connectors, and coaxial cable of known attenuation of 3 dB and impedance of 50 ohms, connect the Spectrum Analyzer to the ADS-B Transmitting Subsystem.

Note: *The use of attenuators is strongly recommended such that the RF receiver front end of the Spectrum Analyzer is not destroyed.*

Configure the ADS-B Transmitting Subsystem to transmit ADS-B Surface Position Messages.

Using the Spectrum Analyzer set at a center frequency of 978 MHz, capture the power envelope of ADS-B Message transmission.

Verify that the frequency is at 978 MHz ±20 PPM.

For Class A0 and A1L equipment, verify that the output power is at least 7 watts (i.e., +38.5 dBm). Log the measurement as P_out.

For Class A1S, A1H and A2 equipment, verify that the output power is at least 15.8 watts (i.e., +42.0 dBm). Log the measurement as P_out.

For Class A3 equipment, verify that the output power is at least 100 watts (i.e., +50.0 dBm). Log the measurement as P_out.

Step 3: Re-connect Aircraft Installation

Disconnect the Spectrum Analyzer from the ADS-B Transmitting Subsystem.

Restore the normal aircraft (or other) installation connection of the ADS-B Transmitting Subsystem antenna to the ADS-B Transmitting Subsystem.

Step 4: Establish Measurement Reference #1

Refer to Figure 3-1.

Using an appropriate strong nylon string or similar, secure the string to the Calibrated Sensing Antenna and to the Aircraft Antenna under test such that the two antenna are exactly 3 meters apart along the reference line shown in Figure 3-1. Make sure that the two antennas are at the same height from a relatively level surface. Note this position of the Calibrated Sensing Antenna as the **baseline** position.

Then, move the Calibrated Sensing Antenna to a point that is 5 degrees above the baseline position while maintaining the Calibrated Sensing Antenna perpendicular to the string with the string being tight but not stretched. Note this position as the **#1 Reference** Position.

Configure the ADS-B Transmitting Subsystem to transmit ADS-B Surface Position Messages.

Using the Spectrum Analyzer set at a center frequency of 978 MHz, capture the power envelope of an ADS-B Message transmission. Measure and note the power.

For Class A0 and A1L equipment, verify that the output power is at least 7 watts (i.e., +38.5 dBm). Log the measurement as ERP_dBm.

For Class A1S, A1H and A2 equipment, verify that the output power is at least 15.8 watts (i.e., +42.0 dBm). Log the measurement as ERP_dBm.

For Class A3 equipment, verify that the output power is at least 100 watts (i.e., +50.0 dBm). Log the measurement as ERP_dBm.

Step 5: Circular Measurements

Keeping the Calibrated Sensing Antenna at 5 degrees above the baseline position as specified in Step 4, move the Calibrated Sensing Antenna in the horizontal plane in approximately 45 degree steps such that new positions are established at approximately 45, 90, 135, 180, 225, 270, and 315 degrees relative to **#1 Reference** Position.

At each new position, repeat the power measurement taken in Step 4 and log the results in dBw.

Verify that the maximum deviation between any two measurements taken in Step 4 and this Step does not exceed 1 dBw.

Step 6: Establish new reference #2

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 15 degrees above the **baseline** position. Note this position as the **#2 Reference** Position.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#2 Reference** Position while maintaining the Calibrated Sensing Antenna at 15 degrees above the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 7: Establish new reference #3

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 30 degrees above the baseline position. Note this position as the **#3 Reference** Position.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#3 Reference Position** while maintaining the Calibrated Sensing Antenna at 30 degrees above the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 8: Establish new reference #4

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 5 degrees below the baseline position. Note this position as the **#4 Reference** Position.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the #4 Reference Position while maintaining the Calibrated Sensing Antenna at 5 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 9: Establish new reference #5

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 15 degrees below the baseline position. Note this position as the **#5 Reference** Position.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#5 Reference** Position while maintaining the Calibrated Sensing Antenna at 15 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

<u>Step 10:</u> <u>Establish new reference #6</u>

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 30 degrees below the baseline position. Note this position as the **#6 Reference** Position.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#6 Reference** Position while maintaining the Calibrated Sensing Antenna at 30 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

3.4.1.8 Verification of Receive Pattern Gain (§3.2.1.8)

The background material of §3.4.1.7.1 through §3.4.1.7.2 applies equally to verification of Receive Pattern gain.

<u>Note:</u> *If the installed equipment uses the same antenna for both transmission and reception of ADS-B Messages, the procedure of §3.4.1.8 is not required. Receive antenna gain pattern is symmetric with the transmitted gain performance.*

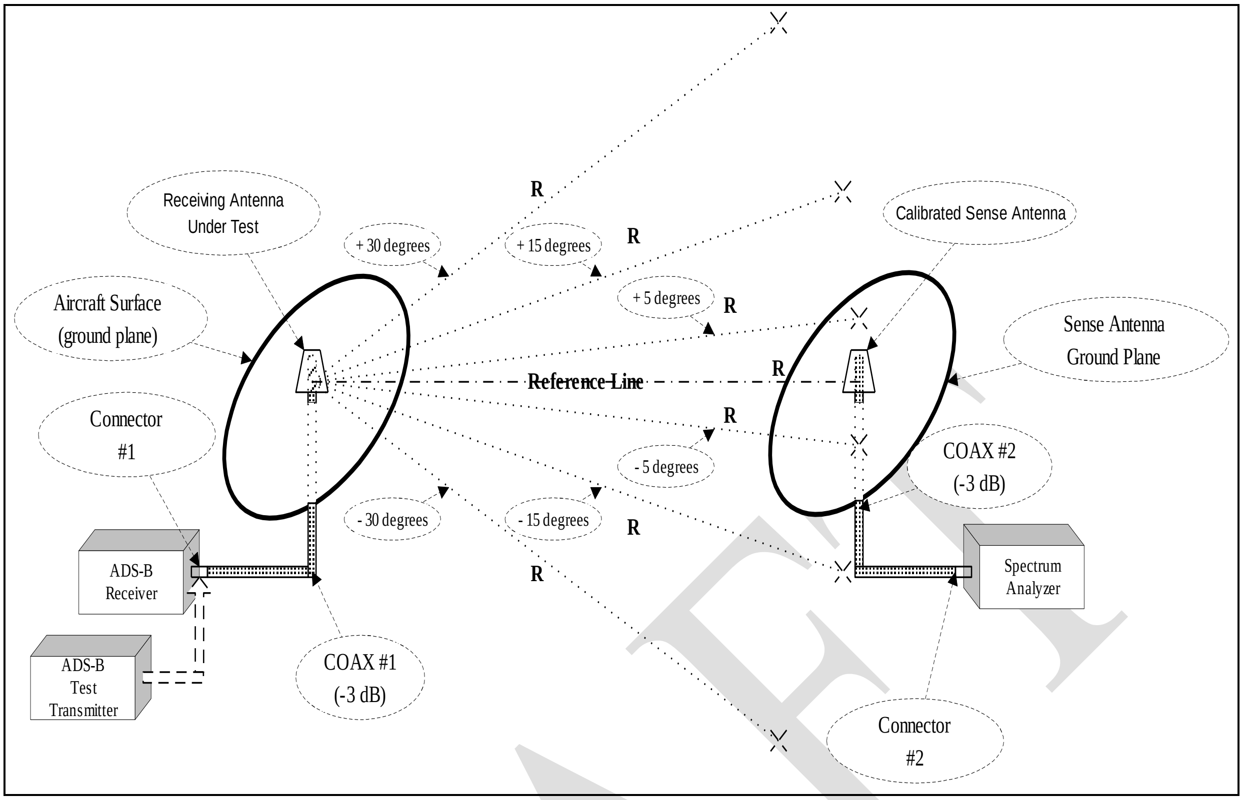
<u>Purpose/Introduction:</u>

The purpose of this procedure is to verify that the gain of an omni-directional antenna should is not less than the gain of a matched quarter-wave stub minus one dB over 90% of a coverage volume from 0 to 360 degrees in azimuth and -15 to +20 degrees in elevation when installed at the center of a 1.2 m (4 ft.) diameter (or larger) circular ground plane that can be either flat or cylindrical.

This procedure shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

<u>Equipment Required:</u>

Provide the same equipment capability as that provided in §3.4.1.7.3.



<u>Figure 3-2:</u> Antenna Test Configuration

<u>Measurement Procedure:</u>

<u>Note:</u> *Figure 3-2, above, is exactly the same as Figure 3-1 provided in §3.4.1.7.3 with the exception that:*

a. The ADS-B Transmitter in Figure 3-1 has been replaced with an ADS-B Receiver and an ADS-B Test Transmitter that is to be patched in for this test procedure.

b. The Transmitting Antenna under Test in Figure 3-1 has been replaced with a Receiving Antenna under Test.

<u>Step 1:</u> <u>Install ADS-B Transmission Capability</u>

On the Aircraft (or other applicable installation), disconnect the ADS-B Receiving Subsystem to Antenna connection at the ADS-B Receiving Subsystem unit connector.

For Class A0 and A1L Receiver installations, install an ADS-B Test Transmitting device having a minimum RF power of at least 7 watts (i.e., +38.5 dBm) ***plus*** 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

For Class A1S, A1H and A2 Receiver installations, install an ADS-B Test Transmitting device having a minimum RF power of at least 15.8 watts (i.e., +42.0 dBm) ***plus*** 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

For Class A3 Receiver installations, install a ADS-B Test Transmitting device having a minimum RF power of at least 100 watts (i.e., +50.0 dBm) ***plus*** 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

At this point, the ADS-B Receiving Subsystem of the ADS-B Receiving installation has been replaced with an appropriate RF source such that the radiated pattern of the receiving antenna installation can be verified. The premise here is that if the radiated pattern is good, then so is the reception pattern.

Step 2: Perform Radiated Pattern Tests

Using the equations given in §3.4.1.7.3, with appropriate modifications if necessary, repeat steps 2 through 10 of §3.4.1.7.3.

Step 3: Restore Original Installation

Disconnect and remove the ADS-B Test Transmitter and restore the original installation of the ADS-B Receiving Subsystem.

3.4.1.9 Verification of Dynamic Response (§3.2.1.9)

No specific test procedures are required for §3.2.1.9. The Dynamic Response requirements of §3.2.1.9 are best verified by analysis of the antenna mechanical properties and the installation locations.

3.5 Flight Environment Data Sources

Aircraft systems and/or sensors, which supply flight environment data to the ADS-B system, shall be selected to meet the accuracy, range, and resolution requirements appropriate to the equipage category (Accuracy, range, and resolution may be shown to be adequate by analysis.).

3.5.1 Navigation Integrity Category (NIC)

The system shall report NIC values appropriate to the navigation source (including its operational mode), which supplies data to the ADS-B system. NIC value varies with navigation source selection and the selected sensor’s current performance. If the aircraft has multiple navigation systems, NIC can vary with system selection and the mode of operation (e.g., Inertial Navigation with DME or GPS augmentation). The reported NIC value must vary to track navigation integrity (NIC) as it increases or decreases, corresponding to navigation system integrity.

3.5.2 Navigation Accuracy Category – Position (NAC_P)

The system shall report NAC_P values appropriate to the navigation source (including its operational mode), which supplies data to the ADS-B system. When the transmitted position is that of the Position Reference Point, the NAC_P value must include any offset between the navigation sensor location and the ADS-B Position Reference Point.

3.5.3 Altitude

Two sources of Altitude data are defined in the ADS-B System.

Barometric Pressure Altitude relative to a standard pressure of 1013.25 millibars (29.92 in.Hg.) shall be supplied to the ADS-B system . Altitude data, which is corrected for local barometric pressure, shall not be supplied to the ADS-B system. The ADS-B system and the ATC transponder (if installed) shall derive Pressure Altitude from the same sensor (e.g., air data computer or encoding altimeter). If a pressure altitude source with 26-foot or better resolution is available on the aircraft, that source shall be connected to the ADS-B Transmitting Subsystem.

Geometric Altitude is derived from the height above the WGS-84 ellipsoid by the GPS/GNSS navigation receiver.

3.5.3.1 Altitude Reporting Source

An interface shall be provided that allows the flight crew to disable the reporting of Barometric Pressure Altitude by the ADS-B equipment.

3.5.4 On-Ground / Airborne Status

Aircraft systems or sensors providing On-Ground versus Airborne status to the ADS-B system shall be implemented such that they provide a reliable indication that the aircraft is on the ground or airborne. When considering likely failure modes, the system should fail to the "air" mode where possible (e.g., air/ground relay should relax to the "air" mode). Other data sources, such as Radio Altitude, may be required for certain types of aircraft.

3.5.5 Short-Term Intent Sources

When it is desired to transmit Short Term Intent messages, data sources for Horizontal (Heading/Track) and Vertical (Target Altitude) Intent are required, along with additional indications of the Horizontal and Vertical modes and capabilities. In addition, an indication of whether the reference direction of Heading is True or Magnetic North is also required.

3.5.6 IDENT Source

An interface shall be provided that allows the flight crew to activate the IDENT function of the ADS-B equipment. If the aircraft is also transponder equipped, it is desired that the IDENT activation should be derived from the same cockpit interface.

3.5.7 Receiving ATC Services Source

An interface shall be provided that allows the flight crew to activate and cancel the "Receiving ATC Services" function of the ADS-B equipment.

3.6 Aircraft / Vehicle Data

ADS-B Messages contain information describing the aircraft or vehicle that is transmitting. It is a responsibility of the installer to insure that the vehicle information provided to the ADS-B system is correct.

3.6.1 Fixed Data

Data that does not change during operation, are selected or loaded at installation (e.g., ADS-B Emitter Category, ICAO address). Fixed data shall accurately represent the individual airplane/vehicle characteristics or registration information. If ADS-B and a Mode-S transponder are installed, both shall use the same ICAO address (whenever both are operating).

3.6.2 Variable Data

Controls used by the pilot/crew for data entry (e.g., Flight Number, Call Sign/Flight Plan ID, Emergency Status) shall correctly perform their intended functions.

When representing the Call Sign, the 8 characters of the "CALL SIGN" field (§2.2.4.5.4.2) shall be encoded with an identifier appropriate for the Emitter Category, operating rules, and procedures under which the A/V is operating. For aircraft, the "Call Sign" could be an abbreviation of the authorized radiotelephone Call Sign for that aircraft as assigned by ATS, the aircraft registration marking, or other authorized identifier for special operations.

The status of other pieces of avionics (e.g., CDTI, TCAS/ACAS Operating or Resolution Advisory Active) shall be provided to the ADS-B equipment, when required for the intended application.

Note: *Where regulations permit variation of the 24-bit Mode-S and /or ADS-B address, ADS-B and a Mode-S transponder shall use the same ICAO address (whenever both are operating).*

3.6.3 On-Condition and Status Sensors

Aircraft systems or sensors used to trigger On-Condition or status messages shall be selected and implemented such that they provide a reliable indication of the specific condition(s) to be reported.

3.7 Flight Test Procedures

This guidance material offers examples of flight test procedures for demonstration of performance of selected functions.

Flight testing of installed systems may be desirable to confirm or supplement bench and ground tests of installed performance.

Flight tests are not necessary to evaluate functions that encode, communicate, and decode messages, assemble reports, or generate displays, except for the radio frequency functions associated with transmission and reception of ADS-B Messages.

3.7.1 Displayed Data Reliability

Determine that normal conditions of flight do not significantly affect the readability of displayed data.

3.7.2 Interference Effects

For those aircraft systems and equipment that can only be tested in flight, determine that no operationally significant conducted or radiated interference exists. Evaluate all reasonable combinations of control settings and operational modes.

Note: *Electromagnetic interference flight tests are often conducted on all electronic systems in one test series, using procedures established by the aircraft manufacturer. If such tests included the ADS-B equipment, no further tests are required. (e.g., ADS-B functionality added to an existing transponder and/or TCAS installation)*

3.7.3 ADS-B Performance Testing

The ADS-B flight test is designed to verify that the installed ADS-B system is capable of transmitting and/or receiving ADS-B Messages from other aircraft. The following suggested procedures are typical flight test plans that could be followed in a region of low air traffic density: but any other test that supplies equivalent data would be acceptable.

ADS-B system testing requires verification of transmission and reception of ADS-B Messages at the minimum range for the equipage class. If testing an aircraft installation ("Subject"), which only broadcasts, the receiving equipment ("Target") must provide a means to display message information, received from the Subject, to the operator.

Shorter range (10-20 NM) operational requirements may be demonstrated using a ground based Target system. Longer range operation might require an airborne Target system. Typically the airborne Target aircraft will fly a holding pattern at a designated fix and within 3000 feet of the Subject aircraft altitude.

Fly the Subject aircraft straight and level at the minimum operational range and verify that data from the Subject aircraft is received reliably by the Target system. If the Subject system has the capability to receive, verify that the Subject system reliably reports information about the Target (e.g., displays Target at appropriate range and altitude with correct identification).

Note: *It is not intended that reception of individual ADS-B Messages be verified.*

Fly the Subject aircraft in a figure-8 pattern, at the minimum operational range, at bank angles consistent with normal operations, at a constant altitude, and verify that transmitted data are received reliably by the Target system. If the Subject system has the capability to receive, then verify that the Subject system reliably reports information about the Target during maneuvering (e.g., displays Target at appropriate range and altitude with correct identification).

4 EQUIPMENT OPERATIONAL PERFORMANCE CHARACTERISTICS

4.1 Required Operational Performance Characteristics

The operation of the UAT ADS-B System should be highly automated, to minimize the need for crew intervention. To ensure operations can be conducted safely and reliably in the expected operational environment, specific operational performance characteristics are required. The following paragraphs identify these requirements.

4.1.1 Power Input and Control

The UAT ADS-B System should be powered whenever primary electrical power is available. Components may receive power from multiple sources or busses (e.g. 115 vac and 28 vdc). Typically, power is controlled by circuit breakers and is only interrupted due to an electrical fault. The system shall retain memory of variable data through power transfers, occurring during normal operations. Typical power transfer involves switching to engine driven generator(s) from external power, battery, or APU generator. The system shall not require re-initialization after a power transfer (i.e., power loss) lasting up to 0.3 second. Normal power transfer shall not latch a failure indication. Momentary failure indications during power transfer or a resulting system recovery are allowed.

4.1.1.1 Power On/Off (Optional)

Aircraft with limited electrical system capacity may employ UAT ADS-B System power controls for energy conservation. Power controls should be designed to prevent the system being turned off inadvertently.

4.1.2 Equipment Operating Modes

The UAT ADS-B System has two basic operating modes, broadcast transmission of own ship information and reception of data from other participants. Both transmit and receive modes are normally active at the same time. Both transmit and receive modes may employ sub-modes, tailored to specific phases of operation. Operating modes control variable characteristics such as message types to be transmitted and message repetition.

4.1.2.1 Transmission Modes

The UAT ADS-B Transmit Subsystem transmits the required messages for the equipment class, without crew intervention. Ownship ADS-B Messages are formatted and transmitted without crewmember inputs or adjustments such as mode selection or channel tuning.

Certain messages related to Mode Status (MS) information and On-Condition reports may be triggered by crew actions satisfying the conditions for the automatic generation of an associated message.

Crew member input of Mode Status (MS) information, where practical, (e.g., flight number) is acceptable. The capability to acquire all message elements automatically is desirable. Automatic acquisition of data reduces crew workload and avoids data entry errors. Supplemental information may be entered via associated equipment.

The Transmit Subsystem shall have at least two (2) transmitting modes corresponding to surface operations and air operations. Switching between surface and air modes shall be accomplished automatically. Automatic mode selection may be determined by reference to State Vector (SV) data elements (e.g., speed, radio altitude) or discrete inputs (e.g., weight-on-wheels switch).

It should be possible to force the system to either mode, while on the ground, for testing. Control of ON-GROUND and AIRBORNE Condition switching shall not be available to the flight crew during normal operation.

4.1.2.1.1 ON-GROUND Condition

When operating in the ON-GROUND condition, Magnetic Heading may be replaced with Ground Track Angle, if Magnetic Heading is not available.

4.1.2.1.2 AIRBORNE Condition

In the AIRBORNE Condition, the UAT Transmitting Subsystem transmits all message types, appropriate to the equipment class**.**

4.1.2.2 Receive Subsystem

The ADS-B Receive Subsystem performs two (2) functions. A UAT receiver detects incoming ADS-B Messages (i.e., ADS-B surveillance messages and Ground Up-link messages) and decodes the message data. A report assembly function collects and organizes the individual messages into reports and provides the reports to user applications via data bus(s). The most likely application is a Cockpit Display of Traffic Information (CDTI).

4.1.2.2.1 Receive Function

The Receive function operates identically in surface and air modes of operation. The UAT receiver continues to detect and decode all recognizable ADS-B Messages and pass them to the report assembly function. The report assembly function may apply filtering criteria to exclude data that is not required by an application.

4.1.2.2.2 Report Assembly Function

The Report Assembly function may accept control inputs from applications. The controls allow the report assembly function to filter out messages that are not important to the application(s). Filtering allows for more efficient use of available computing resources. Filtered messages are supplied to an application only if specific control conditions are met. Controls might specify certain message types, or require data values to be within a given range, for a message to be included in a report (e.g., Altitude ≤ 5,000 ft.). In the Surface Mode, the report assembly function might include ground traffic in the traffic file sent to the CDTI. Ground traffic would likely be omitted from the CDTI while airborne, to reduce clutter.

4.1.3 UAT Link Control (Optional)

A means may be provided for the flight crew to disable the UAT ADS-B link. Disabling results in the cessation of transmission and/or reception of ADS-B Messages on the UAT link. Control of transmission and reception of any other installed ADS-B System(s) shall be independent of the UAT link status.

Note: *It may be necessary to inhibit all transmissions under certain operational circumstances.*

4.1.4 Standby

A means shall be provided for the flight crew to select a standby mode in which UAT transmissions are inhibited. (Reception of messages and report generation may continue.)

4.1.5 Mode Status Message Control

The transmit function shall accept data for on-condition or event driven message transmissions, as appropriate to the equipment capability classification. At the manufacturer's option, a means may be provided for the flight crew to enter this data. (e.g., Minimum fuel, No Communications, Unlawful Interference, etc.)

4.1.6 Barometric Altitude

A means shall be provided for the flight crew to inhibit the broadcast of barometric altitude, if directed to do so by ATC, or if barometric altitude being reported is determined to be inaccurate.

4.1.7 Broadcast Monitor

The Transmit Subsystem shall include an automatic monitor to verify that the UAT transmits messages at a nominal rate. The transmitter is considered to have failed if transmissions are not detected in five (5) consecutive seconds.

4.1.8 Address Monitor

A Participant Address monitor shall be provided for the UAT ADS-B System when it is using the ICAO 24-bit address. In the event that Address Selection Input is set to the "ICAO" value, and the Participant ICAO 24-bit Address is all ZEROs or all ONEs, the system shall declare a failure.

4.1.9 Failure Indication

The detection of a failure shall be annunciated to the flight crew. System output(s) shall be provided to indicate the failed/not-failed state of the ADS-B System. Momentary power interruptions should not cause the output(s) to latch in the failed state. If normal operation is subsequently resumed, the failure indication may be removed. At a minimum, failure to transmit State Vector messages at a nominal rate, a failure detected by self-test, or a failure of the ICAO Participant Address verification, shall cause the Failure Indication output(s) to indicate a failure.

Note: *It is desirable to continue operating the system in the presence of partial system failures (e.g., continue to receive messages and display traffic even though the transmitter has failed). System architects are encouraged to provide partitioning, monitoring, and annunciation, such that unaffected system functions can be identified and used, in the presence of a failure.*

4.2 Certification Test Procedures for Operational Performance Requirements

Equipment operational tests may be conducted as part of normal pre-flight tests. For those tests that can only be run in flight, procedures should be developed to perform these tests as early during the flight as possible to verify that the equipment is performing its intended function(s).

4.2.1 Power Input

Energize the equipment and verify that the equipment operates when powered from all normal electrical power sources.

4.2.1.1 Ground Power Unit (GPU)

If the aircraft and the ADS-B System are designed to accept electrical power from an external source, verify that the equipment is operational when the aircraft electrical system is powered by an appropriate ground power source. At a minimum, system self-tests and crew pre-flight activities (e.g., flight number entry) should be operational.

4.2.1.2 Auxiliary Power Unit (APU)

If the aircraft is equipped with an auxiliary power unit capable of supplying electrical power, verify that the equipment is operational when the APU generator is powering the aircraft and the UAT equipment. At a minimum, UAT ADS-B System self-tests and crew pre-flight activities should be operational.

4.2.1.3 Engine Generator(s)

Verify that the UAT ADS-B System is operational when the engine generator(s) are supplying electrical power to the aircraft. If system operation is limited when powered by the ship's battery, APU or GPU, verify that the system is fully operational when powered by the engine generator(s).

4.2.1.4 Power On/Off (Optional)

If the system uses a power on/off control, verify that the control performs the intended function. The design/installation of the power control should preclude inadvertent system shut off.

4.2.2 UAT Transmitting Subsystem Operating Modes

Verify that the UAT Transmitting Subsystem transmits the messages appropriate to the equipment class designation and mode of operation.

4.2.2.1 ON-GROUND Condition

Verify that the UAT Transmitting Subsystem transmits appropriate messages when in the ON-GROUND condition.

4.2.2.2 AIRBORNE Condition

Verify that the UAT Transmitting Subsystem transmits all the messages required of its equipment class, when in the AIRBORNE condition.

4.2.2.3 Automatic Operation

Verify that the UAT Transmitting Subsystem switches between the surface and air modes without crew intervention. If the system installation design includes On-Condition reports, verify that the appropriate report is transmitted when the condition(s) are satisfied. Verify that interfaces to Mode Status (MS) information operate as designed, providing the correct information (e.g., tail number, flight number, etc.).

4.2.3 Controls and Indicators

Verify that all required controls and indicators are installed. Verify all controls and indicators perform their intended function(s).

4.2.3.1 Standby Mode

Verify that a means is provided for the crew to inhibit UAT transmissions.

4.2.3.2 UAT Link Control (Optional)

If a UAT link control is installed, verify that deselecting the UAT link has no affect on operation of any other installed ADS-B System.

4.2.3.3 Barometric Altitude

Verify that a means is provided for the crew to inhibit the broadcast of barometric altitude.

4.2.3.4 Failure Indication

Verify that an indication of UAT system failure is provided to the crew.

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Appendix A
Acronyms & Definition of Terms

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A. Acronyms & Definition of Terms

A.1 Acronyms

AC - Advisory Circular

ACARS - Aircraft Communications, Addressing and Reporting System

ACAS – Airborne Collision Avoidance System

ACR – Adjacent Channel Reduction

ADS - Automatic Dependent Surveillance

ADS-B - Automatic Dependent Surveillance-Broadcast

AGL - Above Ground Level

APDU – Application Protocol Data Unit

A/V - Aircraft/Vehicle

ATCRBS - Air Traffic Control Radar Beacon System

ATC - Air Traffic Control

ATM - Air Traffic Management

ATS - Air Traffic Services

ATIS - Automatic Terminal Information Service

BCD - Binary Coded Decimal

BDS - Comm-B Data Selector

BER - Bit Error Rate

BNR - Binary Numbers

bps – Bits Per Second

BW - Bandwidth

C/A - Coarse Acquisition

CPA - Closest Point of Approach

CNS - Communications, Navigation and Surveillance

CDTI - Cockpit Display of Traffic Information

CEFR – CDTI-based Electronic Flight Rules

CPDLC – Controller-Pilot Data Link Communications

CRC - Cyclic Redundancy Check

CW - Continuous Wave

dB – Decibel

dBm – Decibel with respect to 1 milliwatt

DME - Distance Measuring Equipment

DOD - U.S. Department of Defense

DOP - Dilution Of Precision

ELT - Emergency Locating Transmitter

EPU - Estimated Position Uncertainty

E/W – East/West

ERP - Effective Radiated Power

ETA - Estimated Time of Arrival

EUROCAE - European Organization for Civil Aviation Equipment

FAA - Federal Aviation Administration

FAR - Federal Aviation Regulation

FEC – Forward Error Correction

FIS-B - Flight Information Services-Broadcast

FMS - Flight Management System

f_0 – Nominal or Center Frequency

fpm - Feet Per Minute

FSD - Full Scale Deflection

FSS - Flight Service Station

FTE - Flight Technical Error

GNSS - Global Navigation Satellite System

GPS - Global Positioning System

h – Modulation Index

Hz - Hertz

IAS - Indicated Airspeed

ICAO - International Civil Aviation Organization

IFR - Instrument Flight Rules

ILS - Instrument Landing System

IMC - Instrument Meteorological Conditions

INS - Inertial Navigation System

I/O - Input and/or Output

ISI – Inter-Symbol Interference

ITU - International Telecommunication Union

JAA - Joint Aviation Authorities

JAR - Joint Aviation Requirements

JTIDS – Joint Tactical Information Distribution System (a.k.a. Link 16)

kHz – Kilohertz

L1 - 1575.42 MHz (a navigation frequency associated with GPS)

LAAS - Local Area Augmentation System

LADGPS - Landing Area Differential GPS

LSB - Least Significant Bit

MASPS - Minimum Aviation System Performance Standards

MAUS – Multi-Aircraft UAT Simulator

Mbps – Million Bits Per Second

MFD - Multi-Functional Display

MHz - Megahertz

MIDS – Multifunctional Information Distribution Systems

MOPS - Minimum Operational Performance Standards

MS - Mode Status

ms – Milliseconds

MSL - Minimum Signal Level

MSO – Message Start Opportunity

MTBF - Mean Time Between Failure

MTL - Minimum Trigger Level

NAS - U.S. National Airspace System

NAV - Navigation

NAVAID - Navigation Aid

NM - Nautical Mile

NOTAM - Notice to Airmen

N/S – North/South

NAC$_P$ - Navigation Accuracy Category - Position

NAC$_V$ - Navigation Accuracy Category - Velocity

NAC$_{baro}$ - Navigation Accuracy Category - Barometric

NIC$_{baro}$ - Navigation Integrity Category - Barometric

OC - On Condition

PIREP - Pilot Report

PPM – Parts Per Million

PPS – Pulse Per Second

P_r - Probability of Receipt

PS – Payload Selection

PSR - Primary Surveillance Radar

PUME – Probability of Undetected Message Error

RA - Resolution Advisory

RAIM - Receiver Autonomous Integrity Monitoring

RCP - Required Communication Performance

RF - Radio Frequency

rms - Root Mean Square

RNP - Required Navigation Performance

RS – Reed-Solomon

RSP - Required System Performance

rss - Root-Sum-Square

RVR - Runway Visual Range

RVSM - Reduced Vertical Separation Minimum

SA or S/A - Selective Availability

SAE - Standard Aerospace Equipment

SAR - Search And Rescue

SARPS - Standards and Recommended Practices

SID - Standard Instrument Departure

SIR – Surveillance Integrity Level

SNR - Signal-to-Noise Ratio

SPS - Standard Positioning Service

SSR - Secondary Surveillance Radar

SUA - Special Use Airspace

SV - State Vector

TA - Traffic Advisory

TACAN – Tactical Air Navigation

TAS - True Airspeed

TCAS - Traffic Alert and Collision Avoidance System

TCP - Trajectory Change Point

TERPS - Terminal Instrument Procedures

TIS - Traffic Information Service

TIS-B - Traffic Information Service-Broadcast

TMA - Terminal Maneuvering Area

TOMR – Time of Message Receipt

TOMT – Time of Message Transmission

TS – Target State

TSD - Traffic Situation Display (see also CDTI)

TSDF – Time Slot Duty Factor

TSE - Total System Error

TSO - Technical Standards Order

TTG - Time to Go

UAT – Universal Access Transceiver

U.S. - United States

μsec – Micro Second

UTC - Coordinated Universal Time

UUT – Unit Under Test

VFR - Visual Flight Rules

VMC - Visual Meteorological Conditions

VSWR – Voltage Standing Wave Ratio

W – Watts

WAAS - Wide Area Augmentation System

WGS-84 - World Geodetic System 1984

Xmt - Transmit

A.2 Definition of Terms

Accuracy - A measure of the difference between the A/V position reported in the ADS-B message field as compared to the true position. Accuracy is usually defined in statistical terms of either 1) a mean (bias) and a variation about the mean as defined by the standard deviation (sigma) or a root mean square (rms) value from the mean. The values given in this document are in terms of the two-sigma variation from an assumed zero mean error.

Active Waypoint - A waypoint to or from which navigational guidance is being provided. For a parallel offset, the active waypoint may or may not be at the same geographical position as the parent waypoint. When not in the parallel offset mode (operating on the parent route), the active and parent waypoints are at the same geographical position.

ADS-B Broadcast and Receive Equipment - Equipment that can transmit and receive ADS-B messages. Defined as Class A equipment.

ADS-B Broadcast Only Equipment - Equipment that can transmit but not receive ADS-B messages. Defined as Class B equipment.

ADS-B Message – A modulated packet of formatted data which conveys information used in the development of ADS-B reports.

ADS-B Report – Specific information provided by the ADS-B user participant subsystem to external applications. Reports contain identification, state vector, and status/intent information. Elements of the ADS-B Report that are used and the frequency with which they must be updated will vary by application. The portions of an ADS-B Report that are provided will vary by the capabilities of the transmitting participant.

ADS-B Subsystem - The set of avionics or equipment that performs ADS-B functionality in an aircraft or for ground-based, non-aircraft, participants.

ADS-B System - A collection of ADS-B subsystems wherein ADS-B messages are broadcast and received by appropriately equipped participant subsystems. Capabilities of participant subsystems will vary based upon class of equipage.

Advisory - An annunciation that is generated when crew awareness is required and subsequent crew action may be required; the associated color is unique but not red or amber/yellow. (Source: Advisory Circular AC 25 - 11).

Aircraft Address - The term “address” is used to indicate the information field in an ADS-B message that identifies the ADS-B unit that issued the message. The address provides a continent means by which ADS-B receiving units—or end applications—can sort messages received from multiple issuing units.

Aircraft/Vehicle (A/V) - Either 1) a machine or service capable of atmospheric flight, or 2) a vehicle on the airport surface movement area. In addition to A/Vs, ADS-B equipage may be extended to temporarily uncharted obstacles (i.e., obstacles not identified by a current NOTAM).

Air Mass - Air mass data includes barometric altitude and air speed.

Alert Zone - In the Free Flight environment, each aircraft will be surrounded by two zones, a protected zone and an alert zone. The alert zone is used to indicate a condition where intervention may be necessary. The size of the alert zone is determined by aircraft speed, performance, and by CNS/ATM capabilities.

Along-Track Distance - The distance along the desired track from the waypoint to the perpendicular line from the desired track to the aircraft.

Applications - Specific use of systems that address particular user requirements. For the case of ADS-B, applications are defined in terms of specific operational scenarios.

Application Interface – The Application Interface is responsible for the extraction of ADS-B Reports from the Report Output Storage Buffer via the Report to Application Interface. Requirements for the Application Interface and Report to Application Interface are to be specified in various Application Interface specifications and therefore are not addressed in this document.

Barometric Altitude - Geopotential altitude in the earth's atmosphere above mean standard sea level pressure datum surface, measured by a pressure (barometric) altimeter.

Barometric Altitude Error - For a given true barometric pressure, P_o, the error is the difference between the transmitted pressure altitude and the altitude determined using a standard temperature and pressure model with P_o.

Call Sign - The term "aircraft call sign" means the radiotelephony call sign assigned to an aircraft for voice communications purposes. (This term is sometimes used interchangeably with "flight identification" or "flight ID"). For general aviation aircraft, the aircraft call sign is normally its national registration number; for airline and commuter aircraft, it is usually comprised of the company name and flight number (and therefore not linked to a particular airframe); and for the military, it usually consists of numbers and code words with special significance for the operation being conducted.

Caution - An annunciation that is generated when immediate crew awareness is required and subsequent crew action will be required; the associated color is amber/yellow. (Source: Advisory Circular AC25 - 11).

Closest Point of Approach (CPA) - The minimum horizontal distance between two aircraft during a close proximity encounter, a.k.a. miss distance.

Cockpit Display of Traffic Information (CDTI) - A function which provides the pilot/flight-crew with surveillance information about other aircraft, including their position. The information may be presented on a dedicated multi-function display

(MFD), or be processed for presentation on existing cockpit flight displays. Traffic information for the CDTI function may be obtained from one or multiple sources (including ADS-B, TCAS, and TIS) and it may be used for a variety of purposes. Requirements for CDTI information will be based on intended use of the data (i.e., application).

Collision Avoidance - An unplanned maneuver to avoid a collision.

Conflict - Any situation involving two or more aircraft, or an aircraft and an airspace, or an aircraft and ground terrain, in which the applicable separation minima may be violated.

Conflict Detection - The process of projecting an aircraft's trajectory to determine whether it is probable that the applicable separation minimum will not be maintained between the aircraft and either 1) another aircraft or vehicle, 2) a given airspace, or 3) ground terrain. The level of uncertainty in the projection is reduced with increased knowledge about the situation, including aircraft capabilities, flight plan, short term intent information, etc.

Conflict Management - Process of detecting and resolving conflicts.

Conflict Probe - The flight paths are projected to determine if the minimum required separation will be violated. If the minima are not [projected to be] violated, a brief preventive instruction will be issued to maintain separation. If the projection shows the minimum required separation will be violated, the conflict resolution software suggests an appropriate maneuver.

Conflict Resolution - The process of identifying a maneuver or set of maneuvers that, when followed, do not cause a conflict or reduce the likelihood of conflict between an aircraft and either 1, another aircraft or vehicle, 2, a given airspace, or 3, ground terrain. Maneuvers may be given to multiple aircraft to fully resolve a conflict.

Conformance - The condition established when the surveillance report of an aircraft's position at some time "t" (established by the Automated Tracking function) is within the conformance region constructed around that aircraft at its nominal position at time "t", according to the agreed upon trajectory.

Cooperative Separation - This concept envisions a transfer of responsibility for aircraft separation from ground based systems to the air-crew of appropriately equipped aircraft, for a specific separation function such as In-trail merging or separation management of close proximity encounters. It is cooperative in the sense that ground-based ATC is involved in the handover process, and in the sense that all involved aircraft must be appropriately equipped, e.g., with RNAV and ADS-B capability, to perform such functions.

Co-ordinated Time Scales – A time scale synchronised within stated limits to a reference time scale. Co-ordinated Universal Time (UTC) is the time scale maintained by Bureau International des Poids et Mesures (BIPM), and the International Earth Rotation Service (IERS), which forms the basis of a co-ordinated dissemination of standard frequencies and time signal. It corresponds exactly in the rate with the International Atomic Time (TAI), but differs from it by an integer number of seconds.

Cross-link - A cross-link is a special purpose data transmission mechanism for exchanging data between two aircraft — a two-way addressed data link. For example, the TCAS II system uses a cross-link with another TCAS II to coordinate resolution advisories that are generated. A cross-link may also be used to exchange other information that is not of a general broadcast nature, such as intent information.

Desired Course - Can be either 1) True - A predetermined desired course direction to be followed (measured in degrees from true north), or 2) Magnetic - A predetermined desired course direction to be followed (measured in degrees from local magnetic north).

Effective Update Interval - The time interval between successful message receipt with at least 98% probability of successful reception. For example, if ADS-B messages are sent at one second intervals in signal-to-noise conditions with 75% probability of success per transmission, then the probability of obtaining at least one message in three tries is $= 1. - (0.25)^3 \sim 98.4\%$. Thus the effective update interval for this case = 1 sec x 3 = 3 sec.

Effective Update Rate - The reciprocal of effective update interval, e.g. rate = 1/3 ~ 0.33 Hz for the example above.

En Route - A phase of navigation covering operations between departure and termination phases. En route phase of navigation has two subcategories: en route domestic/continental and en route oceanic.

Event Driven - Messages that are broadcast periodically for a duration of the operational condition. Examples of event driven messages include Emergency/Priority Status *(ref. RTCA/DO-242A, Section 2.1.2.18)* and aircraft intent *(ref. RTCA/DO-242A, Section 2.1.2.19)*.

Eye Diagram – The eye diagram of the transmitted UAT wave form can be constructed from a graph of frequency deviation versus time by overlaying multiple versions of the graph shifted by integral numbers of symbol (bit) periods. An example can be seen in Figure A-1. The timing of the points where the lines converge defines the “optimum sampling point.” Figure A-2 shows an eye pattern that has been partially closed.

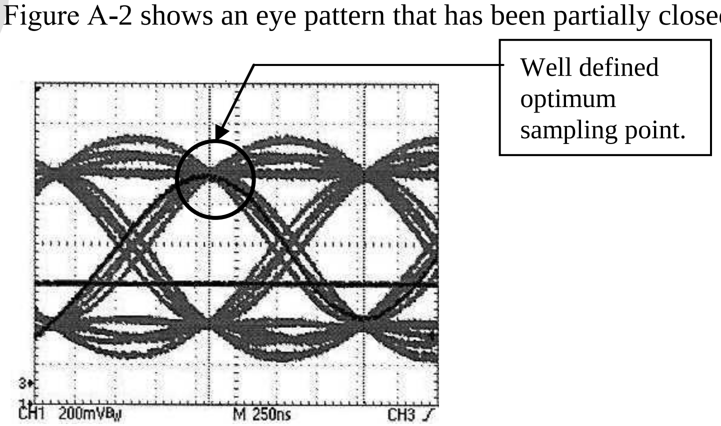

Figure A-1: Ideal eye diagram

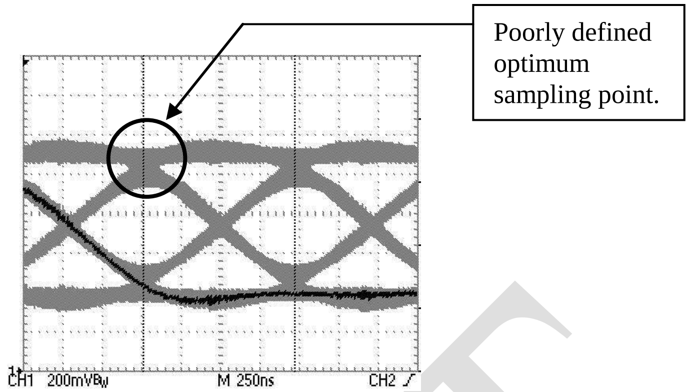

Figure A-2: Distorted eye diagram

Field – The elements of ADS-B message payload. Most of these elements are enumerated in RTCA Document DO-242A (e.g., Latitude, Longitude, Velocity, etc.)

Free Flight - Free Flight is a safe and efficient flight operating capability under IFR in which the operators have the freedom to select their path and speed in real time.[TF3, Oct. 1995].

FRUIT – Transponder replies unsynchronized in time. See Garble, Non-synchronous.

Garble, Non-synchronous – Reply pulses received from a transponder that is being interrogated from some other source. Also called FRUIT.

Geometric Dilution of Position (GDOP) - The ratio of position error of a multi-lateration system. More precisely, it is the ratio of the standard deviation of the position error to the standard deviation of the measurement errors, assuming all measurement errors are statistically independent and have a zero mean and the same standard distribution. GDOP is the measure of the "goodness" of the geometry of the multi-lateration sources as seen by the observer; a low GDOP is desirable, a high GDOP undesirable. (See also PDOP, HDOP and VDOP.)

Geometric Height - The minimum altitude above or below a plane tangent to the earth's ellipsoid as defined by WGS84.

Geometric Height Error - Geometric height error is the error between the true geometric height and the transmitted geometric height.

Global Navigation Satellite System (GNSS) - GNSS is a world-wide position, velocity, and time determination system, that includes one or more satellite constellations, receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation.

Global Positioning System (GPS) - A space-based positioning, velocity and time system composed of space, control and user segments. The space segment, when fully operational, will be composed of 24 satellites in six orbital planes. The control segment consists of five monitor stations, three ground antennas and a master control station. The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

GNSS Altitude (MSL) - The height of the aircraft (or of its GNSS antenna) above the *geoid*, which is the surface that represents mean sea level. The term *geoid*, as defined by the National Geodetic Survey's *Geodetic Glossary*, is the equipotential surface of the Earth's gravity field which best fits, in the least squares sense, mean sea level.

Graticule – A network of lines on a map representing geographic parallels and meridians.

Ground Uplink Message – A message containing 432 bytes of payload transmitted only by UAT ground stations and only within the ground segment of the UAT frame.

Horizontal Dilution of Precision (HDOP) - The ratio of user-referenced horizontal position error to measurement error of a multi-lateration system. (See GDOP for a more detailed description.)

International Atomic Time (TAI) – The time scale established by the Bureau International des Poids et Mesures (BIPM) on the basis of data from atomic clocks operating in several establishments conforming to the definition of the second, the unit of the time of the International System of Units (SI).

In-Trail Climb - In-trail climb (ITC) procedures enables trailing aircraft to climb to a more fuel-efficient or less turbulent altitude.

In-Trail Descent - In-trail descent (ITD) procedures enables trailing aircraft to descend to a more fuel-efficient or less turbulent altitude.

Interactive Participants - An ADS-B network member that is a supplier of information to the local ADS-B subsystem and a user of information output by the subsystem. Interactive participants receive messages and assemble reports specified for the respective equipage class.

Latency - The latency of an ADS-B transmission is the time period from the time of applicability of the aircraft/vehicle position ADS-B report until the transmission of that ADS-B report is completed.

Latency Compensation - High accuracy applications may correct for system latency introduced position errors using ADS-B time synchronized position and velocity information.

Message – The actual RF transmission on the UAT channel. There are fundamentally two message types: ADS-B Messages and Ground Uplink Messages. (See ADS-B Message.)

Message Overhead – The portion of the message which supports the physical layer transfer of the data.

Message Payload – The portion of the message that carries data (user information) that will be consumed by application systems outside the UAT system.

Message Reception and Decoding – The primary function of the Message Reception and Decoding function is to deliver all Successful Message Receptions to the Report Assembly Function.

Message Start Opportunity – Discrete times separated by 250 μsec which define the moments when messages can be transmitted. The MSO selected for each transmission changes each second as a result of a pseudorandom process.

Message Transmission Cycle – A period of 16 seconds in which each MTO appears four times in a pattern that ensures a proper mix of message types are distributed to both Top and Bottom antennas when diversity transmission is used.

Near Term - Near-term applications are defined as those that can be supported by an initial ADS-B implementation and that may be operationally feasible within the context of a current ATC system or the ATC systems of the near future.

Normal Maneuver - Any maneuvers within the aircraft's approved flight-loads envelope that does not exceed 60 degrees angle of bank, or results in an abrupt change in the aircraft's attitude or accelerations. Abrupt changes in accelerations are those that exceed the values shown below. *Note that g = acceleration of gravity = 9.8 m/s^2.*

Horizontal Acceleration	Vertical Acceleration	Total Jerk
0.58 g	0.5 g	0.25 g/s

Optimum Sampling Point – The point during the bit period at which the opening of the eye diagram (i.e., the minimum separation between positive and negative frequency offsets at very high signal–to-noise ratios) is maximized.

Payload Selection Cycle – A 16 second time interval during which each of up to 4 ADS-B Message types is transmitted at least 4 times (in order to optimize the effect of antenna diversity).

Planned Primary Means - Use of ADS-B for Planned Primary Means will be possible for selected airspace operations based upon predictable conditions, e.g., GNSS constellation, type of operation, and extent of ADS-B equipage for participating aircraft. That is, ADS-B will be available as a primary means of surveillance for particular periods of time in particular geographical regions for approved operations.

Phase of Flight - The phases of flight are defined as follows:

1. Oceanic/Remote - Radio updating is not viable due to either very limited navigation aid coverage or no navigation aid coverage.

2. En Route/Domestic - Aircraft sequences above 15,500 feet while not actively flying a SID, or is above 15,500 and sequences the last waypoint of a SID, or the phase of flight is Oceanic and radio updating is viable.

3. Terminal - Aircraft sequences below 15,000 feet; or when the aircraft is in Approach and exceeds 3,000 feet above arrival airport elevation if there is no missed approach holding point, or the missed approach holding point is sequenced; or the aircraft is in Takeoff and exceeds 3,000 feet above departure airport elevation if no SID exist in active flight plan, or the last waypoint of the SID is sequenced below 15,500.

4. Approach - The first waypoint on the active approach or approach transition is sequenced, or the aircraft sequences below 2,000 feet above arrival airport elevation. Approach flight phase will not be active when a VFR approach is in the active flight plan.

Primary Means of Navigation - The airborne navigation equipment that meets the requirements of radio navigation for the intended phase of flight (route to be flown). These requirements include satisfying the necessary level of accuracy, integrity, continuity, and availability for a particular area, route, procedure, or operation. Examples of systems which provide a primary means of navigation include:

a. VOR for domestic en route, terminal, and non precision approach where it is available;

b. VOR/DME for domestic en route above flight level 240, terminal, and non precision approach where it is available;

c. OMEGA for Oceanic Operation;

d. INS for Oceanic Operation;

Protected Zone - In the Free Flight environment, each aircraft will be surrounded by two zones, a protected zone and an alert zone. The protected zone must remain sterile to assure separation. It can be envisioned as a distance-based "hockey puck" with radius equal to half the horizontal separation minimum and vertical extent equal to ± half the vertical separation minimum. The size of the protected zone is a direct reflection of the position determination accuracy.

Received Update Rate – The sustained rate at which periodic ADS-B messages are successfully received, at a specified probability of reception.

Reliability - The probability of performing a specified function without failure under given conditions for a specified period of time.

Resolution – The smallest increment reported in an ADS-B message field. The representation of the least significant bit (LSB) in an ADS-B message field.

Report – The encapsulated payload of received messages that is forwarded to on-board application processors. (See ADS-B Report.)

Report Assembly Function – The Report Assembly Function receives all Successful Message Receptions from the Message Reception and Decoding function and structures Reports for delivery to the Report Output Storage Buffer.

Required Navigation Performance (RNP) - A measure of the navigation system performance within a defined airspace, route, or procedure, including the operating parameters of the navigation's systems used within that airspace. (Source: Adapted from the ICAO Separation Panel).

Report Output Storage Buffer – The primary purpose of the Report Output Storage Buffer is to store and maintain all Reports such that the Reports are available for extraction by the Application Interface upon demand or as needed.

Seamless - A "chock-to-chock" continuous and common view of the surveillance situation from the perspective of all users.

Sole Means of Navigation - An approved navigation system for a given operation or phase of flight that must allow the aircraft to meet, for the operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability, and continuity of service.

Station-keeping - Station-keeping provides the capability for a pilot to maintain an aircraft's position relative to the designated aircraft. For example, an aircraft taxiing behind another aircraft can be cleared to follow and maintain separation on a lead aircraft. Station-keeping can be used to maintain a given (or variable) separation. An aircraft that is equipped with an ADS-B receiver could be cleared to follow an FMS or GNSS-equipped aircraft on a GNSS/FMS/RNP approach to an airport. An aircraft doing station-keeping would be required to have, as a minimum, some type of CDTI.

State Vector - An aircraft or vehicle's current kinematic state.

Successful Message Reception – Detection of synchronization pattern and successful FEC decoding for either ADS-B or uplink (i.e., FIS-B) messages.

Supplemental Means of Navigation - An approved navigation system that can be used in controlled airspace of the NAS in conjunction with a sole means of navigation.

Tactical Parameters - Tactical information may be used to enhance the performance of designated applications. System designs should be flexible enough to support tactical parameters; however, it is not required to provide the parameters in all implementations.

Target State (TS) Report – The Target State (TS) Report provides information on the horizontal and vertical targets for the active flight segment

Terminal Area - A general term used to describe airspace in which approach control service or airport traffic control service is provided.

Total System Error (TSE) - Generic: The root-sum-square of the navigation source error, airborne component error, display error and flight technical error. Specific: The root-sum-square of the position fixing error, display error, course selection error and flight technical error.

Track Angle - Instantaneous angle measured from either true or magnetic north to the aircraft's track.

Transition Level – The beginning of Class A Airspace, typically at 18,000 feet, pressure altitude.

Transmission Rate - The sustained rate at which periodic ADS-B messages are transmitted.

Traffic Situation Display (TSD) - A TSD is a cockpit device that provides graphical information on proximate traffic as well as having a processing capability that identifies potential conflicts with other traffic or obstacles. The TSD may also have the capability to provide conflict resolutions.

Trajectory Change Point (TCP) - TCPs provide tactical information specifying space/time points at which the current trajectory of the vehicle will change. This change in vehicle trajectory could be in the form of a change in altitude (climb/descent), a change in heading, a change in airspeed (increase/decrease), or any combination thereof.

Trigger – Detection of ADS-B or Ground Uplink synchronization sequence.

UAT Frame – In the UAT system, the *frame* is the most fundamental time unit. Frames are one second long, and begin at the start of each UTC (or GPS) second. Each frame is divided into two segments: one segment in which Ground Uplink messages occur, and another segment in which ADS-B messages occur.

Universal Time (UT) – Universal Time is the general designation of time scales based on the rotation of the Earth.

UTC (Co-ordinated Universal Time) – See co-ordinated time scales.

UTC 1 second epoch signal – The reference timing used to establish message transmit and reception times with precision, as well as the time of applicability of Position and Velocity when the UAT transmitter is "UTC Coupled" to a GPS/GNSS navigation source.

Velocity Uncertainty Category (VUC) - The velocity uncertainty category (VUC) is needed for surveillance applications to determine whether the reported velocity has an acceptable level of velocity uncertainty.

Vertical Profile - A line or curve, or series of connected lines and/or curves in the vertical plane, defining an ascending or descending flight path either emanating from or terminating at a specified waypoint and altitude, or connecting two or more specified waypoints and altitudes. In this sense, a curve may be defined by performance of the airplane relative to the airmass.

Warning - An annunciation that is generated when immediate recognition and corrective or compensatory action is required; the associated color is red. (Source: Advisory Circular AC25 - 11)

World Geodetic Survey (WGS) - A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth, transformations from major geodetic datums, and the potential of the earth (usually in terms of harmonic coefficients).

World Geodetic System 1984 - A set of quantities, developed by the U.S. Department of Defense for determining geometric and physical geodetic relationships on a global scale, based on a geocentric origin and a reference ellipsoid with semi-major axis 6378137 and flattening 1/298.257223563.

Appendix B

MASPS Compliance Matrix

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B. MASPS Compliance Matrix

B.1 Introduction

In previous versions of this document, Appendix B, in Section B.2, contained a traceability matrix mapping the compliance of these MOPS with all requirements specified in the ADS-B MASPS (RTCA DO-242/DO-242A). A similar traceability matrix was also produced for RTCA DO-260A, "*Minimum Operational Performance Standards (MOPS) for the 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)*." These traceability matrices permitted both ADS-B link MOPS to be assessed as to their compliance with the ADS-B system requirements specified in the ADS-B MASPS.

B.2 ADS-B MASPS Compliance Matrix

The development of revised MOPS, for both UAT and 1090ES, has been performed in direct support of FAA and EASA rulemaking for ADS-B equipage, without first revising the ADS-B MASPS. Agreed-to changes which necessitate changes to ADS-B system requirements and are not merely link implementation specific have been documented in a series of Issue Papers maintained within RTCA Special Committee 186. These Issue Papers will serve as the basis for a future revision of the ADS-B MASPS (presumably RTCA DO-242B). At the time of publication of these MOPS, it is planned that part of any future revision of the ADS-B MASPS will include a matrix listing all MASPS requirements and mapping the corresponding requirement(s) from the current versions of both the UAT and 1090ES ADS-B link MOPS to the updated MASPS requirements.

B.3 FIS-B MASPS Compliance

This Appendix provides information on UAT compliance with data link-related requirements specified in RTCA/DO-267, *Minimum Aviation System Performance Standards (MASPS) for Flight Information Services—Broadcast (FIS-B) Data Link*. <u>UAT equipment meeting the requirements of this document will fully support FIS-B MASPS-compliant FIS-B implementations</u>.

The FIS-B MASPS defines a broadcast protocol for FIS-B products that can be used in any broadcast medium. Application Protocol Data Units (APDUs) are the smallest incremental units of data conveyed over the broadcast medium. An APDU consists of a header that can be up to 26 bytes in length followed by an APDU payload. The FIS-B MASPS specifies the format of the APDU header and encodings for fields of payloads but has no minimum requirement for APDU payload length. A single UAT Ground Uplink message can support FIS-B APDUs with payloads of up to 398 bytes. This capacity supports FIS-B services meeting FIS-B MASPS requirements for providing APDU headers and significant payload per APDU capacity.

Further FIS-B MASPS derived requirements on UAT/UAT equipment (as opposed to the FIS-B providing application or the FIS-B user application which uses data provided by the UAT equipment) and UAT compliance with those requirements are discussed below:

MASPS Section 2.1.1: FIS-B implementations are recommended to use equipment developed according to regulatory guidance for at least a "minor" failure mode classification. All UAT equipment is envisaged as being certified to at least this level.

MASPS Section 2.1.2: The FIS-B function **shall** not degrade the required performance of other higher priority, more safety critical CNS applications. This requirement is met with UAT because of the separation of FIS-B uplink messages into the Ground Uplink Segment of UAT frames. Furthermore, appropriate UAT ground infrastructure design will prevent FIS-B broadcasts from one ground station from interfering in more than an insubstantial manner with Ground Uplink messages from other ground stations.

MASPS Section 2.1.3: All FIS-B products **shall** use the standard application layer protocol and format. As discussed above, UAT capacity readily enables FIS-B UAT implementations to meet this requirement.

MASPS Section 2.2.1: Data contents of all FIS-B Product Files **shall** be transferred by a loss-less and transparent process from the broadcast transmitter through the data link medium to the FIS-B airborne system and its display. UAT ground uplink equipment will transmit whatever Ground Uplink messages it receives from FIS-B providers without UAT-based compression and using loss-less and transparent processes.

MASPS Section 2.2.3: UAT FIS-B uplink data link-level integrity is required to be at least as good as that provided by the frame check sequence in the HDLC standard (FIS-B MASPS, Appendix F). As discussed in Appendix M, data link-level integrity of UAT Ground Uplink messages is far greater than that provided by the 16-bit frame check sequence in HDLC.

MASPS Appendix F: UAT is expressly exempt from the HDLC-based frame layer requirements of the FIS-B MASPS. A future change of the MASPS is cited as outlining the frame layer format used within the UAT design to achieve equivalent function performance. As stated above, APDU capacity and FIS-B data integrity are amply supported by the requirements of this document.

Appendix C

Example ADS-B Message Encoding

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C. Example ADS-B Message Encoding

C.1 Reed Solomon Encoding of Message Payload

The encoding is accomplished by means of a **systematic** RS 256-ary code with 8 bit code symbols (Bytes). The first parity symbol out of the FEC encoder is treated as the most significant symbol of the parity sequence. The parity check symbols are appended to the trailing end of the sequence of data symbols.

The ordering of the Bytes is from MSB to LSB, left to right, as they enter and exit the Reed Solomon encoder, as is the ordering of the bits within each Byte (MSB to LSB). When treated as polynomial coefficients this is equivalent to transmitting the high order coefficient(s) first. Since the systematic Reed Solomon Code is defined over the Galois Field GF(2^8), using the primitive polynomial [with binary coefficients, i.e., GF(2)] given as:

$$p(x) = x^8 + x^7 + x^2 + x + 1$$

all of the non-zero elements of the extension field GF(256) can be described as powers of a root of p(x); that is, for α such that $p(\alpha) = 0$, the nonzero elements of GF(256) are given as α^m, for m = 0, 1, 2, ..., 254 (where $\alpha^{255} \equiv \alpha^0 = 1$). For example,

$\alpha^8 \equiv \alpha^7 + \alpha^2 + \alpha + 1 =$ (1,0,0,0,0,1,1,1) as a binary 8-tuple (Byte).

To complete the description of the extension field elements, the "zero" element (additive identity) is denoted as **0** = (0,0,0,0,0,0,0,0).

The generator polynomial for the Reed Solomon codes is given as:

$$G(x) = \prod_{i=120}^{P} (x - \alpha^i)$$

where P = 131 for RS (30,18) and P = 133 for RS (48,34) codes used for two ADS-B messages.

C.2 Reed Solomon Encoding of Basic Type 0 ADS-B Message Payload

The generator polynomial for the RS (30,18) Reed Solomon code is given as:

$$G(x) = x^{12} + \alpha^{76}x^{11} + \alpha^{66}x^{10} + \alpha^{157}x^{9} + \alpha^{28}x^{8} + \alpha^{92}x^{7} + \alpha^{220}x^{6} + \alpha^{88}x^{5}$$
$$+ \alpha^{20}x^{4} + \alpha^{145}x^{3} + \alpha^{50}x^{2} + \alpha^{56}x + \alpha^{231}$$

Table C-1 represents an example of a Basic ADS-B Message Payload with selected values for individual fields and the equivalent bit oriented representation. Each data field from Table C-1 is arranged in sequence as shown to depict the transmitted Basic ADS-B Message data sequence.

Transmitted Basic ADS-B Message Data Byte #

MSB **1**	**2**	**3**	**4**	**5**	**6**	**7**
0000 0000	**1111 1010**	**1010 0001**	**0010 0011**	**0101 0101**	**0101 0101**	**0101 0101**
8	**9**	**10**	**11**	**12**	**13**	**14**
1100 0000	**0000 0000**	**0000 0000**	**0000 0011**	**0101 0100**	**0000 0110**	**0100 0100**
15	**16**	**17**	**18**			
0011 0010	**1100 0000**	**0010 1000**	**0000 0000**$_{\text{LSB}}$			

Table C-1: Example of Basic ADS-B Message Payloads

Data Field	**Value**	**Bit-Oriented Equivalent**
Payload Type Code	0	0 0000
Address Qualifier	0	000
Aircraft Address	FAA123 (HEX)	1111 1010 1010 0001 0010 0011
Latitude (WGS-84)	60° N	010 1010 1010 1010 1010 1010
Longitude (WGS-84)	45º W	1110 0000 0000 0000 0000 0000
Altitude Type	0	0
Altitude	300 feet	0000 0011 0101
NIC	4	0100
Air/Ground State	0	00
[Reserved Bit]	0	0
North Velocity or Ground Speed	400 knots North	001 1001 0001
East Velocity or Heading	100 knots East	000 0110 0101
Vertical Velocity	+64 feet/minute (UP)	100 0000 0010
UTC coupled	1(YES)	1
[Reserved Bits]	0	000
[Reserved Byte]	0	0000 0000

Note: *The payload field definition of ADS-B Type 0 and Type 1 Messages in Table C-1 and Table C-2 respectively are current as of issue of this MOPS, version 1. These two messages are given as an example to describe how the field element α is defined within each symbol and how the data symbols sequence enter RS encoder and exit with FEC parity sequence at its trailing end.*

In generating the FEC, the ADS-B Message data bits are arranged into eight bit bytes assuming that the leftmost byte is the Most Significant Byte. The encoder accepts the 18 information symbols (Bytes) as:

$$\leftarrow[\underline{0},\alpha^{165},\alpha^{124},\alpha^{232},\alpha^{84},\alpha^{84},\alpha^{84},\alpha^{105},\underline{0},\underline{0},\alpha^{99},\alpha^{214},\alpha^{100},\alpha^{143},\alpha^{222},\alpha^{105},\alpha^{201},\underline{0}]$$

and generates the 12 symbols parity sequence:

$$\leftarrow[\alpha^{60},\alpha^{145},\alpha^{41},\alpha^{128},\alpha^{120},\alpha^{183},\alpha^{138},\alpha^{76},\alpha^{220},\alpha^{90},\alpha^{175},\alpha^{71}]$$

The parity sequence is then appended to the (right) end of the information sequence to complete the 30 symbols Codeword for transmission (left symbol first).

MSB **ADS-B Basic Message Payload Bits + FEC Parity Bits**

0000 0000 1111 1010 1010 0001 0010 0011 0101 0101 0101 0101 0101 0101 1100 0000 0000 0000
0000 0000 0000 0011 0101 0100 0000 0110 0100 0100 0011 0010 1100 0000 0010 1000 0000 0000
1111 1110 1001 0111 1100 0100 0011 0100 1110 0001 1111 1111 0101 0011 0110 0101 1100 1111
1000 1111 1010 1111 1110 0100$_{\mathbf{LSB}}$

C.3 Reed Solomon Encoding of Long Type 1 ADS-B Message Payload

The generator polynomial for the RS (48,34) Reed Solomon code is given as:

$$G(x) = x^{14} + \alpha^{82}x^{13} + \alpha^{49}x^{12} + \alpha^{21}x^{11} + \alpha^{70}x^{10} + \alpha^{26}x^{9} + \alpha^{140}x^{8} + \alpha^{135}x^{7} + \alpha^{138}\alpha^{6}$$
$$+ \alpha^{22}x^{5} + \alpha^{64}x^{4} + \alpha^{13}x^{3} + \alpha^{39}x^{2} + \alpha^{70}x + \alpha^{241}$$

Table C-2 represents an example of Long Type 1 ADS-B Message payload (Basic ADS-B State Vector plus MS [Mode Status] elements, and AUX State Vector report elements fields) and the equivalent bit oriented representation.

Table C-2: Example of Long Type 1 ADS-B Message Payloads

Data Field	Value	Bit-Oriented Equivalent
Payload Type Code	1	0 0001
Address Qualifier	0	000
Aircraft Address	FAA123 (HEX)	1111 1010 1010 0001 0010 0011
Latitude (WGS-84)	60° N	010 1010 1010 1010 1010 1010
Longitude (WGS-84)	45º W	1110 0000 0000 0000 0000 0000
Altitude Type	0	0
Altitude	+300 feet	0000 0011 0101
NIC	4	0100
Air/Ground State	0	00
[Reserved Bit]	0	0
North Velocity or Ground Speed	400 knots North	001 1001 0001
East Velocity or Heading	100 knots East	000 0110 0101
Vertical Velocity	+64 feet/minute(UP)	100 0000 0010
UTC coupled	1(YES)	1
[Reserved Bits]	0	000
Emitter Category Code and Call Sign Characters#1 and #2	2 (Small) and "AB"	0000 1110 0001 1011
Call Sign Characters#3, #4, and #5	"CD1"	0100 1101 0000 1001
Call Sign Characters#6, #7, and #8	"234"	0000 1100 1111 1100
Emergency	0	000
MOPS Version	1	001
SIL	0	00
TMSO(6 LSBs of 12-bit MSO #)	1250 (only 6 LSB is transmitted)	10 0010
[Reserved Bits]	0	00
NAC_P	7	0111
NAC_V	2	010
NIC_{BARO}	0	0
Capability Class (CC) Codes	0	00
Operational Mode (OM) Codes	0	000
True Magnitude	0	0
[Reserved Bits]	0	00 0000 0000 0000 0000
Secondary Altitude	+300 feet	0000 0011 0101
[Reserved Bits]	0	0000 0000 0000 0000 0000 0000 0000

Note: *The payload field definition of ADS-B Type 0 and Type 1 Messages in Table C-1 and Table C-2 respectively are current as of issue of this MOPS, version 1. These two messages are given as an example to describe how the field element* α *is defined within each symbol and how the data symbols sequence enter RS encoder and exit with FEC parity sequence at its trailing end.*

Each data field from Table C-2 is arranged in sequence as shown to depict the transmitted Long Type 1 ADS-B Message data sequence.

Transmitted Long Type 1 ADS-B Message Data Bytes #

MSB----1	2	3	4	5	6	7
0000 1000	**1111 1010**	**1010 0001**	**0010 0011**	**0101 0101**	**0101 0101**	**0101 0101**
8	**9**	**10**	**11**	**12**	**13**	**14**
1100 0000	**0000 0000**	**0000 0000**	**0000 0011**	**0101 0100**	**0000 0110**	**0100 0100**
15	**16**	**17**	**18**	**19**	**20**	**21**
0011 0010	**1100 0000**	**0010 1000**	**0000 1110**	**0001 1011**	**0100 1101**	**0000 1001**
22	**23**	**24**	**25**	**26**	**27**	**28**
0000 1100	**1111 1100**	**0000 0100**	**1000 1000**	**0111 0100**	**0000 0000**	**0000 0000**
29	**30**	**31**	**32**	**33**	**34**	
0000 0000	**0000 0011**	**0101 0000**	**0000 0000**	**0000 0000**	**0000 0000**$_{LSB}$	

In generating the FEC, the ADS-B Message data bits are arranged into eight bit bytes assuming that the leftmost byte is the Most Significant Byte. The encoder accepts the 34 information symbols (Bytes) as:

$$\leftarrow[\alpha^{3},\alpha^{165},\alpha^{124},\alpha^{232},\alpha^{84},\alpha^{84},\alpha^{84},\alpha^{105},\underline{0},\underline{0},\alpha^{99},\alpha^{214},\alpha^{100},\alpha^{143},\alpha^{222},\alpha^{105},\alpha^{201},\alpha^{107},\\ \alpha^{49},\alpha^{117},\alpha^{205},\alpha^{101},\alpha^{58},\alpha^{2},\alpha^{144},\alpha^{34},\underline{0},\underline{0},\underline{0},\alpha^{99},\alpha^{202},\underline{0},\underline{0},\underline{0}]$$

and generates the 14 symbol parity sequence:

$$\leftarrow[\alpha^{107},\alpha^{221},\alpha^{159},\alpha^{183},\alpha^{133},\alpha^{63},\alpha^{240},\alpha^{100},\alpha^{51},\alpha^{146},\alpha^{15},\alpha^{13},\alpha^{206},\alpha^{35}]$$

The parity sequence is then appended to the (right) end of the information sequence to complete the 48 symbols Codeword for transmission (left symbol first).

MSB **Long Type 1 ADS-B Message Payload Bits + FEC Parity Bits**

0000 1000 1111 1010 1010 0001 0010 0011 0101 0101 0101 0101 0101 0101 1100 0000 0000 0000
0000 0000 0000 0011 0101 0100 0000 0110 0100 0100 0011 0010 1100 0000 0010 1000 0000 1110
0001 1011 0100 1101 0000 1001 0000 1100 1111 1100 0000 0100 1000 1000 0111 0100 0000 0000
0000 0000 0000 0000 0000 0011 0101 0000 0000 0000 0000 0000 0000 0000 0000 1110 0001 1001
1000 0101 1111 1111 1001 1100 0110 1011 0011 0011 0000 0110 0110 1100 1010 1001 1111 0100
0011 1101 0001 0010 1110 1000 LSB

Appendix C References

References for forward Error Coding and the Galois Field are listed below:

C-1. Peterson, W.W., and E.J. Weldon, Jr., Error-Correcting Codes, 2nd ed., MIT Press, Cambridge, MA, 1972.

C-2. Michelson, A. M., and A. H. Levesque, Error-Control Techniques for Digital Communication, John Wiley & Sons, New York, NY 1985.

Appendix D
UAT Ground Infrastructure

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D UAT Ground Infrastructure

As part of the Minimum Operational Performance Standard for the UAT, this informative appendix describes the working concept for a UAT ground infrastructure. This infrastructure supports the ground-air segment of the overall UAT network. This is not intended to be a specification or set of requirements for such a ground infrastructure, but rather a context in which to understand the intentions of the UAT data link and the provisions made to support the ground infrastructure.

D.1 General Description

The role of the ground infrastructure is twofold:

a. To receive ADS-B broadcasts and generate a summary of the air traffic in a given area, possibly fusing it with other surveillance data (e.g. radar or multilateration systems).

b. To transmit this traffic data along with other flight service information, e.g. weather, NOTAMS, and differential GPS corrections to the airborne traffic for use in the cockpit.

There is considerable flexibility within the UAT MOPS for the deployment and functionality of the ground infrastructure. The receive and transmit functions may be physically separate and even have different providers, or they could be a single ground network of transceivers feeding an integrated system providing all the above functions. This will probably be decided more by economics and regulations than by engineering design. This Appendix only describes enough of the system to allow understanding of the UAT data link and be reasonably sure that it will provide the necessary functionality.

D.1.1 Uplink: Broadcast

D.1.1.1 Geometric Coverage

Due to the limited range and geometry of a single ground station, a network of ground broadcast transmitting stations will be required. Each station will have associated with it two types of coverage. One is the *radio coverage* of the transmitted signal. This is the airspace that can be usefully reached by signal from the ground station. The other type of coverage is the *product coverage*. This is the geographic scope of responsibility the ground station assumes for each product (such as a weather map) broadcast. Two product categories, TIS-B and FIS-B, are discussed separately, since they require different strategies.

D.1.1.1.1 Radio Coverage

In designing the radio coverage, there are two concerns. One is the coverage being *relied upon*. This is the minimum required coverage. The other is the maximum coverage under the “best” conditions. This can cause one station to interfere with another distant station. Minimum radio coverage is designed to assure a data link under worst-case cable loss, receiver sensitivity, unfavorable antenna attitude (a banking aircraft), etc. When experiencing conditions better than the worst case, the coverage can be considerably greater.

The UAT system uses time division multiplexing to allow multiple stations to operate on the same frequency. At the designer's disposal are the 32 time slots within the Ground Segment of the UAT frame (see Section 1.2.2). Since time slots must be re-used geographically, there is a potential for self-interference where radio coverage is greater than the designed minimum. The allocation of one or more time slot resources to a given ground station based on some re-use pattern will mitigate this self-interference.

As a sample coverage scheme, a hexagonal "cellular" pattern of ground stations with a nominal intersite spacing of 100 NM would assure coverage everywhere down to about 3000 feet above ground level (AGL). (This is based on a 4/3 earth refraction model, a nominal antenna height, and ignores terrain effects.) This intersite spacing would require a minimum broadcasting range of about 58 NM. A longer range may be specified if overlapping coverage is desired. A nominal coverage cell layout is shown in Figure D-1. In this example case, the radio coverage covers about half way into the adjacent cell, giving at least dual coverage to every point. Such a system is tolerant of single station failures if the product coverage is sufficient, as discussed below.

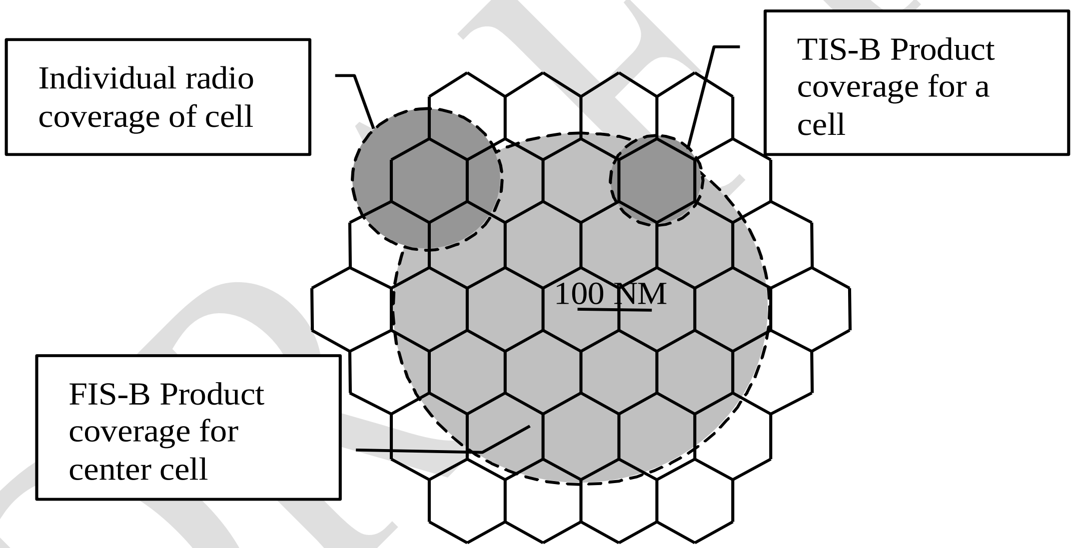

Figure D-1: Example Coverage Cell Layout

D.1.1.1.2 FIS-B Product Coverage

The FIS-B product coverage and update rate can be tailored to suit the characteristics of individual products. For example, products that are relatively small in terms of total data volume and that are updated infrequently such as Automated Terminal Information Service (ATIS) messages could have a relatively large product coverage (e.g., a circle of diameter 500 NM) and a relatively low update rate. A weather map product coverage should exceed the radio coverage by a significant amount. This type of information requires a context much larger than one radio coverage cell to be meaningful.

When an aircraft receives uplinks from multiple ground stations, it has the task of fusing these data. This task can be minimized by having the ground infrastructure assure that redundant information from different ground stations is identical. For example, adjacent uplink stations reporting precipitation strength for a given point or grid element should report exactly the same data. Then the application in the aircraft need only associate the reports and choose either for displaying or processing (rather than averaging, interpolating, or inferring data integrity). Note that with autonomous, isolated ground stations this is not an issue.

Looking back at Figure D-1, a sample product coverage is shown along with radio coverage for a single cell. For this coverage, there is ample overlap for at least dual coverage of any point and a seamless, consistent picture of the product as the aircraft flies through, even with failure of a single ground station.

D.1.1.1.3 TIS-B Product Coverage

A product such as traffic data (TIS-B) calls for a relatively high update rate and a smaller coverage area to keep data link bandwidth requirements at a reasonable level. TIS-B product coverage, in contrast to FIS-B data, should actually be smaller than the radio coverage, assuming that the radio coverage has significant overlap to assure no coverage gaps. TIS-B overlap between sites should be just enough to assure service continuity across the boundary. This approach keeps the link bandwidth as low as possible and minimizes the burden on the ADS-B Receiving Subsystems to eliminate redundant reports.

D.1.1.2 Data Source For Ground Broadcast

Contents of the ground broadcast messages can be put in the following categories:

1. Flight Information Services-Broadcast (FIS-B) – the broadcast distribution of weather and aeronautical information.

2. Traffic information from other surveillance sources (radar, multilateration) – this augments the ADS-B data received directly from the air-to-air link.

3. ADS-B data collected from non-UAT links.

4. Other.

In the UAT data link, FIS-B and “other” information is sent during the ground broadcast segment. Traffic uplink (TIS-B) data can be sent during the air-to-air segment of the UAT epoch in a form similar to the air-to-air format or during the ground segment in a special uplink format.

There are many possible configurations for the flow of information for the uplink stations. Not all stations need to be configured the same way. The one chosen will depend on the products being provided. In any case, the UAT equipment is a minor part of the ground system. The system will be primarily defined by the ground communication links (satellite, land line (phone, fiber) or microwave or other dedicated RF link), by the sources of the data for ground broadcast (radar, multilateration, weather observation and forecast), and by the applications that fuse this data and generate the ground broadcast reports.

D.1.2 Downlink: Surveillance

ADS-B data being transmitted by aircraft will be received (in general) at multiple ground receiving stations. This redundancy is readily fused since all stations are receiving the same message contents. Because of the required frame synchronization of all UAT transmitters and receivers, there is ample accuracy in the time-of-arrival stamp on each message to readily associate them and merge them. No averaging or weighting need be done on the contents as they are all the same.

A rough range from the receiving station can be determined from the Transmission Epoch (MSO number) inferred by the receiver or actually provided in some ADS-B Messages (see Appendix I). A very accurate time stamp on arrival and a more accurate receiver synchronization would allow multilateration on ADS-B reports received at multiple ground stations. Either method of independent position verification can be used in a health monitoring check on the reports (a check of the on-board GPS equipment in the aircraft).

D.1.3 Summary of Infrastructure and Implications

Figure D-2 shows a generalized diagram of the components and interconnnect of a ground infrastructure for the UAT data link. Many variations of this general structure are possible. Transmitters and receivers may or may not be co-located. Different sites may have different levels of service. This data link will have to support a transition period for a considerable time period before the fleet is fully equipped. The UAT data link has the necessary flexibility to handle these conditions.

Because of the generality of the data link, the system can be expanded as the ground infrastructure is developed and “filled in.” The UAT ground station is adapted to each specific deployment by the application driving it.

The characteristics of the UAT link required to support this general structure are in the areas of time stamps and predictable latency, one second frame synchronization, time division coordination of adjacent ground cells, and a waveform tolerant of self-interference.

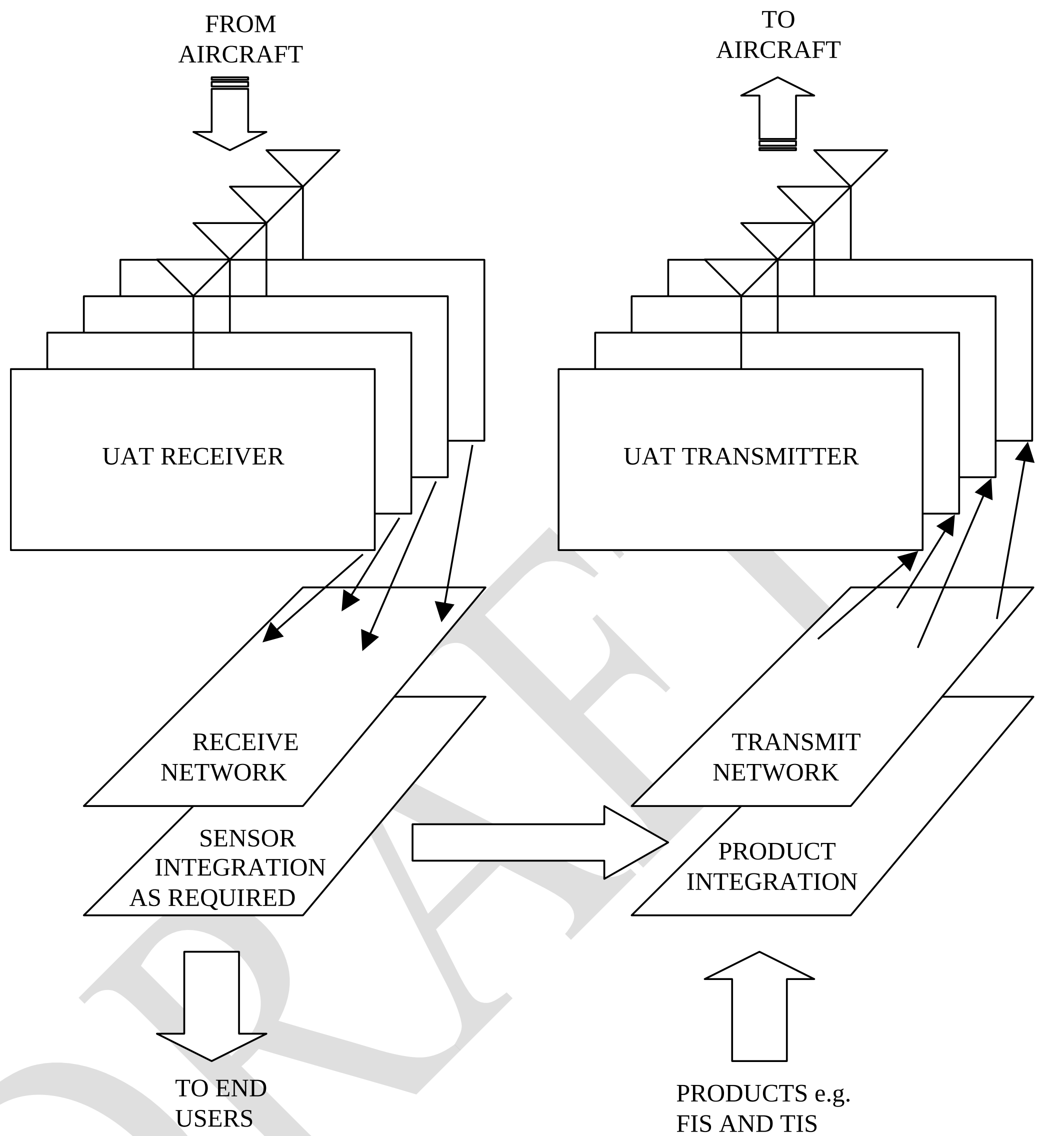

Figure D-2: General Form of Ground Infrastructure

D.2 Ground Station Deployment

D.2.1 Time Slots

The UAT data link has 32 uplink time slots available within the Ground Segment of the UAT frame. The separate slots represent the incremental resource that can be assigned to ground station transmitters so they can operate without mutual interference. A conservative approach to allocating the time slots is to give one slot to each ground station. In a hexagonal deployment, for example, the nearest station using the same slot as a given station will on average be about 6 cell spacings away. (A cell and 3 tiers around it totals 37 cells. This is roughly a circle with a diameter of 7 individual cell spacings.) Considering propagation loss and the horizon, there would be essentially no chance of significant interference.

It will be desirable to have higher reuse in practice. This will allow the uplink bandwidth necessary for each ground station to deliver its entire product. A re-use pattern of 7 will meet this objective by allowing cells to re-use a given time slot to be separated by about 2.5 cell diameters as shown in Figure D-3.

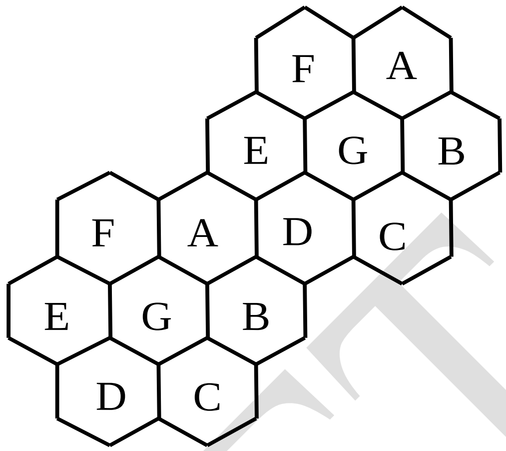

Figure D-3: 7-Cell Re-Use Pattern

D.2.2 Slot Rotation

In general, the UAT link design tolerates occasional missed messages due to random pulse interference. However, if a ground uplink transmission is repeatedly masked by another interferer that is synchronized to the UTC second (e.g., a JTIDS/Link 16 system participant), interference could persist for long periods of time. To minimize this possibility, it is expected that ground stations will continually shift the timing for their uplink transmissions. It is envisioned that this will be accomplished as follows:

- Time Slots 1-32 are at fixed time offsets. Ground Uplink messages will always occur within a Time Slot
- Channels 1-32 represent the incremental resource assignable to ground stations.
- Channels are shifted by one Time Slot each second. Channel # matches Time Slot # at midnight GPS time and every 32 seconds thereafter.
- The ground transmitter will always encode the proper (changing) time slot number in each ground uplink message

Note that this rotation scheme is part of the ground broadcast resource allocation and can be different from one non-contiguous region to another without affecting compatibility.

D.2.3 Antenna Considerations for Uplink

Considering the cell re-use described above, the possibility arises for self-interference with the UAT signal. The Ground Uplink message can readily be received in self-interference if the interference is sufficiently below the desired signal level. The required ratio depends on the target density and distribution. The two figures below show a self-interference analysis for a given set of ground station assumptions.

- 7 cell reuse pattern
- 90 NM intersite spacing of ground stations
- 10 dB desired/undesired signal ratio for successful operation.

Each figure shows two sets of seven cells in a repeating reuse pattern as in Figure D-3 above. Consider the two cells labeled “G” sharing time slot resources. The shaded area in each figure represents the area where *neither* ground station can be successfully received due to the fact that the signal strength ratio between the desired and undesired station falls below 10 dB. The curved arcs are the line-of-sight limits for a 40,000 foot target for each “G” station.

Figure D-4 is the interference analysis using low gain ground station antennas much like that on an aircraft. The shaded area confines itself to the area between and outside of the cells of interest. This is of no harmful consequence, as the other ground stations cover the area in between with non-interfering time slots.

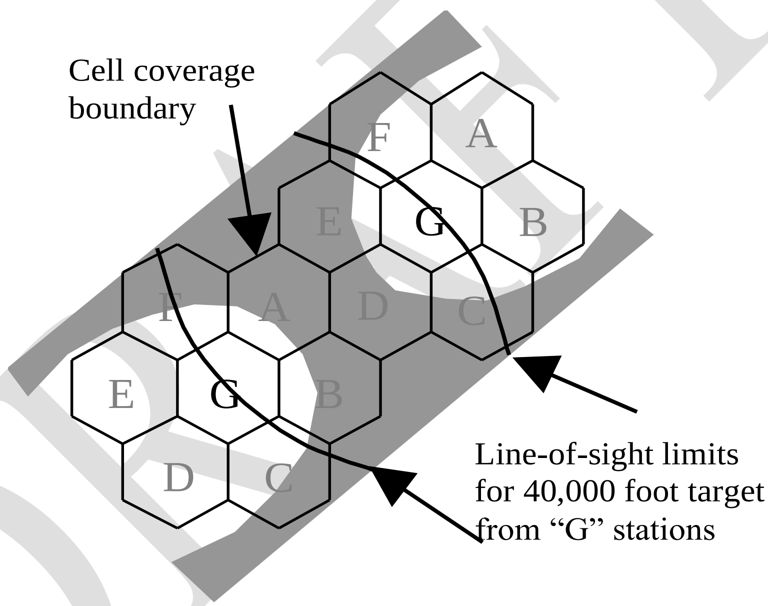

Figure D-4: Self-Interference with Low-Gain Antenna

Figure D-5 shows the results of the same analysis except that the transmit antenna is a Ground DME Antenna Type-10153 made by JTP Radiation Inc., which has a higher gain on the horizon but nulls at higher elevations. There is an additional shaded region within each “G” cell due to the stronger signal from the distant site and the null at the desired site. The use of the DME antenna for ground reception is beneficial to get gain on long-range targets, but for transmit the interference produced by the far sites is harmful.

This specific example shows that care must be taken in the selection of the transmit antenna with respect to the ground radio density to avoid substantive self-interference. An antenna with nulls that are less deep may be available. Another approach is to space the cells and allocate cell re-use such that the nearest interfering station is over the horizon for targets in the vertical coverage region.

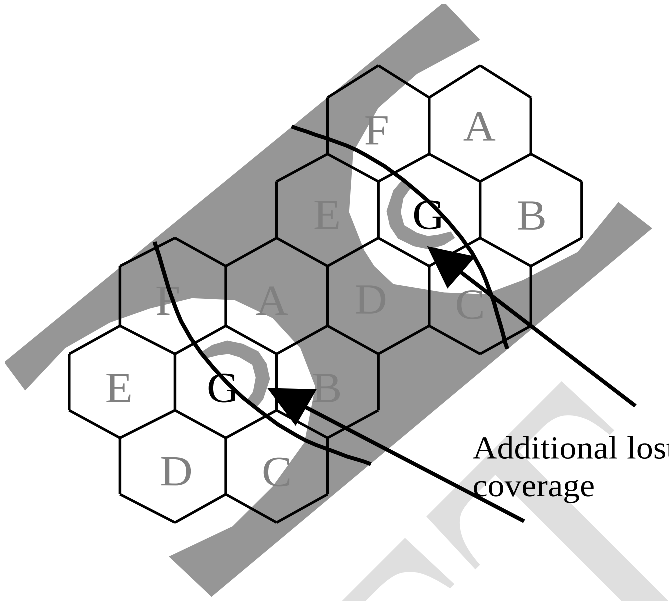

Figure D-5: **Self-Interference with DME-Type Antenna**

D.2.4 TIS-B Site ID

Each station is assigned a TIS-B Site ID number (§2.2.3.2.2.1.8). This number is not unique, having only a 4-bit value. The purpose of the ID is to give a brief (few bits) way of identifying the source of a TIS-B uplink message. This source identification is useful for confidence measures of time synchronization and to counteract spoofing. In low-density areas, only one station with a given ID will be within reception range. In more dense areas, more than one can be received (but not a large number) with the same ID and any range checking can be performed on all stations with that ID to get verification.

As an example, consider a 7-cell reuse pattern of Channels (see D.2.2, "Slot Rotation", for the definition of "Channel"). Figure D-6 shows an assignment of the 7 Channels (labeled A through G) and of the 16 TIS-B Site ID numbers (labeled 0 through 15). To see the repeat pattern in this example, look at a cell with slot label "G" as the center of a 7-cell cluster. A through F are clockwise around it. These clusters are then packed hexagonally. This is just an illustrative example to demonstrate the idea.

The approximate reception area of an aircraft is shaded in the Figure. The aircraft's trajectory is shown by the arrowed line and the swath of the reception area is shown by the dotted lines. During the Ground Uplink Segment, the aircraft is solidly receiving data in Channels A, B, D, and E (labeled A9, B14, D10, and E5). The aircraft can tell that these stations are within a normal reception range based on the location broadcast in the uplink.

Table D-1shows a list of these locations and TIS-B Site ID's as they can be kept in the aircraft's ADS-B application. The aircraft receives uplinks possibly from two different G Channels (G13 and G6). It may get either or neither in any one-second epoch and may get both over many seconds. In any event, it can place them into the table. The same can be said for two F Channels (F8 and F15). The aircraft may also receive occasional data from cell C4. Due to the trajectory of the aircraft, it has recently received information on one of the F Channels (F15) as well as other Channels (C11, E0, A4, and G8). These channels are still in the table as well. Entries can be dropped from the table when they are beyond range by some pre-determined amount. At the time shown, there are two entries with TIS-B Site ID 4 and two with TIS-B Site ID 8. Note that the Channel (A-G) in the table is for clarity of the example only. It is not important for the range validation process or for any ground station function once propagation time has been computed.

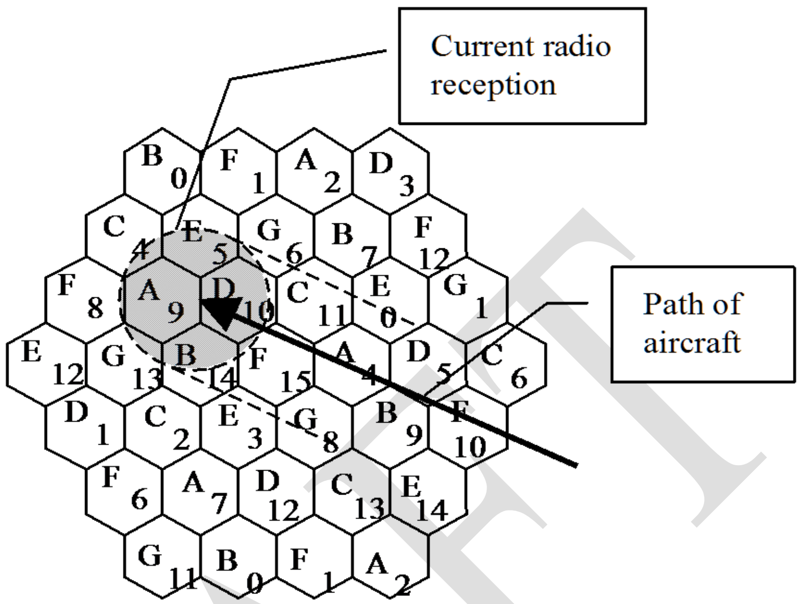

Figure D-6: **Example of TIS-B Site ID and Channel**

Table D-1: **Example of Site ID Table**

TIS-B Site ID	Location	Channel
9	lat long	A
14	lat long	B
4	lat long	C
10	lat long	D
5	lat long	E
13	lat long	G
6	lat long	G
8	lat long	F
15	lat long	F
11	lat long	C
0	lat long	E
4	lat long	A
8	lat long	G

Each of these ground stations transmits TIS-B messages in the ADS-B Segment of the UAT frame. Since these are in random MSO's, they can all be received with high probability. In addition, other more distant stations can transmit TIS-B messages and be received. When any TIS-B message arrives with its Site ID (0-15), its apparent distance from the aircraft (from the time-of-arrival) can be checked with *all* entries in the table having that Site ID. If it matches, that message is validated. If not, it can be rejected as unreliable.

It is possible that a legitimate TIS-B message can be rejected from a distant station based on this method, if the station is not on the list. This is not a problem because if the target is important to the aircraft it will be included in the TIS-B uplinks of a nearer station giving good range validation checks. This can be assured by the design of the product coverage for each cell.

D.2.5 Sectorized Cells and Co-Site Transmission Isolation

In some areas of dense air traffic, a ground station at maximum range can experience poor ADS-B target state update performance due to UAT self-interference. In this event, the area of coverage might be reduced, but it is undesirable to have multiple equipment sites to cover the range. An alternative solution to this problem is to co-locate several units with sectorized radio coverage.

In cases where UAT ground equipment is co-located with other transmitting equipment at a nearby frequency (e.g. a DME/TACAN installation in Europe at 979 MHz,) it is desirable to get as much rejection of that interfering signal as possible. In these cases, the same sectorized antenna mentioned above can also help. Section D.3.2 discusses the required signal rejection in cases of interference.

Figure D-7 shows a pattern for a 3-sector UAT ground station antenna. The solid curve is one sector and the dashed curves are the other two sectors. This pattern is representative of a DME-type column antenna with a reflector behind it to shape the pattern and block the backlobe. Figure D-8 shows two possible geometries that will produce isolation between co-sited DME equipment and UAT equipment. The required isolation will depend on the power of the DME equipment and the desired maximum signal level of the interference at the UAT equipment. Sections ~~K.3.3.2~~K.4.1 and ~~K.3.4~~K.4.2 in Appendix K discuss performance with various scenarios of DME/TACAN interference. For a low-density scenario and a DME at 979 MHz, the UAT equipment can tolerate a DME level of –30 dBm. In a future Core Europe scenario, the tolerable level is –50 dBm. ~~This is discussed further in Section D.3.1.2.~~

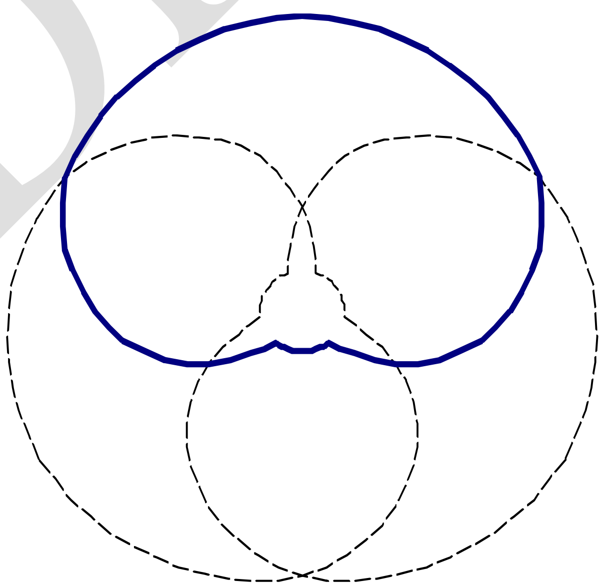

Figure D-7: Sectorized Antenna Pattern (3 sectors)

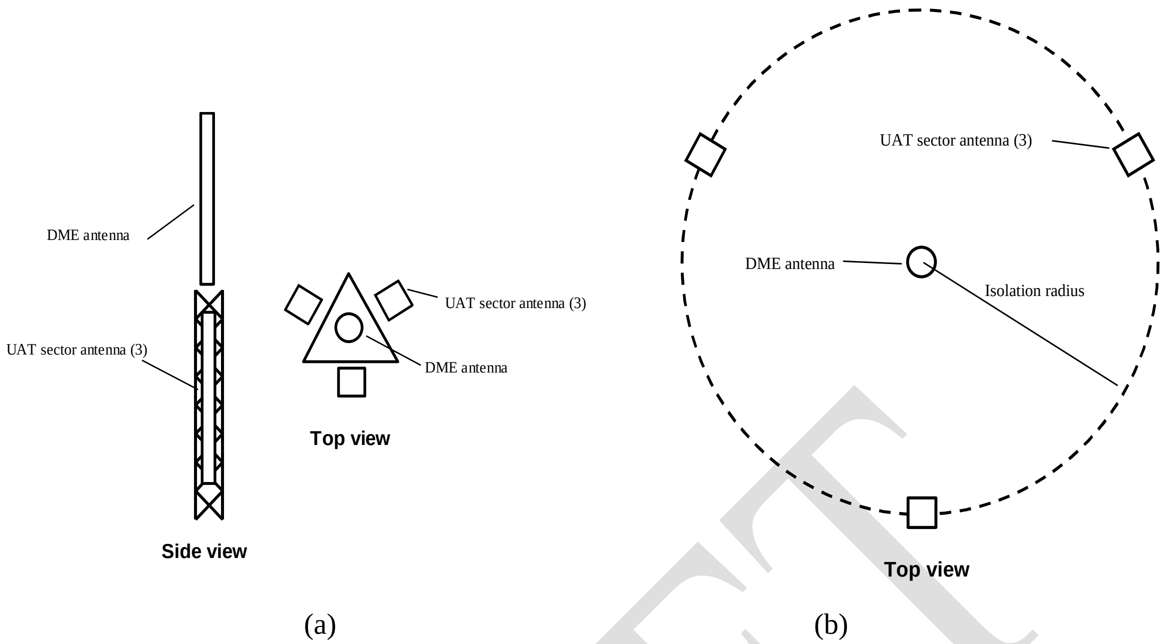

Figure D-8: Possible antenna locations

D.3 RF Interference

There are two primary sources of interference from other systems at the UAT operational frequency of 978 MHz: JTIDS (Link 16) and DME. There has been a considerable amount of analysis, simulation, and laboratory measurement to determine the working limitations of UAT with these other two systems. Most of the issues occur with DME equipment and are discussed below.

D.3.1 JTIDS Interference

The mutual effects of JTIDS and UAT are discussed in Appendix K. In short, between the spread spectrum nature of JTIDS and the interference rejection of the UAT modulation, the systems operate compatibly.

D.3.2 DME Interference

An important source of interference to the UAT link operating at 978 MHz is DME equipment operating near that frequency. For MASPS compliant operation of UAT, DME equipment at 978 cannot be co-located. In the US, there are no operational DME installations at 978 MHz. This frequency is allocated for DME ramp testers operating at a power level low enough to not interfere. In Europe, there are a small number of 978 MHz installations. The effect of this is that ground stations co-located with this DME equipment will experience degradation of the update rate on aircraft in a dense environment. This can be mitigated by separating the UAT and DME ground equipment and by reassigning the DME equipment to other frequencies as the UAT equipage grows to problem levels.

For a DME/TACAN at 979 MHz and operating at 10 kW ERP, and for siting to allow at least 1000 foot separation of the DME and UAT omni-directional antennas, there is a DME/TACAN signal level of approximately –10 dBm at the UAT ground station. Even with this separation (too large for many installations), results in Appendix K indicate that this power level gives enough interference to cause unacceptable update time for targets in a dense target scenario (Core Europe or LA 2020.) In these scenarios, the interfering power level must be reduced to a level between –30 dBm (for minimum performance) and –50 dBm (for good performance). If the site is using sectorized antennas (Section D.2.5) there may be, on the order of, a 25 dB attenuation by having the DME antenna in the UAT antenna backlobe. Vertical stacking of the antennas may yield even more isolation. The performance is ultimately a function of the interfering signal level.

Other possible techniques to achieve the necessary isolation are a very sharp (e.g. tuned cavity) filter, or adaptive cancellation. In the case of a filter, the approach would be to find a filter for the UAT receiver with acceptable in-band loss for the desired sensitivity to be achieved and then use the 979 MHz rejection of the filter to ease the burden on the antenna separation. A representative filter will give less than 5 dB of in-band (insertion) loss while rejecting the out-of-band (979 MHz) interference by 40 dB. This net benefit of 35 dB is available if the insertion loss can be tolerated by the receiver sensitivity and the intended range of the ground station.

In the case of adaptive cancellation, an auxiliary array can be positioned to sample the interferer signal or it can be delivered by a direct connection. The system can then adaptively subtract a replica of this sample from the received UAT signal to achieve the best signal-to-interference ratio. This approach requires considerable equipment expense, but may be economical in difficult siting situations if it avoids needing additional sites.

In environments where the nearest DME is at 980 MHz (or higher frequencies) instead of 979 MHz, the above isolation techniques may not be necessary.

D.4 Multiple ADS-B Links

It is likely that the ADS-B system in high-density airspaces will include multiple data links. The UAT data link is capable of supporting a multi-link deployment. Power levels and antenna locations are specified such that air-air as well as air-ground links are established over the coverage area. This allows the ground infrastructure to obtain the UAT ADS-B picture and to supply to the air traffic any non-UAT ADS-B traffic using the TIS-B capability.

Appendix E

Aircraft Antenna Characteristics

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E. Aircraft Antenna Characteristics

E.1 Antenna Characteristics

E.1.1 General Characteristics

The UAT System is expected to be able to utilize any standard transponder/DME antenna. Potential sharing of existing transponder antennas is discussed in Section E.3 below. The antenna must be suitable to receive and transmit vertically polarized signals at 978 MHz. The VSWR produced by the antenna into a manufacturer specified load must not exceed 1.7:1 at 978 MHz +/- 1 MHz.

E.1.2 Radiation Patterns

Performance of the UAT ADS-B System was estimated using a model of antenna gain that was developed for the FAA Safe Flight – 21 (SF-21) Technical Link Assessment Team (TLAT) Report. See Appendix K of this document. In practice, equipment designers assume 0.5 dB less average gain in the azimuth plane than that given in the TLAT Antenna Gain Model. However, in data links such as UAT, which are interference limited, this difference should not be expected to affect the performance presented in Appendix K of this document.

E.1.3 Directional Gain Radiation Patterns

For some applications (such as applications specific to Class A3 equipment), it may be suitable to use antennas with directional gain patterns to increase the range in the forward direction. Limitations on such directional gain antennas include not creating undesired nulls in the azimuth pattern, maintaining the minimum air-to-air range in the aft direction, and ensuring that any future requirements for minimum air-to-ground range are met. This subparagraph contains some examples of antennas that can achieve these goals.

The Figure E-1 shows the azimuth pattern of an antenna that has been evaluated through the development of RTCA DO-260A. This antenna achieves its gain through use of passive reflector elements. The antenna has a peak gain of 7.5 dBi, and a F/B ratio of 5 dB. This antenna could be easily scaled for 978 MHz, or undergo additional investigation to determine its characteristics as a combined antenna for both 978 and 1090 MHz.

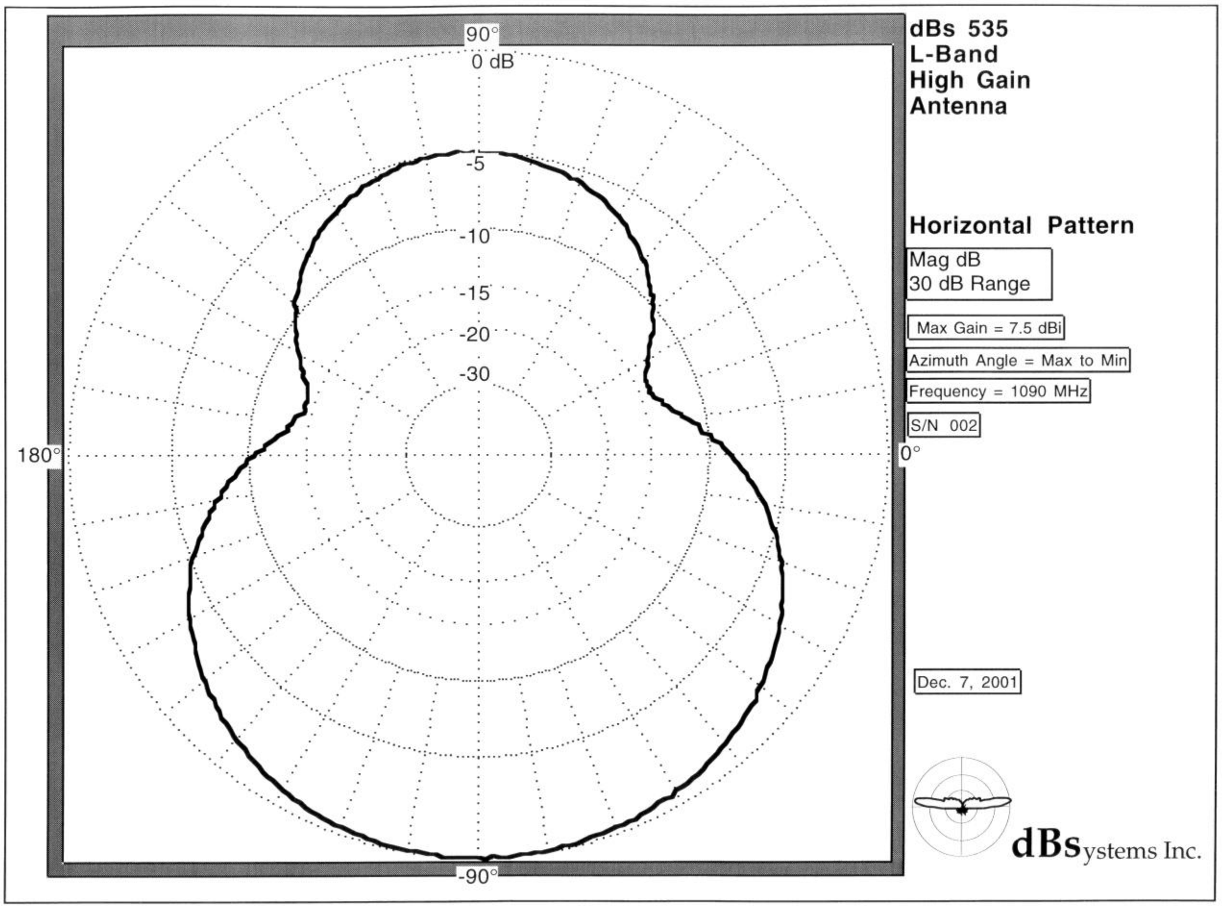


Figure E-1: L-Band Passive Gain Antenna

Figure E-2 shows a theoretical antenna that uses a pair of active driven elements to achieve directional gain while creating a uniform pattern. This antenna consists of a pair of quarter-wave resonant elements spaced at 1/8 wavelength, and driven 45 degrees out of phase.

This antenna design achieves 6.4 dBi of gain at an elevation angle of 13 degrees, with a F/B ratio of 4 dB.

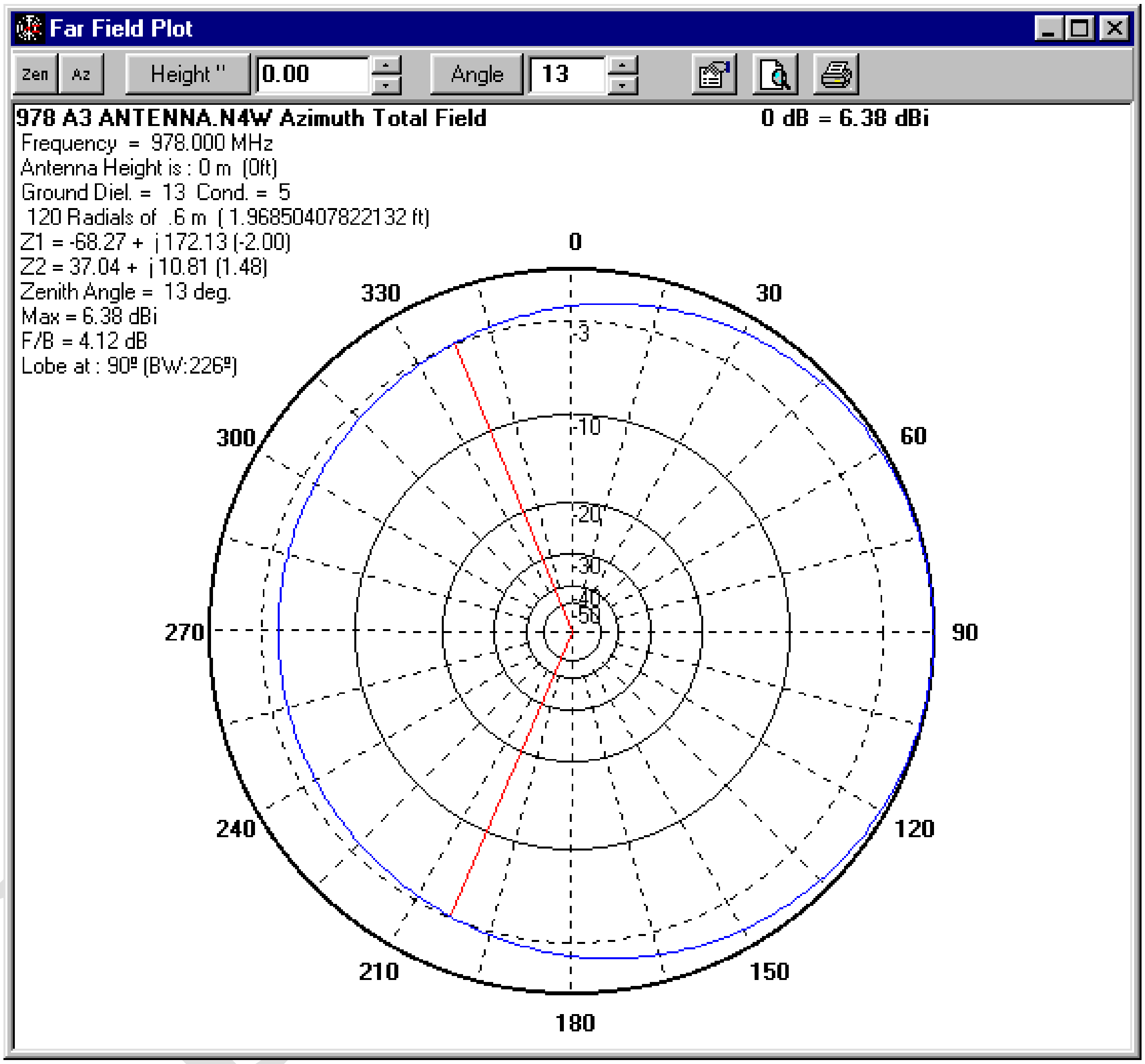


Figure E-2: Gain Array Antenna Azimuth Pattern

E.2 Typical VSWR Measurements of Existing Transponder / DME Antennas

There are several varieties of existing antennas that are suitable for use with the UAT datalink. These are summarized in Table E-1 below.

Table E-1: Typical Antennas

FAA TSO	RTCA	Equipment Type	VSWR & Frequency
TSO-C66c	DO-189C	DME	2:1 from 960-1215
TSO-C74c	DO-144	Transponder	1.5:1 on 1030, 1090
TSO-C112	DO-181C	ATCRBS Mode S	1.5:1 from 1030-1090

Typically, antennas that comply with TSO-C112 are specified with VSWR < 1.5:1 from 1030 to 1090 MHz, and VSWR < 1.7:1 over the remainder of the band from 978 to 1215 MHz. Certain types of transponder antennas that utilize very thin radiator elements are only intended for use at 1030 and 1090 MHz. These types of antennas should be evaluated on a model-by-model basis to determine their suitability as UAT datalink antennas.

Note that RF system performance is not strongly affected by VSWR values. A VSWR value as high as 2:1 does not increase the losses in the transmitted signal by more than 0.5 dB. This lack of sensitivity in system performance to VSWR values should be kept in mind when evaluating antennas for UAT applications.

The following subparagraphs illustrate these VSWR characteristics for specific antenna models. These measurements were performed with the antenna mounted in the center of a 4-foot diameter conductive ground plane.

E.2.1 Sensor Systems L Band Blade Antenna P/N S65-5366-7L

This antenna is typical of those found on jet transport aircraft, and is rated for TSO C66b, C74c, and C112. This antenna would be suitable as a UAT antenna.

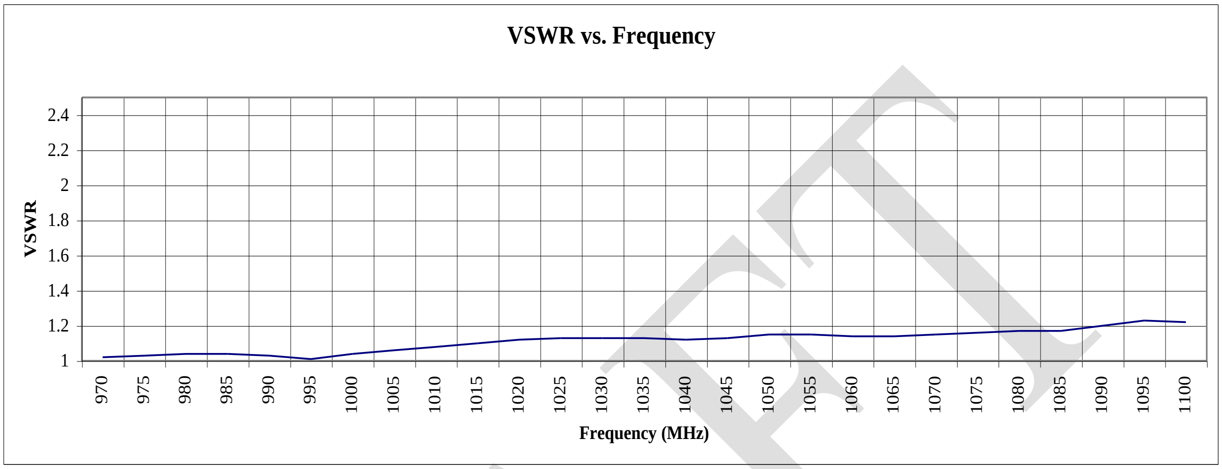


Figure E-3: Jet Transport Antenna

E.2.2 AeroAntenna P/N AT-130-1

This antenna was designed for the FAA Capstone program as a dedicated UAT antenna.

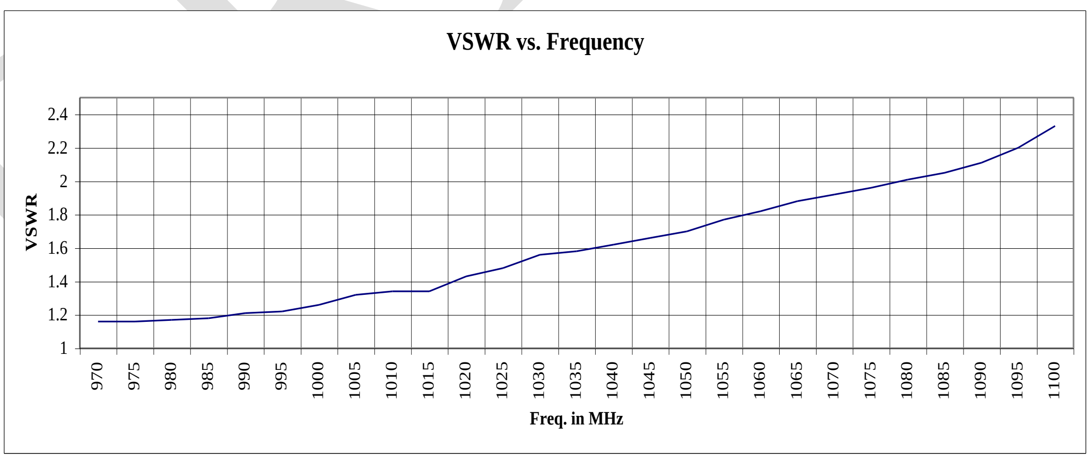


Figure E-4: Capstone Antenna

E.2.3 ¼ Wave Whip Antenna

This data represents a typical GA-application thin whip antenna, such as a RAMI Model AV-22 (TSO C-74c). Note that although not specified for performance outside of the 1030 to 1090 MHz range, it actually performs best at frequencies lower than 1030 MHz.

This antenna would be a suitable UAT datalink antenna, and illustrates the need to look at the characteristics of each candidate antenna closely.

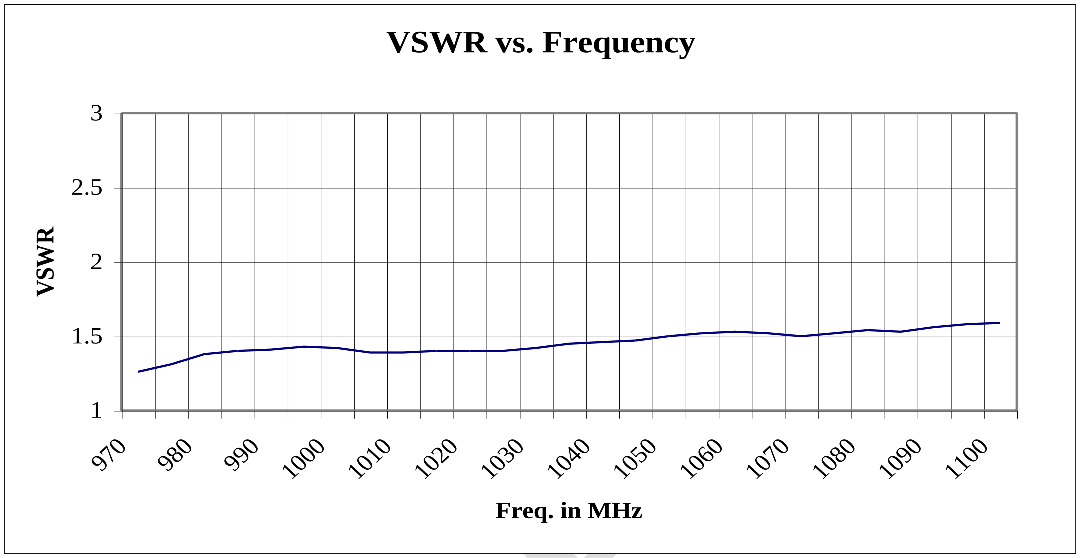


Figure E-5: ¼ Wave Whip Antenna

E.3 Passive Antenna Diplexer Characteristics

A potential method of providing an antenna for the UAT is to use a passive frequency Diplexer that is installed between an existing transponder and its antenna. Allowing the use of a Diplexer to operate UAT equipment and the on-board SSR transponder required extensive validation to verify that the use of a Diplexer would not degrade the operation of either system. A test effort utilizing a prototype Diplexer conforming to the requirements of §2.2.14.3 was utilized to conduct the necessary testing.

Upon initial investigation into the concept of antenna sharing by use of a Diplexer, certain characteristics were critical to enable use of a Diplexer. The power loss across the Diplexer was an important consideration. The typical loss that installations allow between the transponder and antenna is 3 dB. The Diplexer cannot use up a significant portion of this allocation without eliminating most existing transponder installations as candidates for UAT antenna sharing. The requirement that the Diplexer loss cannot exceed .5 dB is expected to enable most existing installations to use a Diplexer and share the transponder antenna. The goals of the Diplexer design were to support a transponder port that would minimize the insertion loss in the 1030/1090 MHz band and possessing adequate passband so that 1030 MHz interrogation signals and 1090 MHz reply signals were unaffected by the Diplexer. An optional DC path in the Diplexer's transponder channel is allowed so that installations that require antenna sensing can maintain the capability to sense the presence of an antenna. The Diplexer's transponder channel will attenuate signals at 978 MHz, providing isolation from the UAT. In some cases, Diplexer isolation actually exceeds the level of isolation obtained by using separate transponder and UAT antennas. The latter is a function of distance between antennas. The UAT's Diplexer port can provide minimal insertion loss to the antenna at 978 MHz, while manifesting a high impedance at the 1030/1090 MHz band.

E.3.1 Antenna Diplexer Testing

Tests were conducted to validate the performance of ATC transponders sharing an aircraft antenna with a UAT by incorporating a Diplexer into the installation. The purpose of the tests was to insure that both the UAT equipment and transponders perform according to the applicable standards and that the Diplexer does not introduce any signal distortions on the 978 MHz frequency of UAT and the 1030/1090 MHz frequencies of ATC transponders. A selected set of tests was performed to measure any potential degradation of equipment performance due to the Diplexer installation. The tests measured the effect of both the UAT/Diplexer on the performance of the transponder and the effect of the transponder/Diplexer on the performance of the UAT system.

E.3.1.1 SSR Transponder Testing

Tests were conducted to measure the effect of the Diplexer installation on the performance of ATC transponders. Two prototype Diplexers built by two different manufacturers were tested. Each Diplexer was tested with seven different transponders including 3 Mode S, and 4 ATCRBS only transponders.

A comprehensive set of tests were run on each transponder to measure transmitter and receiver characteristics, reply pulse characteristics, side lobe suppression, undesired replies, and pulse decoder characteristics. Each test was performed both with and without the Diplexer installed to measure the relative effects of the Diplexer. Where appropriate, with the Diplexer installation, the UAT system was connected and transmitting.

Table E-2 shows a summary of the test results. Parameters labeled “none” under measured effects showed no measurable effect within the accuracy of the test system. The test system measurement accuracy either met or exceeded the specified test conditions in the appropriate MOPS.

Table E-2: Diplexer Testing with ATC Transponders

TEST PARAMETER	MEASURED EFFECT
Reply Power	0.2 to 0.4 dB loss
Reply Frequency	None
Reply Delay (ATCRBS & Mode S)	Increased 0.01 to 0.018 microseconds
Reply Delay Jitter (ATCRBS & Mode S)	None
Reply Pulse Spacing (ATCRBS & Mode S)	None
Reply Pulse Shape (ATCRBS & Mode S)	None
Undesired Replies	UAT transmission triggered ATCRBS replies with some units
Sensitivity (ATCRBS & Mode S)	0.25 to 0.35 dB loss
Dynamic Range	None
Sensitivity Variation with Frequency	None
Bandwidth	None
Pulse Position Tolerance (ATCRBS & ATCRBS/Mode S)	None
Pulse Duration Tolerance (ATCRBS & ATCRBS/Mode S)	None
Pulse Level Tolerance P4 (ATCRBS/Mode S)	None
Sync Phase Reversal Position Tolerance (Mode S)	None
SLS Decoding (ATCRBS & ATCRBS Mode S)	None
SLS Pulse Ratio (ATCRBS & ATCRBS/Mode S)	None
Suppression Duration	None
Suppression Reinitiation	None
Recovery From Suppression	None
Mode S SLS	None
ATCRBS Desensitization Pulse and Recovery	None

The Reply Power and Receiver Sensitivity of the transponders were reduced a fraction of a dB through the Diplexer. This is expected due to the insertion loss of the transponder channel of the Diplexer that is specified to be 0.5 dB maximum. This should not be a detriment to proper operation as long as the installation accounts for the additional loss.

The reply delay showed an increase of about 10 to almost 20 nanoseconds average for all Diplexer and transponder combinations. This is an effect of the sum of the 1030 MHz interrogation and the subsequent 1090 MHz reply each being delayed through the Diplexer about 5 to 10 nanoseconds.

The Undesired reply rate was measured by monitoring ATCRBS and Mode S reply transmissions without interrogating the transponder. With the Diplexer and UAT installed and operating with the transponder, some of the transponder/Diplexer combinations resulted in unsolicited ATCRBS replies. This was caused by the low-level UAT signal leakage into the transponder channel of the Diplexer. This occurred significantly more with one of the Diplexers than with the other and it varied with the transponder type. The worst case measured was at an average rate of about 0.75 ATCRBS per UAT transmission. There were no unsolicited Mode S replies with any of the test configurations. The undesired reply rate for ATCRBS modes is required to be 5 replies per second or less averaged over a 30 second interval. (This is the requirement for Mode S transponders – RTCA DO-181B) The MOPS for Airborne ATC Transponder Systems (RTCA DO-144) requires that the random triggering rate not exceed 30 replies per second. This latter requirement is after installation with all possible interfering equipment operating. Although the undesired reply rate caused by the UAT transmissions were within the requirements, it was not desirable to trigger transponder emissions by the UAT signal. This issue was not solely a Diplexer issue, since depending upon UAT antenna and transponder antenna proximity in an installation, UAT transmissions could cause transponder responses during UAT transmissions without a Diplexer. For this reason, UAT equipment is required to output a suppression pulse to the transponder to inhibit the transponder receiver during UAT transmissions.

Measurements also indicated that the Diplexer installation does affect VSWR. With ATCRBS transponders, the change in VSWR altered the transponder reply frequency. Mode S transponders were more immune to VSWR variations. Proper tuning of the installed cabling and adjusting for VSWR as specified in section 3.2.1.2 of this document for UAT installation, and for the transponder, as required by the applicable standard, is required.

Since the passive Diplexer integrates UAT equipment with the SSR transponder on the aircraft, it was necessary to coordinate the use of a Diplexer with the Surveillance and Collision Resolution Systems Panel (SCRSP) of the International Civil Aviation Organization (ICAO). SCRSP produces and maintains international standards for the Mode S and SSR systems. The results of the extensive tests that were conducted to verify proper operation of the SSR transponder with a passive Diplexer were made available to SCRSP to evaluate the performance of the SSR transponder through the Diplexer.

An additional set of tests were recommended by SCRSP to investigate the performance of a Mode S transponder with the use of a Diplexer and its ability to properly decode Mode S interrogations with numerous Differential Phase Shift Keying (DPSK) phase shifts. These tests would verify that the bandwidth of the Diplexer does not cause distortion of the interrogation signal that would degrade the ability of the Mode S transponder receiver to properly decode these interrogations. In order to evaluate the Diplexer impact on DPSK, the transponder receiver sensitivity was tested as interrogation frequency was varied. Three Mode S type transponders were tested both with and without the Diplexer installed in order to make a direct comparison of the Diplexers effect. The transponders tested were from three different manufacturers. The installation of the Diplexer affects the Voltage Standing Wave Ratio (VSWR) of the antenna ports, so a slotted line and stub tuner were used to monitor and control VSWR. The stub tuner was used to set the VSWR to the same minimum value obtainable with and without the Diplexer. This was done to minimize the VSWR influence on the sensitivity measurements.

Figure E-6 shows a plot of the Sensitivity Variation with Frequency measurements for one of the transponders tested. The interrogation consisted of a legal uplink format defined by the first five bits of the interrogation. All other data bits equal to binary '1' except the Address Parity (AP) field, which was properly coded to elicit a response from the transponder. The all binary 1's format was used to maximize the number of phase shifts in the uplink interrogation. This was the primary interrogation format used to test all three transponders.

The data shows a consistent average reduction in sensitivity of about 0.2 dBm, the loss through the Diplexer, which does not vary significantly with frequency. Additional tests were conducted with all variable data bits equal to binary '0' to minimize the number of phase shifts with nearly identical results.

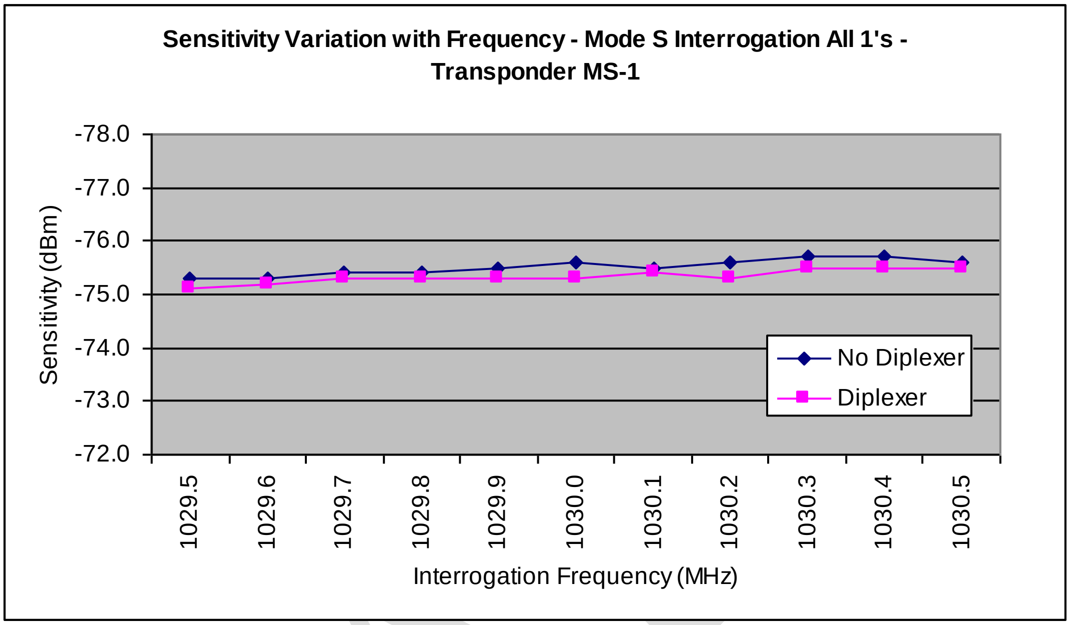


Figure E-6: Sensitivity Variation with Frequency, All 1's Interrogation, Transponder MS-1

All three tested Mode S transponders yielded similar results. The conclusion from running these tests is that other than the expected reduction in the transponder receiver sensitivity from the loss across the Diplexer, the Mode S sensitivity is not affected as a function of frequency within the operating bandwidth of the transponders. The Diplexer bandwidth characteristics for the SSR transponder channel adequately handles 1030 MHz Mode S interrogation signals with excessive DPSK phase variations.

E.3.1.2 UAT Diplexer Testing

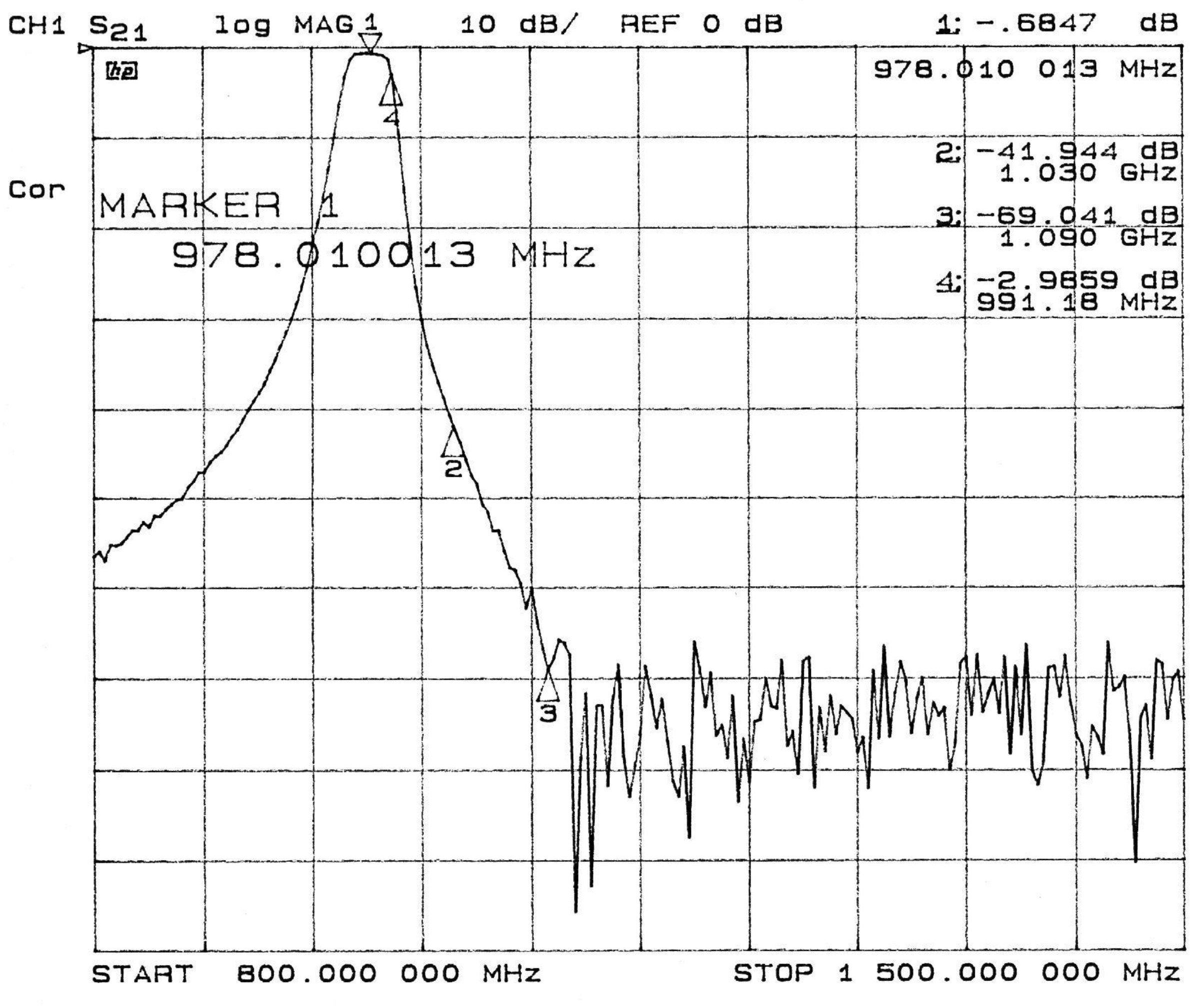
A variety of tests were conducted to determine the effects of UAT signals through a Diplexer. Testing was facilitated using nine different configurations to test various combinations of remote or onboard UAT receivers, remote Ground Uplink transmissions, interference to UAT from remote or onboard Mode S or ATCRBS transponders, as well as onboard transponder leakage, in circuit with an implemented antenna Diplexer.

Since no performance difference was measured looking at UAT reception at the on-board UAT receiver nor remotely when looking at UAT signals from the on-board transmitter through the Diplexer, the severe case of onboard interference from Mode S or ATCRBS transmissions through the transponder port of a Diplexer to a UAT receiver, was investigated. Even though the assumptions for the UAT performance model assume no UAT receptions when UAT signals are overlapped by on-board SSR transmissions, the test results show that the Diplexer provides sufficient isolation from the on-board 1030 MHz and 1090 MHz transmissions to enable a high probability of successful reception of low-level UAT messages. In all of the test cases where Mode S or ATCRBS transmissions interfered with UAT message receptions, the test was particularly severe. The transponder transmissions were overlaid in time with the UAT messages 100 % of the time, yet the UAT receiver, isolated by the antenna Diplexer, performed with no significant degradation

E.3.1.3 Prototype Diplexer Performance

The following figures show measured data obtained from a prototype L-band Diplexer.

Figure E-7 shows the performance between the Antenna and UAT ports.



<u>Figure E-7:</u> Diplexer UAT Port

Figure E-8 shows the performance between the Antenna and Transponder ports.

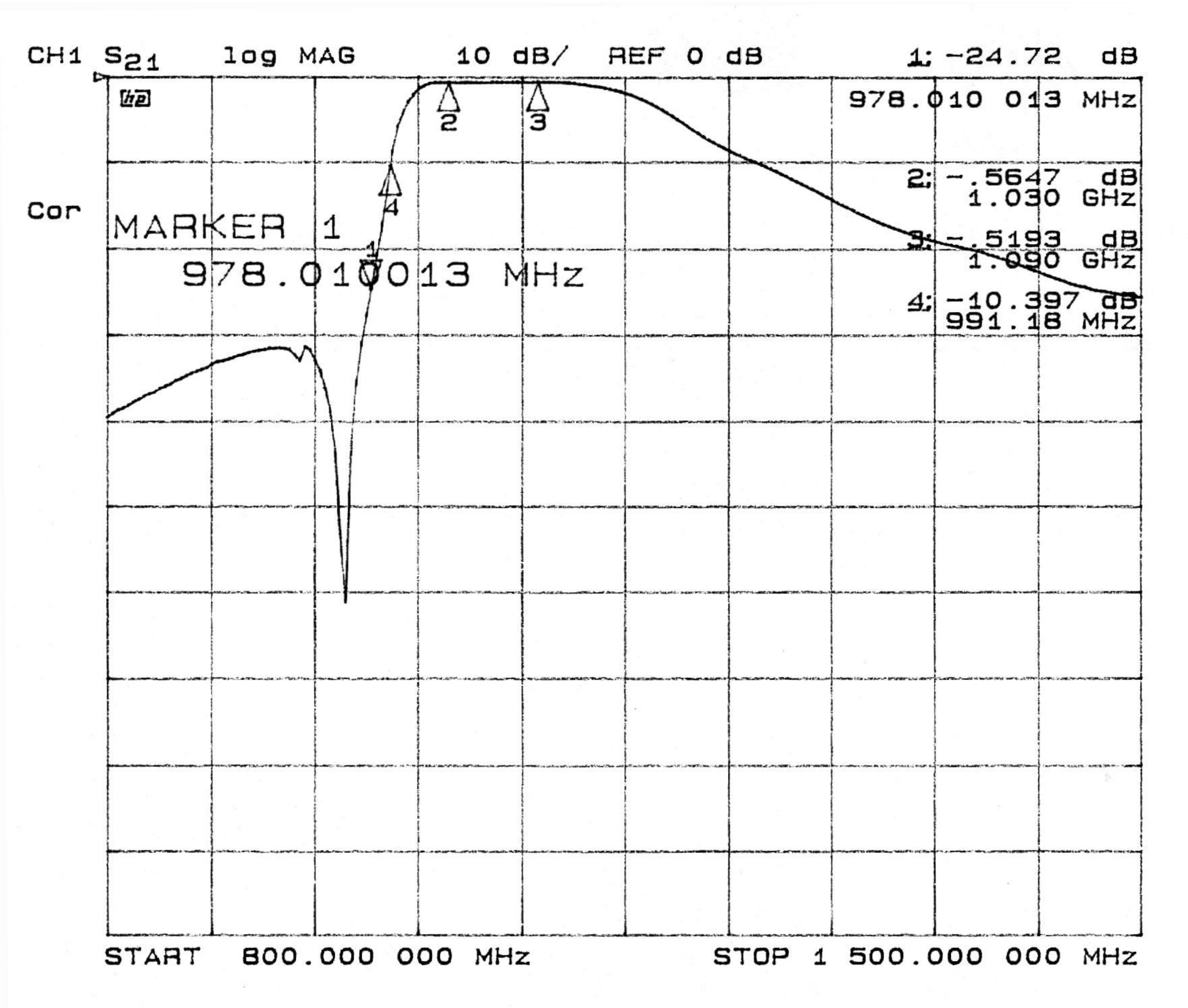


Figure E-8: Diplexer Transponder Port

Figure E-9 shows the isolation between the UAT and Transponder ports. Note that the isolation between the ports at the UAT frequency is 25 dB, and the isolation at the Transponder frequencies are 42 dB at 1030 MHz, and 64 dB at 1090 MHz.

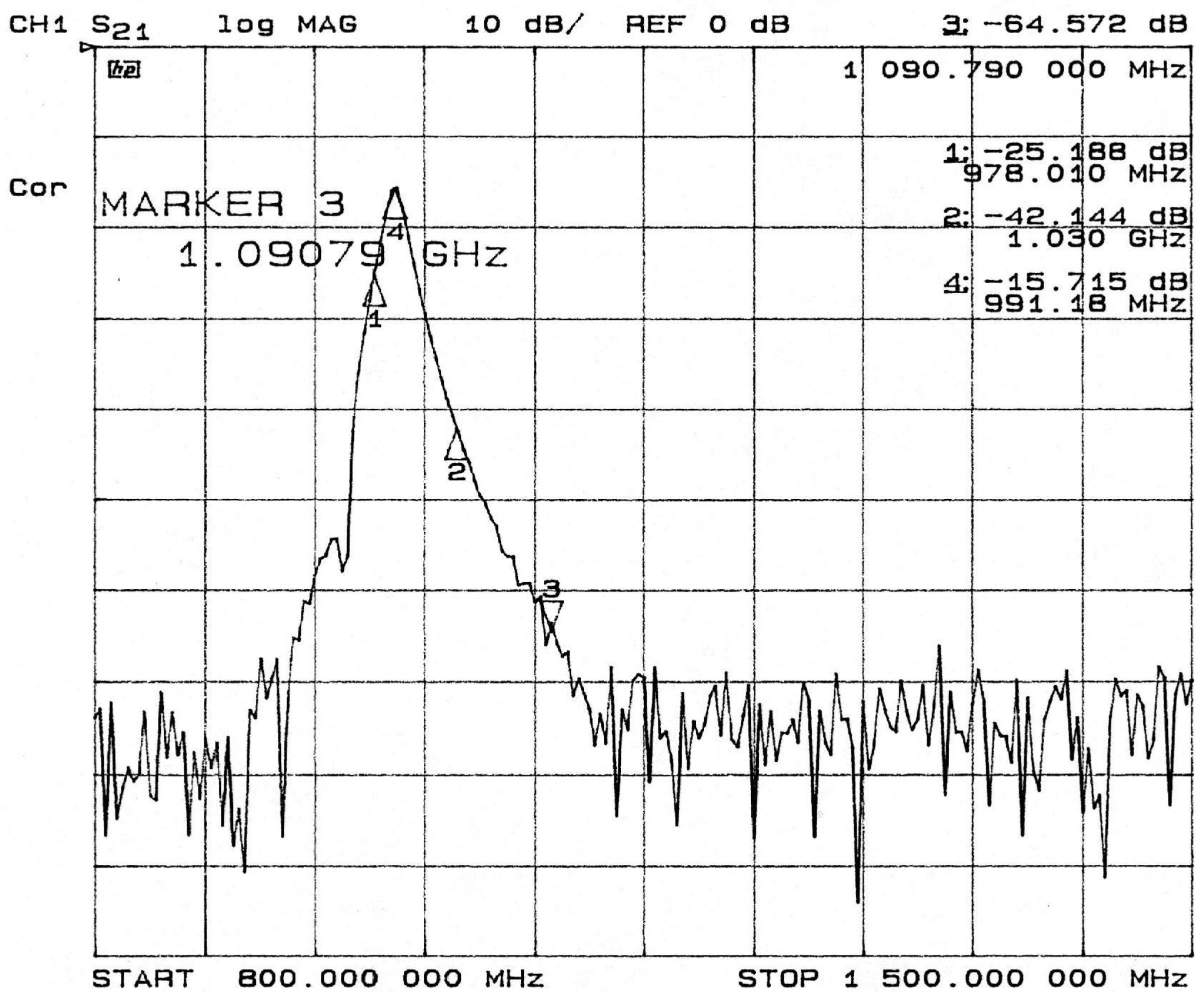


Figure E-9: Diplexer UAT-to-Transponder Port Isolation

E.3.2 Typical Installation Diagram

Figure E-10 illustrates how a UAT might be added to a typical existing transponder installation by using frequency Diplexer/combiner. Shaded boxes indicate the new components added to the existing installation. The Diplexer can be added anywhere in the antenna's feedline. The most logical place for this addition would be in the aircraft's equipment bay in close proximity to both the UAT and transponder units. This way, existing feedlines would not have to be re-routed or altered.

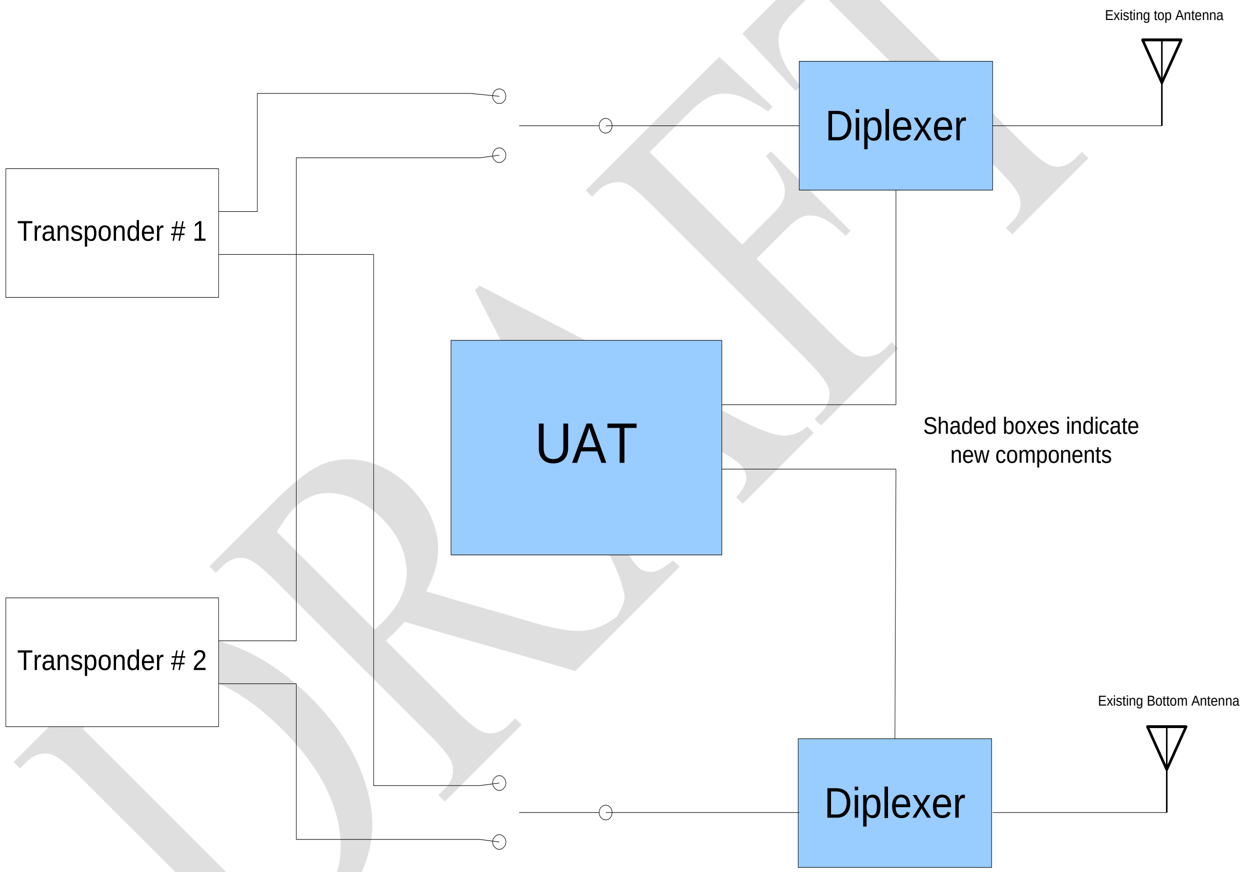


Figure E-10: Diplexer Installation

Appendix F
Link Budgets and Scenario Dependent Ranges

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F. Transmitter and Receiver Power Requirements

The requirements given in Section 2.2 for transmitter power and receiver sensitivity (signal level which provides 90% probability of decode in the absence of interference) were selected based upon consideration of the air-to-air ranges at which ADS-B report update requirements were levied in the ADS-B MASPS (RTCA DO-242A): 10 NM for Class A0, 20 NM for Class A1, 40 NM for Class A2, and 90 NM for Class A3. The following air-to-air link budgets summarize the relationships, for each class of ADS-B equipment, between transmitter power, receiver sensitivity, and range (for a 90 percent reception probability, in an interference-free environment, of each ADS-B Message) under worst-case conditions for transmitter power and receiver sensitivity. Performance in likely practical implementations, translated into the context of the MASPS received report update requirements, is summarized in the note that follows.

Table F-1: Air-To-Air Link Budgets

Equipment Class		**A0/A1L**	**A1H/A2**	**A3**
Basic Requirements	Transmitter power (dBm at antenna)	38.5 to 42.5	42 to 46	50 to 54
	Receiver Sensitivity (dBm at antenna)	< = -93	< = -93	< = -93
Transmitter power	dBm at Antenna, worst case (minimum power)	38.5	42	50
Antenna gain, Transmitter	dBi	0	0	0
Antenna gain, Receiver	dBi	0	0	0
Received power	dBm at Antenna	-93	-93	-93
Sensitivity	dBm at Antenna, worst case (minimum Sensitivity)	-93	-93	-93
Available Path Loss	dB	131.5	135	143
Link Budget Ranges	NM	50	74	186

Note: *Other factors that will be present in practical installations were not considered. These other factors include better-than-worst-case transmitter power and receiver sensitivity, antenna gain variations, and receptions below sensitivity. These factors may be expected to support operation in an interference free environment at longer ranges than those depicted in the table.*

In a high interference environment, corresponding to that expected in Los Angeles in 2020, the air-to-air Link Budget described above supports MASPS (RTCA DO-242A) compliant performance at the following ranges:

R = 25 – 40 NM for Class A0/A1L,

R = 40 – 50 NM for Class A1H/A2, and

R = 130 – 150 NM for Class A3.

These estimates include interference associated with both surface and air traffic distributions, co-site interference, and the agreed JTIDS scenario. Further details may be found in Appendix K.

Appendix G

Standard Interference Environment

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G. Standard Interference Environment

G.1 Background

The Universal Access Transceiver (UAT) is designed to operate in the lower portion of the 960-1215 MHz aeronautical radionavigation service (ARNS) band. This portion of the band is heavily utilized throughout the world for International Civil Aviation Organization (ICAO) standard systems such as Distance Measuring Equipment (DME), and military systems such as Tactical Air Navigation (TACAN), and in some countries the Joint Tactical Information Distribution System/Multifunctional Information Distribution Systems (JTIDS/MIDS). Each of these systems share a common characteristic in that they utilize pulses that are short in relation to UAT pulses. As a result, the UAT waveform and receiver front-end has been specifically tailored to tolerate a high-density pulsed environment. In addition, the random-start nature of the UAT ADS-B access protocol results in self-interference. The extent of this interference is dependent on the number of aircraft visible to the "victim" UAT.

Because of the complexity of the potential interference environment, UAT performance in an operational environment was determined through the use of high-fidelity computer simulations. Those simulations were based on two specific inputs:

1. The performance of the UAT receiver in the presence of interference[1] as a function of signal-to-interference and desired-to-undesired signal overlap; and

2. The time/amplitude distribution of interfering signals. This Appendix will address the assumptions driving the latter input, while the UAT test specifications (Section 2.4) will ensure that UAT equipment meeting this MOPS can match the assumed UAT performance.

G.2 Operational Environments

The operating frequency of UAT at 978 MHz was selected to minimize the impact to existing DME/TACAN use. That DME/TACAN channel (17X) is reserved worldwide for "emergency use," and as a result there exist very few operational 978 MHz DME/TACAN systems. In the United States for example, both 978 MHz and 979 MHz are reserved for DME "ramp tester" equipment. Such an application is very low power, offering no interference to UAT usage[2]. Europe however does use both 978 MHz and 979 MHz for operational DME/TACAN, so European scenarios considered DME/TACAN as an interference source. It should be noted that early test and analysis results indicated that, for off-board DME/TACAN, only those that were co-frequency and/or first adjacent-frequency to the UAT (i.e., on 978 or 979 MHz) need be considered. This accrued as a result of the narrow spectral content of the DME/TACAN signals, in concert with the good frequency rejection properties of the UAT receiver.

Driven by the diverse environments in which UAT would operate, a number of different interference scenarios were postulated and simulated. The goal was to ensure that the

[1] This performance was quantified through high-fidelity bench test measurements.
[2] Testing and analysis has also shown that co-frequency UAT usage will not interfere with ramp tester implementation.

UAT design would provide the necessary performance as UAT traffic increases in the future and to ensure that UAT receivers are measured against the most challenging interference environment from JTIDS/MIDS[3] and DME sources. Within a given scenario, UAT receiver locations were chosen to represent the most challenging geographic areas.

Aircraft distributions were based on scenarios developed by the joint Federal Aviation Administration (FAA)/Eurocontrol Technical Link Assessment Team (TLAT) to assess candidate ADS-B links. One scenario was intended to represent a low-density air traffic environment, while another mimicked introducing UAT into today's Core Europe setting. The final two "future" scenarios predicted Los Angeles Basin 2020 and Core Europe 2015 environments respectively. Together these scenarios provided diverse assessments of UAT performance, and their characteristics are catalogued in Table G-2. Note that to fully assess the resulting performance of a victim UAT receiver, practical UAT receiver implementation limitations that impact receiver availability are also included.

To analyze DME interference in core Europe, the International Civil Aviation Organization (ICAO) database[4] of existing and planned DME/TACAN assignments was examined. While the underlying assumption for DME/TACAN is that co-channel assignments will eventually need to be moved in order to achieve full operational UAT performance, it is also recognized that in the near-term low-density UAT self-interference environments offer performance margin that could be used to accommodate co-channel DME/TACAN interference. Geographic analysis of existing DME/TACAN assignments – i.e., quantifying the number and power of received DME/TACAN signals at geographic points in space – resulted in development of the environments shown in Table G-3 to capture current worst-case DME/TACAN conditions. In recognition of future environments, the UAT design was tailored to ensure that UAT could provide an adequate level of performance as 978 MHz DME/TACANs are reassigned over time. As part of this, noting that current "planned" assignments allow latitude for regulators to expand usage of 979 MHz, assumptions were made to predict future DME/TACAN interference. In particular, for the Core Europe 2015 scenario, it was assumed that while all 978 MHz DME/TACANs were reassigned, all planned 979 MHz assignments in ICAO database had become operational. Details of the resultant environments are captured in Table G-4. In total, the goal of each of the test scenarios was to reasonably over-bound any operational environment the UAT could be expected to experience.

Sample Derivation:

Figure G-1 illustrates a scenario in today's environment focusing on an aircraft at 40,000 feet flying over Germany. Using the DME/TACAN emitter location and power information from the ICAO database, the DME and TACAN normalized ground station antenna patterns shown in Figures G-2 and G-3, relative emitter-aircraft geometry, and propagation loss equations, the values in Table G-1[5] can be derived. Repeating for

[3] JTIDS/MIDS scenarios are defined in terms of source time slot duty factor (a measure of number of pulses per second), and source received power level. For the MOPS effort a number of operational JTIDS/MIDS scenarios were provided by the US Department of Defense as representing postulated training needs. These were included as part of the standard interference environment as shown in Table G-2.
[4] Listings were reviewed/verified by Eurocontrol.
[5] Note these levels are also reflected in row 4 of Table G-3. The "All Germany" emitter reflects a mobile TACAN. For the purpose of this assessment it was placed in the worst-case location allowed by channel assignment rules.

various locations/geometries allowed the worst-case positions to be determined and utilized for compatibility analyses.

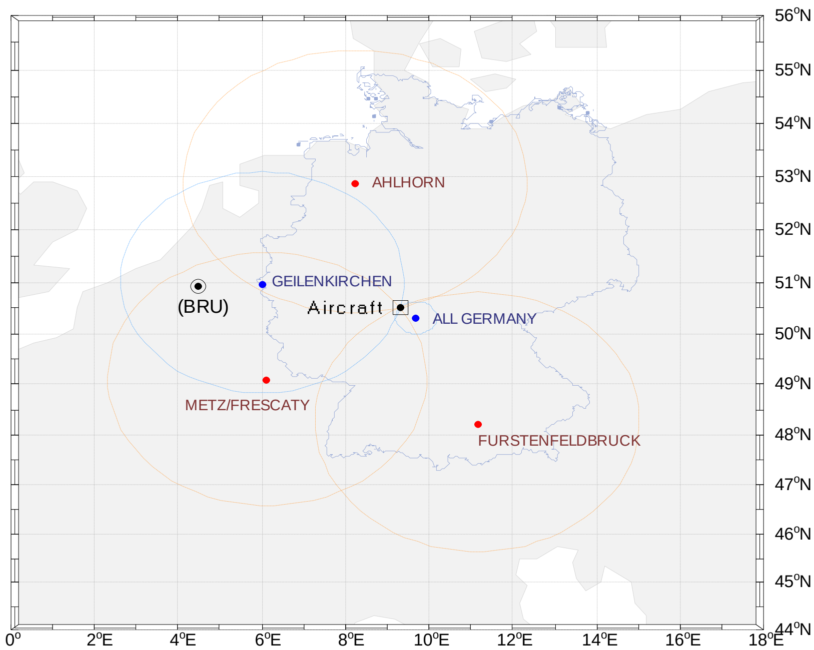

Figure G-1: Sample Scenario

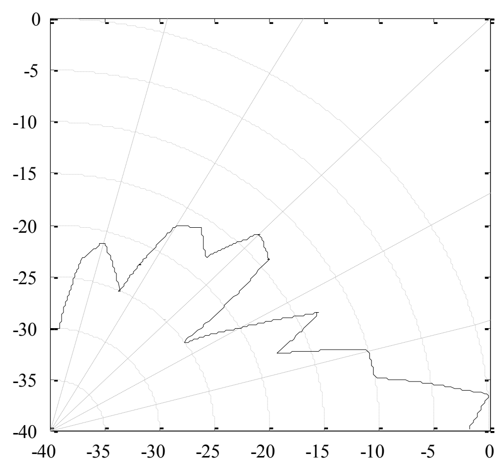

Figure G-2: Normalized DME Pattern

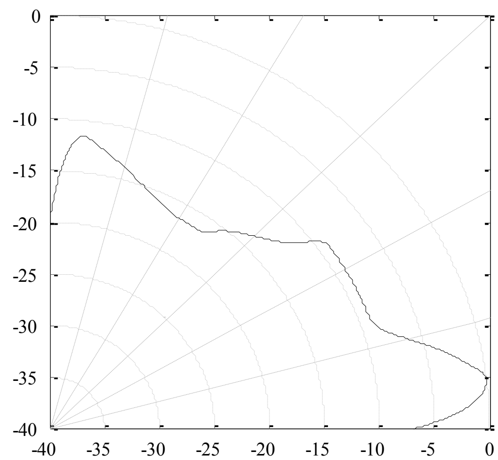

Figure G-3: **Normalized TACAN Pattern**

Table G-1: **Signal Level Analysis of the Sample Scenario**

	AHLHORN	**FURSTENF…**	**METZ/FRE…**	**GEILENKI…**	**ALL_GERM…**
Type	TAC	TAC	TAC	TAC	Mobile TAC
Longitude (deg)	8.233	11.150	6.133	6.017	9.298
Latitude (deg)	52.883	48.217	49.067	50.967	50.525
Frequency (MHz)	978	978	978	979	979
Ground Distance (nmi)	148.7	155.2	150.1	128.0	1.5
Elevation Angle (deg)	2.54	2.43	2.51	2.94	77.13
EIRP (dBm)	70	70	70	67	70
Normalized Ground Antenna Gain (dB)	-2.67	-2.81	-2.71	-2.19	-13.25
Free-Space Propagation Loss (dB)	-141.05	-141.42	-141.14	-139.77	-114.19
Rec. Power at Aircraft Antenna (dBm)	-73.72	-74.23	-73.85	-74.96	-57.44

G.3 Co-Site Environment

In addition to all the scenarios for the external interference environment, effects were included to account for on-board sources of interference from co-aircraft L-Band systems. The components of this co-site environment were estimated during the TLAT deliberations and have been further refined for the expected UAT aircraft installations. This environment was selected to be conservative and consistent for all aircraft classes, which resulted in including, for example, the assumption that A0 aircraft could be equipped with airborne collision avoidance systems (ACAS). The co-site environment is defined in Table G-5, depicting the assumptions of transmission duration and rates of onboard L-Band transmitters, including signals from onboard DME equipment, TCAS and transponders. Also noted is the allowance made for receiver recovery time under the assumption that pulse suppression circuitry is employed.

G.4 Scenario Assessments

With the preceding environments established, ADS-B reception performance was assessed for various receiver types in various locations within the environment[6]. The primary metric was the update interval achieved at a 95% confidence level for 95% of the aircraft population of interest. In early assessments of air-air surveillance performance, the aircraft population of interest was limited in elevation relative to the own aircraft in order to eliminate from consideration targets that were of no operational interest (see Figure G-4). However, this limitation of the aircraft population of interest was not used in the performance assessment reported in Appendix K because an alternate method of using "probes" was employed as described in Appendix K.

Table G-6 is a matrix delineating the individual simulations performed in making design decisions for this MOPS. Results from a select subset of these simulation runs are provided in Appendix K to indicate performance that can be expected of a UAT built to the standards of this MOPS.

[6] It is recognized that UAT ground stations in close geographic proximity to 978 or 979 MHz DME/TACAN transponders may require special siting to ensure proper operation of the UAT equipment.

Table G-2: Interference Scenarios and Implementation Assumptions

		Scenarios: Core Europe 2015	Scenarios: Core Europe Current	Scenarios: LA 2020	Scenarios: Low Density
Standard Interference Environment	UAT Self Interference	Per TLAT Core Europe 2015 (2091 a/c in 300 NM radius) + 100 Surface vehicles per major airport @ 28-32 dBm and 1 Short msg/sec	1193 aircraft 500 ground vehicles 300 NM radius	Per TLAT LA 2020 (2694 a/c in 400 NM radius) + 100 Surface vehicles per major airport @ 28-32 dBm and 1 Short msg/sec	Per TLAT Low Density (360 a/c in 400 NM radius) + No surface vehicles
	DME	All currently planned 979 assignments See Table G-4	All current 978 MHz and 979 MHz assignments See Table G-3	None	Same DME environment as CE 2015
	JTIDS (levels seen at UAT victim antenna port)	TSDF 50% @ -39 dBm + TSDF 50% @ -60 dBm + TSDF 300% @ -84.5 dBm	TSDF 50% @ -39 dBm + TSDF 50% @ -60 dBm + TSDF 300% @ -84.5 dBm	TSDF 50% @ -39 dBm + TSDF 50% @ -60 dBm + TSDF 300% @ -84.5 dBm	TSDF 50% @ -39 dBm + TSDF 50% @ -60 dBm + TSDF 150% @ -78 dBm + TSDF 150% @ -82 dBm
Installation and Implementation Assumptions	Co-site	See Table G-5 (scenario independent)			
	UAT Implementation Effects (Applies to all classes)	Re-trigger capable			
		T/R switching results in 2 millisecond receiver blanking immediately before and after own-ship transmissions			
		-20 dBc pedestal for 4 usec duration immediately before and after own-ship transmission			
		"Pulse stretching" effects from high level DME seen in bench tests of "Pre-MOPS" units included in model			

Table G-3: Received Power Levels (dBm) for Current European DME/TACAN Environment

Aircraft (Lat, Lon)	Alt (ft)	AHLHORN	METZ/FRE…	FURSTENF…	ALL_GERM…	BRUGGEN	GEILENKI…
50.9 deg, 4.5 deg	40000	-76	-72		-79	Not Operational	-66
50.9 deg, 4.5 deg	15000		-75				-69
50.5 deg, 9.3 deg	40000	-74	-74	-74	-57		-75
50.5 deg, 9.3 deg	15000	-76	-76	-77	-53		-78

Table G-4: Received Power Levels (dBm) for 2015 European DME/TACAN Environment

Aircraft (Lat, Lon)	Alt (ft)	AHLHORN	METZ/FRE…	FURSTENF…	ALL_GERM…	BRUGGEN	GEILENKI…
50.9 deg, 4.5 deg	40000	Assumed Cleared			-77	-76	-66
50.9 deg, 4.5 deg	15000				-68	-76	-69
51.0 deg, 6.0 deg	40000				-70	-76	-62
51.0 deg, 6.0 deg	15000				-72	-72	-56

Table G-5: Co-site Environment

Event	Event Blanking Interval (usec)		Events per Second			
	Event Duration	Additional Blanking due to Rx Recovery	**A0**	**A1 (L)/(H)**	**A2**	**A3**
DME Interrogations	19	15 usec	70	70	70	70
ATCRBS Replies	20	15 usec	200	200	200	200
Mode S Replies	64	15 usec	4.5	4.5	4.5	4.5
Mode S Interrogations	20	15 usec	5	5	5	5
Whisper Shout Interrogations	25	15 usec	80	80	80	80

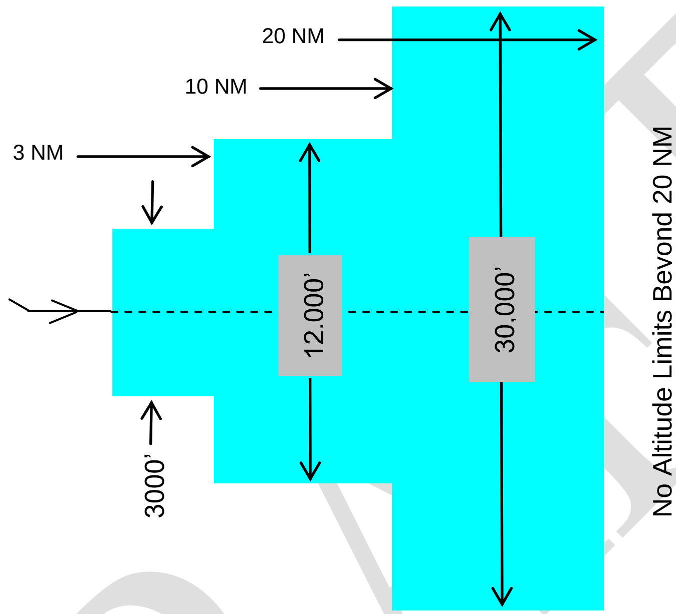

Figure G-4: Targets of Interest for Computing Update Interval

Table G-6: Overview of Scenario Assessments

Perspective of Victim Receiver			Scenario			
Location	**Altitude**	**Rx Type**	**Core Europe 2015**	**Core Europe Current**	**LA 2020**	**Low Density**
At Scenario Center	40,000’	A3	**x**	**x**	**x**	**x**
		A2	**x**	**x**	**x**	
		A1	**x (H)**	**x(H)**	**x (H)**	
	15,000’	A2/A3	**x**	**x**	**x**	
		A1	**x**	**x**	**x**	
		A0	**x**	**x**	**x**	
	On Approach (2000’)	A0-A3[7]	**x**	**x**	**x**	
	On Surface (979 MHz DME @ -10 dBm)	A0[8]	**x**		**x[9]**	
		Ground Station	**x**		**x[10]**	
		Ground Station[11]	**x**			
At Worst Case DME	40,000’	A3	**x**	**x**		**x**
		A2	**x**	**x**		
		A1	**x(H)**	**x(H)**		
	15,000’	A2/A3	**x**	**x**		
		A1	**x**	**x**		
		A0	**x**	**x**		

[7] Update intervals based on aircraft “probe” approaching from 20 miles
[8] Update intervals based on aircraft “probe” approaching from 20 miles at 2000’
[9] No DME interference included in this case
[10] No DME interference included in this case
[11] With cavity filter in line that is assumed to reduce DME interference to that equivalent of on-channel DME at –50 dBm. Filter assumed to introduce insertion loss of 4 dB

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Appendix H

UAT Synchronization Process

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H. UAT Synchronization Issues

H.1 Introduction

Appendix H discusses the UAT synchronization process. The primary purpose of any synchronization process (including that of UAT) is to detect the presence of a signal and to determine as accurately as possible the correct timing of the signal so that it can be successfully demodulated.

For UAT, synchronization is supported by a 36-bit sequence that occurs at the beginning of every message. A simplified version of the synchronization process might consist of comparing samples of the incoming bit stream with the expected sequence. If more than a certain number (say, 31) of these bits were correct, a valid signal would be considered detected. The length of the sequence, the particular sequence used, and the threshold are chosen so that there is a reasonably low probability of false alarm ("synchronizing" with no valid sequence actually present or with the timing incorrect by more than one bit period). In order to insure that the synchronization process determines the bit sampling time to within a small fraction of a bit period (to optimize performance), the waveform is typically sampled more than once per bit during the synchronization process. In the discussion below, we will assume that the sampling rate is six times the bit rate (i.e., 6.25 Msps).

Synchronization for the UAT ADS-B Messages is complicated by the fact that they are transmitted pseudorandomly by each user and there is, therefore, a high probability of signal overlap. Overlap is not necessarily an overwhelming problem because UAT is fairly robust in the presence of self-interference. This is primarily due to the fact that the waveform is basically binary FM. Very good performance results when the desired-to-undesired ratio (D/U) is as little as 6 dB (with a single interferer). However, this property could be rendered irrelevant if receivers that have already synchronized to weak signals cannot resynchronize (or "retrigger") on strong signals arriving slightly later. Thus, good performance in the presence of a heavy self-interference environment is dependent upon the ability to continue to search for synchronization while demodulating a signal. If a new synchronization correlation is found during the course of demodulating a message, the receiver can either switch from processing the old signal to the new one, or it can attempt to demodulate both. There is some danger in the switching option because the sequence used for synchronization (or something very close to it) may be embedded in a valid message. In the next section we will show an example of how to implement the option of demodulating both.

Caveat: The discussions in this appendix pertain to a particular implementation of a transceiver. Other techniques may also be viable.

H.2 Synchronization Process Description

Figure H-1 is a top-level diagram of a possible UAT synchronization scheme. It shows that after the received signal passes through an IF filter, it is detected by a limiter/discriminator that generates a string of ones and zeros at a rate of 6 times per symbol. The sample stream then goes through a correlator, which is looking for the synchronization pattern. As the samples stream out of the correlator, they enter a 6 by N byte memory. This is arranged so that each “row” of the memory contains samples separated by the bit period. In the meantime, whenever the box labeled “threshold” determines that a signal is present, it will attach a flag to the appropriate location in the memory. The processor will then read out bits from the memory (on a row-by-row basis) according to the locations of the flags. This read-out process will allow the processor to deal with overlapping messages, whether or not they are in the same row of the memory. Note that *all* samples follow this path, even when “information” is being processed. Thus, the receiver can continuously look for new synchronization patterns.

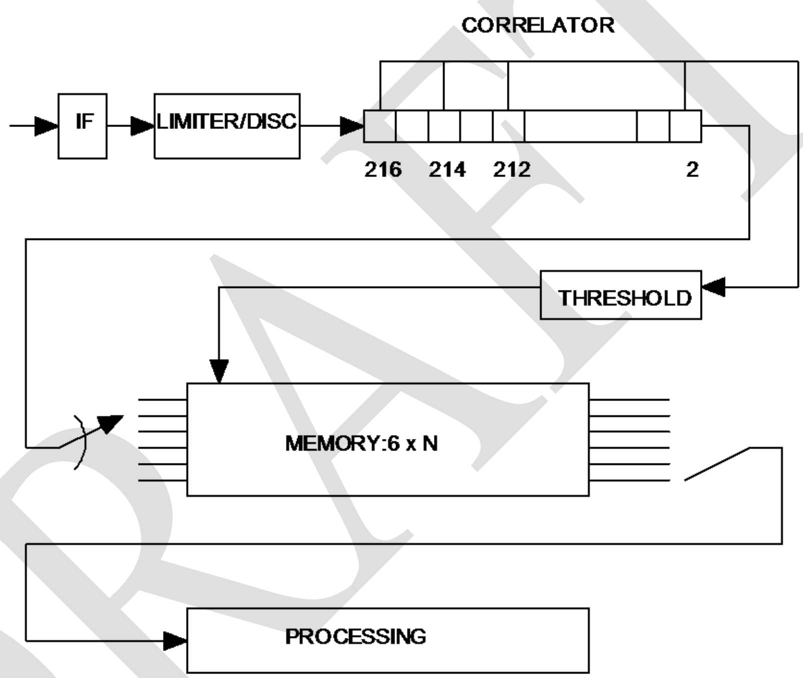


Figure H-1: UAT Receiver Processing

In the paragraphs below, the components of Figure H-1 are dealt with in more detail.

The **correlator** is basically a tapped delay line whose length is long enough to hold about 36 x 6 = 216 samples. The taps are arranged so that every other location is used to compare the incoming sample sequence with the fixed synchronization sequence. The expected sequence consists of triplets of ones and zeros. The output of the taps is a sequence of correlation scores that can range anywhere from 0 to 108. A score of 108 indicates that every sample is correct. A value of 0 indicates that every sample is incorrect. Normally, this latter case would only occur if a ground (up link) message were present since the ground message synchronization sequence is just the “opposite” of the ADS-B sequence. These correlation scores are fed at a rate of 6.25 million scores per second to the threshold detector (see below), and the bit samples exiting the back end of the delay line are fed at a rate of 6.25 Mbps into the box labeled “memory.”

The **threshold detector** compares the sequence of correlation samples and looks for values above a threshold. In order to find the optimum sampling point of each bit, the threshold detector will, when confronted with a string of successive threshold crossings, choose the highest one (see section H-3). Having chosen a potential ADS-B Message start point, the threshold detector attaches a marker to the appropriate location in the “memory” (see below), e.g., the first bit sample of the information portion of the message. This process runs continuously.

The **6xN memory** accepts bit samples from the correlator at a rate of 6.25 Msps and arranges them into six separate sequences. Each separate sequence represents a separate string of potential information bits. Those bit strings flagged by the threshold detector are passed to the box called “processing” to determine which comprise real messages. Note that the receiver has, at this point, no way to determine whether a threshold crossing corresponds to a long or a short ADS-B Message. This will be determined in the “processing” box. In the meantime, all ADS-B Messages are treated as if they were long ones. At any given time there can be many potential message starts indicated by pointers in the memory. These can be due to real messages or false alarms that may or may not overlap with other real messages or false alarms. These are all sorted out in the processor.

The **message processing** begins with each potential ADS-B Message being read into a first-in-first-out (FIFO) memory based on the locations of the flags set by the threshold detector. As stated previously every message is temporarily assumed to be a long one. Each message, in turn, is then subjected to Reed-Solomon decoding. Those that are successfully decoded are assumed to be valid long ADS-B Messages. Those that fail are then subjected to Reed-Solomon decoding assuming they are short ADS-B Messages. Those that pass this test are assumed to be valid. Potential messages that fail to decode either way are discarded. Because of the very low undetected error probabilities of the Reed-Solomon codes employed by the ADS-B Messages, this method of sorting through the potential messages should be extremely reliable (see Appendix M).

Note that the ability to process multiple overlapping messages is limited only by the size of the 6xN memory and the ability of the Reed-Solomon decoder to process all potential messages. It appears that neither of these is a real problem. The memory requirement is very small (see section H-7), and the decoder chip in the UAT prototype can handle many times the maximum required decode rate.

H.3 Synchronization Performance

The correlation process described above is designed to provide a high probability of detection, a low false alarm rate, and a reasonably accurate determination of the optimum sampling point for the information bits. To provide the necessary background, we will assume that the transmitted baseband signal has been generated by passing the bit sequence through a Nyquist filter prior to the FM modulation process. The purpose of the filter is to restrict the transmitted spectrum in order to minimize interference to and from other nearby systems (e.g., DME). The filter is assumed to be a raised-cosine with a roll-off factor of 0.5. This is theoretically an infinite impulse response (IIR) filter, but it can be implemented using truncation at plus and minus 3 bit periods. The resulting filter shape is shown in Figure H-2.

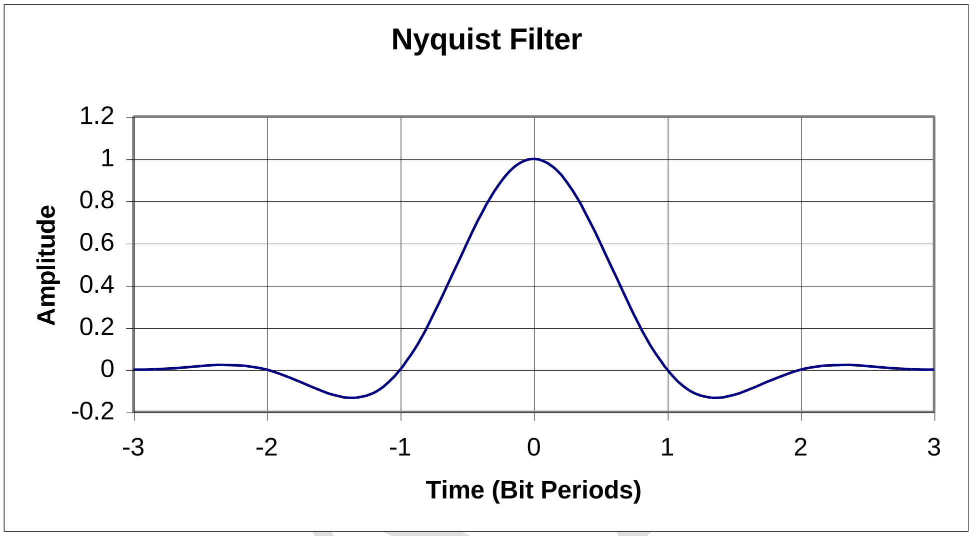
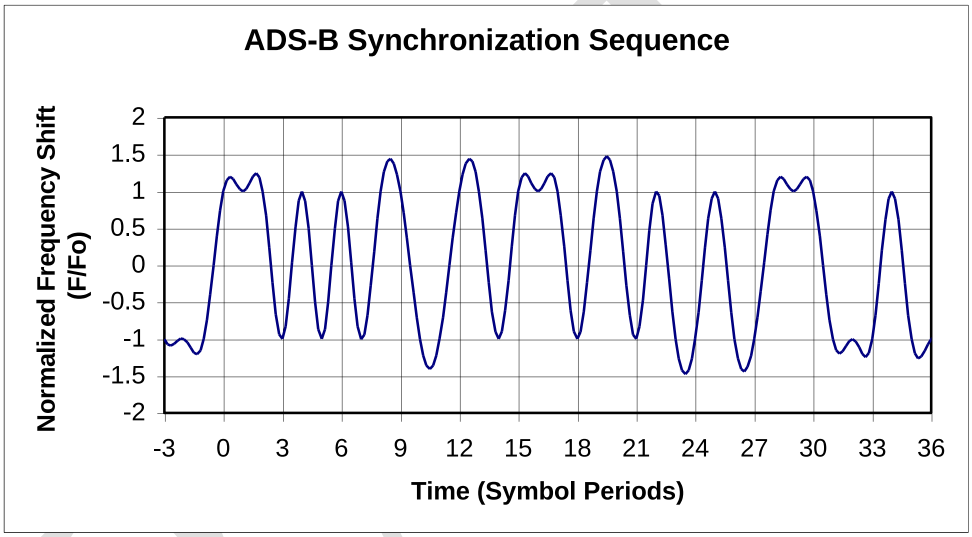


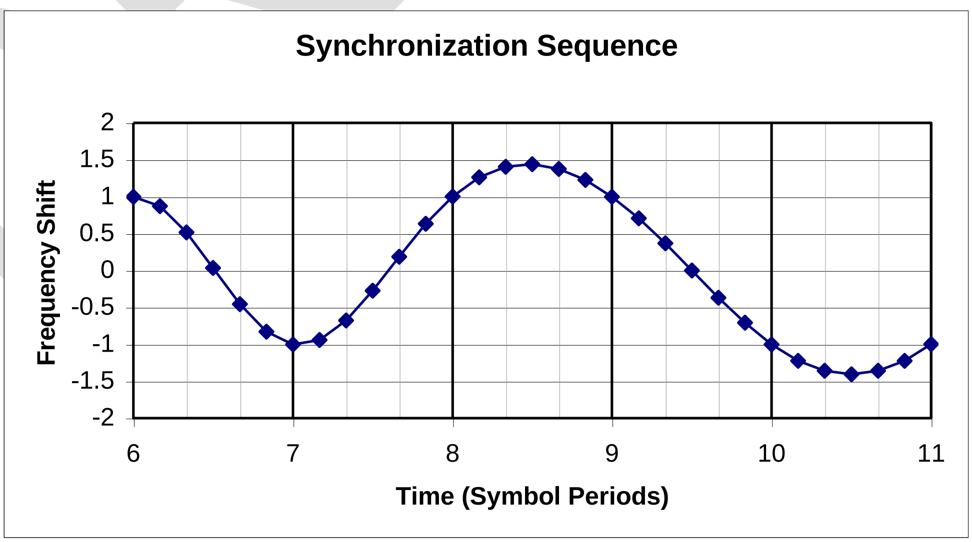
Figure H-2: Baseband Transmit Filter. Truncated Raised-Cosine Nyquist Filter With Roll-Off Factor = 0.5

When the synchronization sequence is passed through this filter the result is a fluctuating signal that can be used to modulate the transmitted frequency. The profile for the sequence is shown in Figure H-3. In the figure, the synchronization sequence is represented so that a 1 is a shift up in frequency by F_0 and a 0 is a shift down by F_0. For UAT, the value of F_0 is 312.5 kHz. The correct frequency values for the synchronization sequence are achieved at the 36 integer values spanning 0 through 35. Due to the action of the filter, the normalized instantaneous frequency smoothly varies from +1 to –1 at non-integer values. Sometimes the magnitude of the instantaneous frequency is actually larger than 1. Note that prior to the synchronization sequence (i.e., during ramp up), the waveform is assumed to be modulated with zeroes. Although these MOPS do not specify the type of modulation to be applied prior to the synchronization sequence, an input of some kind is required by the Nyquist filter, and the all zero bit pattern is shown as a representative example.

A small portion of the sequence is shown in Figure H-4. This picture emphasizes that the frequency deviation is often reduced significantly between the ideal sampling points. This fact might seem to indicate that the most reliable performance would be available to a scheme that relies only on these robust bits (i.e., only use one sample per bit). This may be the case; but, as we will show below, such a method may not accurately determine the location of the waveform's optimum sampling point. To address this issue, the proposed method uses every other sample of 6 samples per bit period to generate a correlation score (number of correct bits) that can vary between 0 and 108 for any given measurement. The general idea behind this scheme is that when the central sample is indeed at the optimum sampling point of the bit period, the 2 "outrigger" samples will typically have the same polarity. On the other hand, if the central sample is off by as little as one sixth of a bit period, some of the outrigger samples will have a high probability of being incorrect (opposite polarity) as indicated in Figure H-4.



<u>Figure H-3:</u> ADS-B Synchronization Sequence



<u>Figure H-4:</u> A Portion of the ADS-B Synchronization Sequence

To analyze how this works we need to establish some mathematical notation. First, assume that the synchronization sequence is given by the vector

$$\vec{B} = (b_1, b_2, b_3, \cdots, b_{36}) .$$

Each component of this vector is +1 or –1 depending on whether the bit is a one or a zero. From this we can define a new vector, $\vec{F}$, whose components are all zero except that

$$F_{6i} = b_i .$$

We can now define a third vector that specifies the correlator tap weights:

$$T_i = F_i + F_{i+2} + F_{i+4} .$$

All the odd tap weights are 0. There are 108 nonzero tap weights (the even ones from 2 to 216) as shown in Figure H-1. For the ADS-B Messages some specific values are given by

$$\vec{B} = (1,1,1,-1,1,-1,1,-1,1,1,-1,-1,1,1,-1,1,1,1,-1,1,1,-1,1,-1,-1,1,-1,-1,1,1,1,-1,-1,-1,1,-1)$$

and

$$\vec{T} = (0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,-1,0,-1,0,-1,0,\cdots) .$$

If the incoming sample sequence at any given time (again, expressed as +1 or –1) is given the notation

$$S_i \quad with \quad i = 1 \; to \; 216 ,$$

then the correlation value is given by

$$Corr = \left(108 + \sum_{n=1}^{108} T_{2n} S_{2n} \right) / 2 .$$

This counts the number of correct samples out of a possible 108.

To estimate performance, we will assume that the incoming sample sequence is generated by a valid synchronization sequence (as portrayed in Figures H-3 and H-4) plus additive white Gaussian noise. (These are only estimates, certain approximations are inherent in this analysis.) In other words,

$$S_i = +1 \quad if \quad x_i = \sum N_{ij} F_j + g_i \geq 0$$
$$S_i = -1 \quad if \quad x_i = \sum N_{ij} F_j + g_i < 0$$

where the N_{ij} are the Nyquist filter coefficients and the g_i are Gaussian noise samples. It can be shown that when noise is absent from the input sequence and there is perfect time alignment between the input and the expected sequence the correlation score will be 108. With finite noise and a possible offset, the expected correlation score can be approximated by

$$< Corr(\gamma, m) >= 108 - \frac{1}{2}\sum_{i=1}^{108} erfc\left(T_{2i} x_{2i+m} \sqrt{\frac{\gamma}{2}} \right)$$

where the value m is an integer that indicates the relative timing offset in units of sample periods. γ is the signal-to-noise ratio (SNR). $erfc$ is the complementary error function [1]. The results of this equation for various values of SNR and offset are shown in Figure H-5.

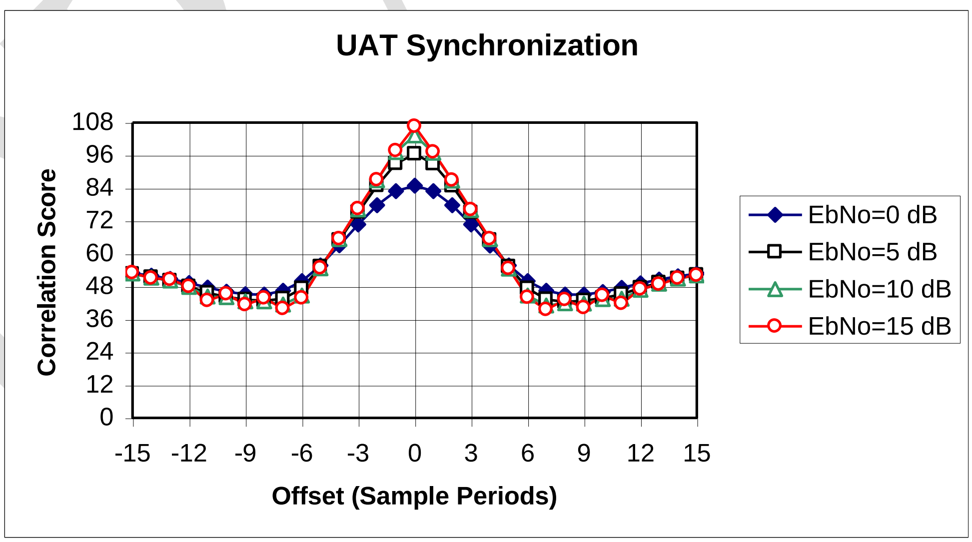


Figure H-5: Performance of the Three Sample per Bit Scheme

Note that the curves in Figure H-5 have some desirable features. In particular the curves are quite peaked whenever the SNR (or E_b/N_o) is greater than 5 dB. This feature should make it comparatively easy to identify the sample time with the smallest offset from the optimum sampling point. This performance can be compared with a scheme based on one sample per bit. In that case the tap weights would be given by

$$T_i = F_i$$

and the correlation value would be given by

$$Corr = \left(36 + \sum_{n=1}^{36} T_{6n} S_{6n}\right) / 2 .$$

The expected correlation value is given by an equation similar to the one for the three-sample case. It is evaluated for various values of SNR and time offset in Figure H-6. In the one sample per bit scheme the correlation "peak" is actually a plateau, and at high SNR there is a very good likelihood that several samples will have the maximum possible value. The optimum sampling point will be very difficult to identify. This provides the rationale for the first scheme.

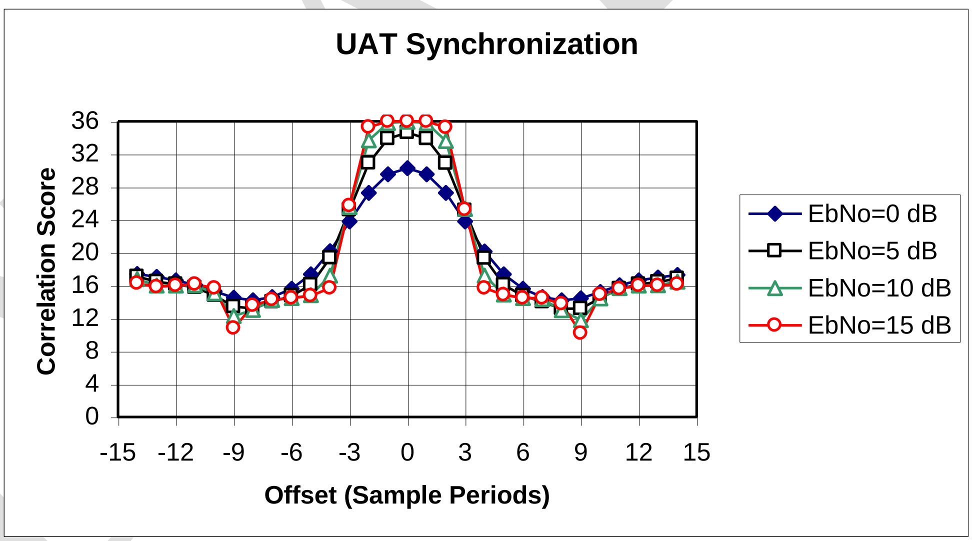


Figure H-6: Performance of the One Sample per Bit Scheme

H.4 False Alarm Rate (Noise)

The noise-induced false alarm rate is related to the probability that random noise creates a correlation value that exceeds the synchronization threshold. A reasonable rate of false alarms can be tolerated provided that the receiver has a retrigger capability. If all of the 108 samples that are used to create the correlation value were statistically independent, then we could write the false alarm probability as

$$P_{fa} = (0.5)^{108} \sum_{n=0}^{107-T} \frac{108!}{n!(108-n)!}$$

where T is the synchronization threshold. (Note that the highest possible threshold is 107 since the correlation score must *exceed* the threshold.) In that case the false alarm rate (number per second) would be

$$FAR = 6.25x10^6\, P_{fa}$$

since the samples are taken at a rate of 6.25 MHz. This method is clearly not correct because it fails to take into account the finite bandwidth involved in the overall synchronization process. The narrow IF filter limits the bandwidth, and the addition of three samples per bit acts as a crude version of a digital filter matched to the transmitter Nyquist filter. Neighboring estimates of the correlation score are *not* independent. An extreme manifestation of this effect would be to interpret the synchronization as being based on only 36 independent bit samples occurring once each bit period. This would mean that the false alarm probability would be given by

$$P_{fa} = (0.5)^{36} \sum_{n=0}^{36-(T+1)/3} \frac{36!}{n!(36-n)!}$$

and the FAR by

$$FAR = 1041667\ P_{fa}\,.$$

In actuality the truth probably lies somewhere between these two extremes. As an *ad hoc* guess, we can try the following:

$$P_{fa} = (0.5)^{NE} \sum_{n=0}^{NE(107-T)/108} \frac{NE!}{n!(NE-n)!}$$

and

$$FAR = 3.125x10^6\,(NE/108)P_{fa}$$

where NE is the effective number of bits.

In Figure H-7 we plot the FAR versus T for two hypothetical values of NE. With these curves we have also plotted measured data for a number of different receiver bandwidths. The nominal (3 dB) bandwidths of the receiver filters are 1.75 MHz, 1.2 MHz, and 0.8 MHz. Figure H-7 has some interesting features. First, the fit between the curves and the data points is quite good provided an appropriate value of NE is chosen. Second, the value of NE appears to decrease as the width of the receiver filter narrows. This variation can be understood as a consequence of the fact that as the filter narrows, rapid frequency swings (i.e., apparent bit changes) become less likely. Thus, the effective number of independent samples decreases and the false alarm rate has a corresponding increase.

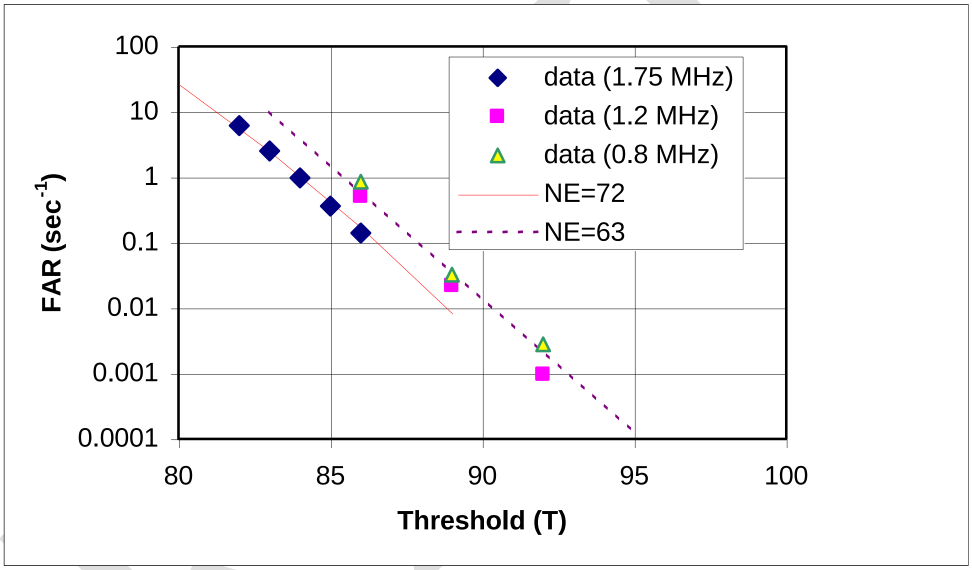


Figure H-7: False Alarm Rate versus Threshold

(Parameter is Effective Number of Bits, NE)

H.5 False Alarm Rate (Embedded Synchronization Sequence)

Another situation where the correlator can exceed the threshold in the absence of an actual received synchronization sequence occurs if there happens to be a bit sequence embedded in the message payload that has a high correlation with the expected sequence. In such a case, the fact that the receiver is demodulating an actual message forces the samples to exist in groups of three. In other words, the effective number of bits in this case is, in fact, 36. Thus, the probability of false alarm is given by

$$P_{fa}(T) = (0.5)^{36} \sum_{n=0}^{36-(T+1)/3} \frac{36!}{n!(36-n)!}.$$

The number of opportunities, N_{OP}, for a false alarm to occur during the receipt of a long ADS-B Message is equal to the number of bits in such a message minus the length of the synchronization sequence, or 348 (= 384 – 36). Thus, the probability that a long ADS-B Message with random bits will cause a false alarm is given by:

$$P_{EMB}(T) = N_{OP}P_{fa}(T) = 348P_{fa}(T) .$$

For example, if the threshold is set at T=86, then the probability of an embedded ADS-B synchronization is:

$$P_{EMB}(86) = 0.0544 .$$

Thus, the embedded synchronization phenomenon would increase the apparent load of ADS-B Messages by about 5% if the threshold is set at 86.

H.6 Up Link Message Considerations

Synchronization performance for up link messages should be very similar to that of ADS-B Messages because the up link synchronization sequence is just the complement of the ADS-B sequence, i.e., the ones and zeros are inverted. This allows the same correlator to search for both synchronization types simultaneously. When an ADS-B Message is present the correlation score should be very high (near 108). In the presence of an up link message the correlation score should be very low (near 0) since it will appear to the ADS-B correlator that nearly all the samples are incorrect.

Measurements of false alarms due to random noise indicate that the performance of the two synchronization types is quite similar when equivalent thresholds are used. There are some small differences that may be due to the fact that the numbers of ones and zeros in the synchronization sequences are not quite equal.

For false alarms generated by the embedded synchronization process, the rates (for equivalent threshold values) will differ because the up link messages are much longer. There are 4380 false alarm opportunities per up link message as opposed to 348 for long ADS-B Messages. When the up link threshold is set at 22 (equivalent to 86 for ADS-B Messages) the probability of false alarm is estimated to be 0.685. Because this high rate may use up more processing resources than is acceptable, it may be prudent to make the up link threshold more stringent than the ADS-B threshold. If the threshold were set to 16 (equivalent to 92 for the ADS-B Messages), the probability estimate would fall to 0.0283. Changing the threshold in this way will lower the probability of synchronization for a valid message in the presence of noise. However, the synchronization process is generally more robust than the data demodulation process. Thus, there appears to be plenty of margin to change the threshold, particularly for the up link messages, which have slightly degraded message decoding performance (see Appendix M) compared to ADS-B.

H.7 Required Memory Size

The block labeled "Memory: 6xN" is provided to allow the receiver to sort out numerous (possibly overlapping) received signals and feed potentially valid bit streams into the "processing" block in the form of a sequence of long ADS-B RS code words. This block is essentially an elaborate deinterleaver. It is assumed that the bits are fed into the memory at a rate of 6.25 Mbps and can be read out at a rate of 6.25 Mbps at the same time. In other words, it must be capable of reading in one bit and reading out one bit during the same clock cycle (160 nanosecond). The question addressed here is the required size of the memory, or "What should N be?"

To answer that question, a simulation was created which generated 2200 ADS-B Message starts each second. This corresponds to the worst-case loading scenario. These messages were then sorted according to time-of-arrival. It was then assumed that every one of these messages would result in a crossing of the synchronization threshold, i.e., every message would need to pass through to the processing block. That is actually an unrealistic assumption since many of the synchronization attempts may fail due to self-interference. Thus, this analysis will provide an overestimate of the memory requirement.

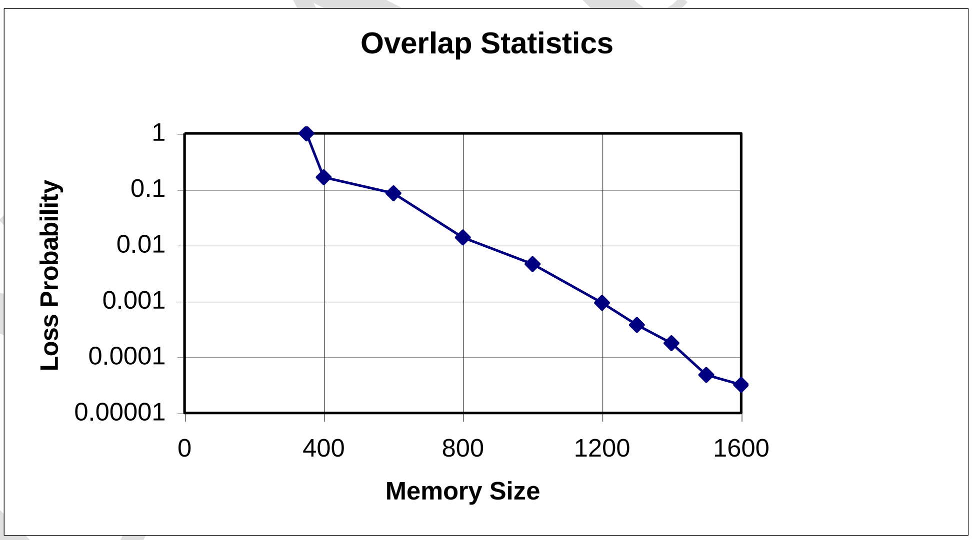


Figure H-8: Memory Length Determination (Memory Size in bits)

The simulation operated by marching along in time and noting each message start. When a message start was encountered, a backlog of bits to be processed was added to a running total. This total was incremented when encountering new messages and decremented by feeding bits into the processing block. The maximum size of the backlog is the length of the memory, N. The simulation was run repeatedly to determine the probability that the backlog would overflow versus the memory size. This is equivalent to the probability that an ADS-B Message will be dropped because it gets overwritten before it can be transferred to the processing block. The results of the simulation are shown in Figure H-8.

Figure H-8 indicates that if the memory length is 1200 bits, the probability that an ADS-B Message will be dropped is 0.001. If that loss rate was acceptable, the total memory size required to implement the sorting function would be about 6 x 1200/8 = 900 bytes.

H.8 Summary

This Appendix has described a possible mechanism for allowing a UAT receiver to synchronize to and demodulate multiple overlapping ADS-B signals. This capability is essential for successful operation in environments with many aircraft. The suggested technique does not require extensive resources in terms of memory space or processing speed. The appendix also briefly examines the choice of the thresholds for the synchronization processes. Based on the information provided, it appears that it may be desirable to have a slightly more stringent threshold for up link messages than for ADS-B Messages.

Reference

[1] Abramowitz, M., and I. A Stegun, Handbook of Mathematical Functions, Dover Publications, Inc., New York.

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Appendix I

UAT Timing Requirements

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I. UAT Timing Requirements

I.1 Background

This UAT MOPS contains timing requirements related to both the transmission of ADS-B Messages and reception of ADS-B and Ground Uplink messages. The primary objective of these requirements is to support a range measurement between an ADS-B Transmitting and Receiving Subsystems that is independent of the ADS-B reported position data. This range calculation can be made from knowledge of the precise Time of Message Transmission (TOMT) and Time of Message Receipt (TOMR) of ADS-B Messages. An *ADS-B validation* application can compare this one-way time of propagation range measurement with the range determined from the ADS-B Message to increase confidence that the message came from a bona fide transmitter. As an example, certain pairwise procedures may only be authorized when the opposing target passes some range validation criteria.

This ADS-B validation procedure is only available in cases where both the transmitting and receiving stations are *UTC coupled*, that is, they are receiving time from a GPS/GNSS source or equivalent. This UAT MOPS allows for GPS/GNSS timing sources that are either *external* or *internal* to the UAT equipment. Whether the timing source is external or internal, the UAT MOPS requires UTC coupling as the normal operational condition. A non-UTC coupled condition can occur due to a temporary unavailability of the GPS/GNSS source or equivalent. At any given time, a UAT transmitter is obligated to announce whether or not it is in the UTC coupled state.

I.2 Purpose

The purpose of this Appendix is not to design or specify an ADS-B validation application. Instead, the purpose of this Appendix is the following:

1. Document the expected total installed end-to-end timing performance as guidance to UAT installers and to developers of ADS-B validation applications.

2. Provide rationale for the timing related requirements given in this MOPS in the context of the expected total installed performance.

3. List additional considerations for developing an ADS-B validation application.

I.3 Installed End-End Timing Performance

Listed below are the identified components of possible timing errors and their assumed worst-case values using a GPS/GNSS source as an example.

a) Errors due to the GPS signal in space: This is assumed bounded by the performance specifications of the GPS Standard Positioning Service with SA OFF. Uncertainty range = **-100 to +100 ns**.

b) GPS antenna and coax effects. This is assumed bounded by a 20 meter maximum installed cable length. Uncertainty range = **-0 to +66 ns**

c) GPS-UTC time offsets: This is applicable to GPS receivers that output GPS time instead of UTC time. Since GPS sensors that may be used for ADS-B are not required to make the UTC correction, this offset must be included. GPS specifications allow GPS time to deviate from UTC time by up to 1 microsecond. This is expected to be very conservative. . Uncertainty range = **-1000 ns to +1000 ns**.

d) Delays due to interconnection of GPS sensor and UAT: This component applies to installations with external UTC coupled time source. Allowance is needed for delays induced in lightening protection filters and interconnect cable capacitance between the GPS/GNSS sensor and the UAT. Total uncertainty range based on tests has been determined to be = **-0 to +800 ns**.

e) UAT Tx/Rx time errors: errors due to control of transmitter turn on and in marking message time of arrival within the receiver. An uncertainty range specifically for this component is established in this MOPS. Uncertainty range = **-500 ns to +500 ns**.

f) UAT antenna/coax effects: This is assumed bounded by a 20 meter maximum installed cable length. Uncertainty range = **-0 to +66 ns**

While some of the timing errors are of a fixed offset nature, it was determined that any form of timing calibration procedure required of the UAT system installer would be undesirable.

Table I-1 below shows the worst case timing offset possible between a transmitting UAT and a receiving UAT given the individual error components listed above. This suggests that a value just under 0.7 NM would represent the absolute worst-case range measurement error due to timing offsets between transmitter and receiver under normal (UTC Coupled) conditions.

Table I-1: Transmitter to Receiver Time Offset Worst Case

Error Component	Transmitting Station		Receiving Station		Worst Case transmitter-to-receiver relative timing offset	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
a) GPS signal in space	-100	+100	-100	+100	-200	+200
b) GPS cable delay	-0	+66	-0	+66	-66	+66
c) GPS-UTC time offset	-1000	+1000	-1000	+1000	-2000	+2000
d) GPS-UAT interconnect delay	-0	+800	-0	+800	-800	+800
e) UAT Tx time accuracy	-500	+500	N/A	N/A	-500	+500
f) UAT Rx time stamp accuracy	N/A	N/A	-500	+500	-500	+500
g) UAT cable delay	-0	+66	-0	+66	-66	+66
Total Worst case of all Components ➔					**-4132**	**+4132**

For comparison, note that if both the transmitter and receiver both use GPS time where the GPS receiver is internal to the UAT equipment, then two of the major components (c and d) of timing offset error are largely eliminated. In this case the absolute worst-case range measurement error due to timing offsets between transmitter and receiver would be about 0.25 NM.

I.4 MOPS Timing Requirements

There are essentially two UAT MOPS requirements related to timing: one related to control of ADS-B Message transmission, and one related to time stamping of message receipt. The requirements and test conditions are treated separately depending on whether the UTC coupled time source is internal or external. Timing requirements in this MOPS are specifically limited to items that are testable independent of any other installed equipment.

Message Transmission Timing:

The MOPS section on “Relationship of the MSO to the Modulated Data” (§2.2.6.2.2) specifies the requirement for ADS-B Message transmission timing.

- When an internal UTC coupled time source is used, the requirement and test is designed to verify uncertainty components c) *(GPS-UTC)* and e) *(UAT Tx time)*. This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 ns.

- When an external UTC coupled time source is used, the requirement and test is designed essentially to account only for part of component d) *(GPS interconnection delays)* and component e) *(UAT Tx time)*. This is accomplished by applying a test 1PPS or Time Mark input that is essentially free of uncertainty components a), b), c), and most of d). The maximum timing error allowed is 500 ns.

Accuracy of Time Stamping on Message Receipt:

The MOPS section on "Time of Message Receipt" (§2.2.8.3.5) specifies the requirement for time-stamping of received messages.

- When an internal UTC coupled source time source is used, the requirement and test is designed to verify uncertainty components c) *(GPS-UTC)* and e) *(UAT Rx timestamp)*. This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 ns.

- When an external UTC coupled time source is used, the requirement and test is designed essentially to account only for part of component d) *(GPS interconnection delay)* and component e) *(UAT Rx timestamp)*. This is accomplished by applying a test 1PPS or Time Mark input that is essentially free of uncertainty components a), b), c), and most of d). The maximum timing error allowed is 500 nanoseconds.

I.5 Considerations for ADS-B Validation Applications

Time of Message Receipt (TOMR)

The MOPS details the requirements for accuracy and resolution of making the raw measurements on which a range calculation can be made. TOMR is relative to the start of the UTC second, and typically is measured in units of 100 nanoseconds.

The UAT receiver or an external application can directly calculate the range to the target by knowing how many whole and fractions of an MSO (250 microseconds) elapsed between transmission and receipt of the message. The fractional portion is directly calculated from each SV report received, which gives fine-scale resolution to about 30 meters (100 nanoseconds times 3.0e+8 meters/second). The integer portion provides resolution of about 40.47 NM (250 microseconds times 3.0e+8 meters/second)

Acquisition of full TOMR Range

The full TOMR range (integer and fractional parts) can be determined once a Long message containing the Transmission Epoch field has been received (the Long Type 1 message). The Transmission Epoch field has sufficient span to unambiguously identify in which MSO the message was transmitted. The receiving UAT or the external application can then calculate the integer portion of TOMR, and derive of the full TOMR value.

Once the full TOMR range has been acquired, the fractional portion can be used to maintain a track of the range value during the interval between receipts of a message containing the Transmission Epoch.

TOMR Range Filtering

Due to plant noise and other physical effects, one can expect the raw TOMR range values will require some filtering prior to use. An alpha-beta recursive filter, which allows for uneven time between message receptions (because of dropped messages, etc.), can be used to both smooth and predict range values.

Correlation of TOMR Range vs. SV-based Range

Slant Range: The filtered range value includes the slant range effects, and will normally exceed the great-circle range calculated from the SV position of the target and the ownship SV position. The correlation of the target's range will require either some compensation of the great-circle range to include an estimate of the slant range, or a correlation window that has greater tolerance for increased slant range at high elevation angles. Since it is possible that some targets may not be reporting their altitude, provision must be made for cases where slant range compensation is not possible.

Datalink latency: One other phenomenon affecting the TOMR range calculation is that the range measured is based on the time of transmission, while the SV-based range calculation is based on the message Time of Applicability. This can lead to some additional variation between the measured and calculated range, which would be particularly noticeable in head-on or reciprocal encounters at high velocity. For example, at a closing rate of 1200 knots, the range closes at about 620 meters per second. The range differential amounts to at most 0.33 NM.

Note that for a given pair of aircraft, most of the timing errors can either be compensated for, or are fixed intervals. This allows the possibility that the residual range differential (after removal of fixed or compensate-able errors) could be used as an independent means of closure rate measurement.

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Appendix J

Reference Upper-Layer External Interface Format

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J. Reference Upper-Layer External Interface Format

J.1 Background

The purpose of this Appendix is to provide a reference external interface format for the UAT equipment. This Appendix does not specify a physical layer interface, but instead defines a reference implementation of those layers above the physical layer for byte-wise transmission over a serial interface. This reference interface provides for delivery of received ADS-B and TIS-B traffic, ADS-B ownship position, and FIS-B uplinks.

J.2 Scope

The report assembly function is implemented as a “pipeline” for delivery of messages received, augmented with appropriate report fields, via the UAT equipment. Report management and buffering methods may be used as permitted (see §2.2.10.2), but are not discussed further in this Appendix.

The Time of Message Receipt (TOMR) field is added to the received information by the UAT equipment. TOMR has sufficient resolution and span to resolve the time reference for the received message. Absolute time is not necessary if the end system has access to its own absolute time reference.

The TOMR value is the high-accuracy time measurement within the current second, which may be used by an external application for range measurement and validation.

Note that the UAT receiver cannot, on its own authority, truncate the received Uplink payload below its maximum length of 432 bytes, as it has no knowledge of the uplink Application Data packing format. Truncation of the Uplink Payload to only deliver the Header bytes can be performed, if appropriate for the intended application (e.g., range validation of TIS-B targets, use of Ground Station Uplink for a timing reference).

J.3 Serial Data Format Description

Table J-1 shows one possible definition of a report format.

Table J-1: Report Format

# of Bytes	Content
1	ASCII STX (Start of Text) byte (02_{16})
1	Packet Type (defined in Table J-2 below)
4	Time of Message Receipt (units of hundreds of nanoseconds since UTC midnight modulo 25.6 seconds)
Variable	Message Payload (see Table J-2 below)
1	Checksum (see Note 4)
1	ASCII ETX (end of text) byte (03_{16}).

Notes:

1. *Fields are listed in order of transmission.*

2. *Multi-byte fields are transmitted MS byte first.*

3. *In cases where the STX or ETX byte appears in the data stream, that byte should be preceded by a DLE (data link escape) byte (1016). The DLE byte can appear in the data by sending two consecutive DLE bytes. This allows a for variable length packets without requiring an explicit Length field.*

4. *Checksum is the exclusive-OR of all bytes exclusive of the STX, Checksum, and ETX.*

Table J-2: Report Packet Types

Packet Type #	Packet Type	Content
0	Status	Periodic status report of UAT performance (Note 1)
1	Target Message (received) (Note 2)	18 or 34 bytes, as defined in Table 2-10.
2	Ownship ADS-B Message	18 or 34 bytes, as defined in Table 2-10.
3	Uplink Message	432 bytes of payload data, defined in Table 2-4.
4	Uplink Header	Bytes 1 through 8 of Uplink payload data, defined in Table 2-4 (Note 3)

Notes:

1. *Items that may be included in the Status Packet Type include: GPS time in seconds since midnight (full resolution), number of ADS-B and Uplink synchronization patterns detected, number of ADS-B and Uplink messages FEC decoded successfully, number of ADS-B and Uplink messages that could not be FEC decoded, and the number of reports discarded in the previous second due to report bandwidth starvation.*

2. *Target messages include both ADS-B and TIS-B.*

3. *End system may use Packet Type 4 instead of Packet Type 3, if end system has no need for full content of Uplink Application Data. This can be via either an equipment option, a configuration parameter, or a run-time request. For example, the Uplink Header report contains the field necessary for airborne processing of received TIS-B reports.*

Appendix K

UAT System Performance Simulation Results

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K. UAT System Performance Simulation Results

K.1 Introduction

K.1.1 Organization

This introductory section discusses the background and assumptions for the Multi-Aircraft UAT Simulation (MAUS), which has been used as a tool for evaluating the performance of UAT as an ADS-B data link under a number of different possible system parameters and configurations.

Section K.2 describes in detail the antenna gain model, which is used by MAUS in calculating the signal levels received from the transmitting aircraft in the simulation. This antenna gain model is identical to that used by the ADS-B Technical Link Assessment Team in the simulations used to evaluate all three ADS-B link candidates.

The UAT receiver performance model used by MAUS is described in Section K.3. The model is based on measured data, and both the data and model characteristics are described in this section.

The results shown in Section K.4 are compared to the requirements as specified in RTCA/DO-242A, Table 3-4(a) "SV and MS Accuracy, Update Interval, and Acquisition Range Requirements" and Table 3-4(c) "Summary of TS and TC Report Acquisition Range and Uplink Interval Requirements." Section K.4 presents results for the analysis of UAT performance. Section K.4.1 describes the Los Angeles 2020 scenario and the UAT system performance in this environment. Section K.4.2 presents the Core Europe scenario (both current and 2015), and describes the performance of UAT in these environments. Section K.4.3 describes and presents results for the Low Density scenario. Acquisition performance is presented in Section K.4.4, and aircraft-aircraft performance on the surface is discussed in Section K.4.5. Section K.4.6 presents the results for an A0 receiver on the surface receiving aircraft on approach.

Finally, validation of the MAUS results is presented in Section K.5. This section describes a comparison of MAUS predictions with measured data from specially devised test equipment. This equipment was designed to emulate a high-density UAT self-interference environment, and the MAUS was run for identical conditions.

K.1.2 Background

Analytical models and detailed simulations of data links operating in future scenarios are required to assess expected capabilities in stressed circumstances. Accurately modeling future capabilities for potential system designs in a fair way, however, is challenging. Since validation of simulation results in future environments is unrealistic, other means of verification such as the following are required. System characteristics represented in these simulations should agree with actual measurements on components of the proposed design, e.g., bench measurements on prototype equipment and calibrated flight test data should be used, when possible, for the receiver/decoder capabilities and as comparison with modeled link budgets. Similarly, suitable interference models help to support estimates of how these conditions may change in future scenarios. Credibility of any simulation results for future scenarios also requires that they be able to model current conditions and provide results that appropriately agree with measurements made under these conditions. Existing tools have been used as cross-checks where possible for the final detailed simulations and models.

K.1.3 General Assumptions

In an effort to capture as many real-world effects important to the assessment of the performance of UAT as possible, an attempt was made to include, to the extent possible, representations of the effects of:

- Propagation and cable losses
- Antenna gains
- Propagation delays
- Co-channel interference (specifically, DME/TACAN and JTIDS (Link 16))
- Co-site interference (in and out of band)
- Multiple self-interference sources
- Alternating transmissions between top and bottom antennas (where applicable)
- Performance as a function of receiver configuration (e.g., diversity, switched, bottom only)
- Transmit power variability and configuration
- Receiver re-triggering
- Receiver performance based on bench testing
- Message transmission sequence and information content by aircraft equipage
- Ground receiver assumptions

K.1.4 UAT Detailed Simulation Description and Limitations

The UAT detailed simulation software is written in C and allows for horizontal, constant-velocity motion of the aircraft in the scenario, if the user so chooses. The simulation reads in the inputs specifying the particular case to be run, generates all of the ADS-B transmissions and interference, calculates levels and times of arrival for these transmissions, and determines the corresponding message error rates for each ADS-B transmission by all aircraft within line of sight of the victim receiver. This information is then written to an output file, one entry line for each ADS-B transmission, which is then analyzed by post-simulation software. Each of the effects listed in Section K.1.2 will now be discussed in turn.

- Propagation and cable losses. The UAT simulation calculates the free-space propagation loss for each transmission, using the range between transmitter and receiver at the time of transmission. There is also a receiver cable loss of 3 dB incorporated in the calculation. An optional transmit cable loss is also included in the simulation, but since the transmit powers have been defined at the antenna, the transmit cable loss has been set to zero for this study.
- Antenna gains. The antenna gain model included in the UAT simulation is described in Section K.2.

- Propagation delays. Calculation of the propagation delay incurred by the signal in traversing the free space between transmitter and receiver has been included in the UAT simulation

- Co-channel interference. In certain geographic areas, UAT may have to co-exist with transmissions from DME/TACAN and Link 16 sources. Link 16 scenarios have been provided in cooperation with the USDOD and have been applied to all of the performance analysis shown in this document. Various DME/TACAN scenarios provided by Eurocontrol have been applied to Core Europe analysis. In all cases, every attempt was made to provide conservative estimates of the co-channel interference environment. (see Appendix G for more detailed explanation of the interference environment.)

- Co-site interference. Co-site transmissions of UAT messages, DME interrogations, Mode S interrogations and replies, whisper-shout interrogations, and ATCRBS replies are all modeled as interference in the UAT simulation. All of these are treated as interference that completely blocks UAT reception; therefore, it is assumed that no UAT reception may occur during any of these co-site transmissions (including a "ramp-up" and "ramp-down" period added to the beginning and end of each co-site transmission). (see Appendix G for more detailed explanation of the interference environment)

- Multiple self-interference sources. Although the UAT transmission protocol specifies that a transmission begin on one of a fixed number of message start opportunities, the propagation delay described above will cause the arrivals of messages at the victim receiver to be quasi-random. There may be a number of messages overlapping one another, and these overlaps will be for variable amounts of time. This interference is accounted for in the multi-aircraft simulation. Multiple UAT interferers are treated in the receiver performance model by combining their interference levels in a way consistent with bench test measurements. The simultaneous presence of UAT interference, co-channel interference, and self-interference is treated in a detailed fashion by the model. Further discussion is presented in Section K.3. Since the UAT system description specifies that the ground uplink transmissions occur in a separate, guarded time segment than the air-to-air transmissions, FIS-B should not interfere with the ADS-B transmissions of the aircraft. Therefore, the simulation does not model this data load for the ADS-B performance assessment.

- Alternating transmissions. The model simulates the alternating transmission sequence specified for A1, A2, and A3 equipage, TTBBTTBB…, where T = top and B = bottom. For A0 equipage, the model simulates transmission from a bottom antenna.

- Receiver diversity. For A2 and A3 equipage, the model simulates receiver diversity by calculating the message error rate at both the top and bottom receive antennas and calculating the joint reception probability. For A1 equipage, the model simulates the single-receiver dual-antenna configuration by switching the receive antenna alternately between top and bottom each successive second. For A0-equipped aircraft, reception is only permitted from a bottom antenna.

- Transmit power variability. The transmit power for an aircraft is chosen from a uniform distribution given by the limits specified for the aircraft equipage. The transmit powers for different equipage levels are defined in Sections 2.1.11 and 2.1.12.

- Receiver retriggering. The UAT simulation checks each individual ADS-B Message arriving at the victim receiver for its message error rate. This procedure amounts to allowing for retriggering in the receiver, i.e. the potential for the receiver to switch from receiving a message to a stronger message signal that arrives after the start of the reception of the first message.

- Receiver performance model. The receiver performance model used in the UAT simulation is based on experimental data collected on special UAT receivers that were provided for that purpose. These receivers were modified to be compliant with the requirements specified in this document. Both the 0.8 MHz filter specified for A3 equipage and the 1.2 MHz filter used in A0-A2 equipage were tested. The results of the bench testing and the receiver performance model are described in Section K.3. The sensitivity of the receiver is assumed to be –93 dBm. This represents the signal level at which 10% error rate is achieved in the absence of interfering signals. This parameter was validated in the simulation.

- Message transmission sequence and content. Section 2.2 defines the types of messages, their content, and the sequence of messages transmitted for each category of aircraft equipage. See the table in Section K.4.4 for a summary of all the types of information transmitted by each equipage class. The information content transmitted by each aircraft is explicitly modeled by the multi-aircraft simulation.

- Ground receiver assumptions. For Air-Ground studies that follow, several assumptions were changed for the special case of the ground receiver. There was assumed to be no co-site interference, but the same Link 16 Baseline interference used in airborne receptions was included. The receiver sensitivity used was –96 dBm. The antenna gain was slightly different, in that it used an omni-directional TACAN antenna, with elevation gain based on measured data. The ground antenna uses a 1.2 MHz filter only. In certain cases, a 3-sector antenna is used.

K.2 TLAT Antenna Model

The TLAT antenna gain model contains two components, to accommodate both the elevation pattern variation, as well as non-uniformity in the azimuth pattern. A fixed component is based on the elevation angle between the two aircraft. An additional random component is used to characterize the real-world effects of fuselage blockages in the azimuth pattern. The distributions describing these two components are based on measurement data and are intended to provide sufficient statistical variability to capture a wide variety of antenna installations on aircraft. The two components in dB units are summed to create the total antenna gain pattern for each of a given pair of aircraft.

Figure K-1 shows the elevation gain for a top-mounted antenna. The same gain is used for a bottom-mounted antenna, with the pattern inverted vertically. The antenna has a peak gain of 4.1 dBi at an elevation angle of 26 degrees. For best resolution of display, this figure is limited to a minimum gain of –40 dB.

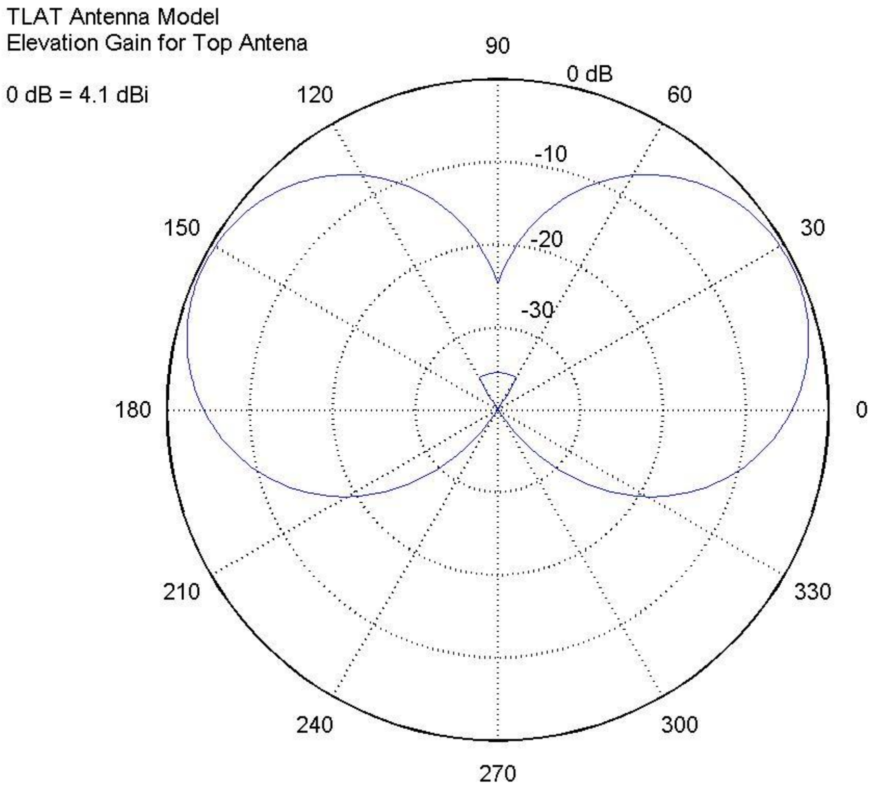


Figure K-1: TLAT Antenna Model Elevation Gain

The variation in gain due to azimuth pattern effects is based on the probability distribution shown in the Figure K-2.

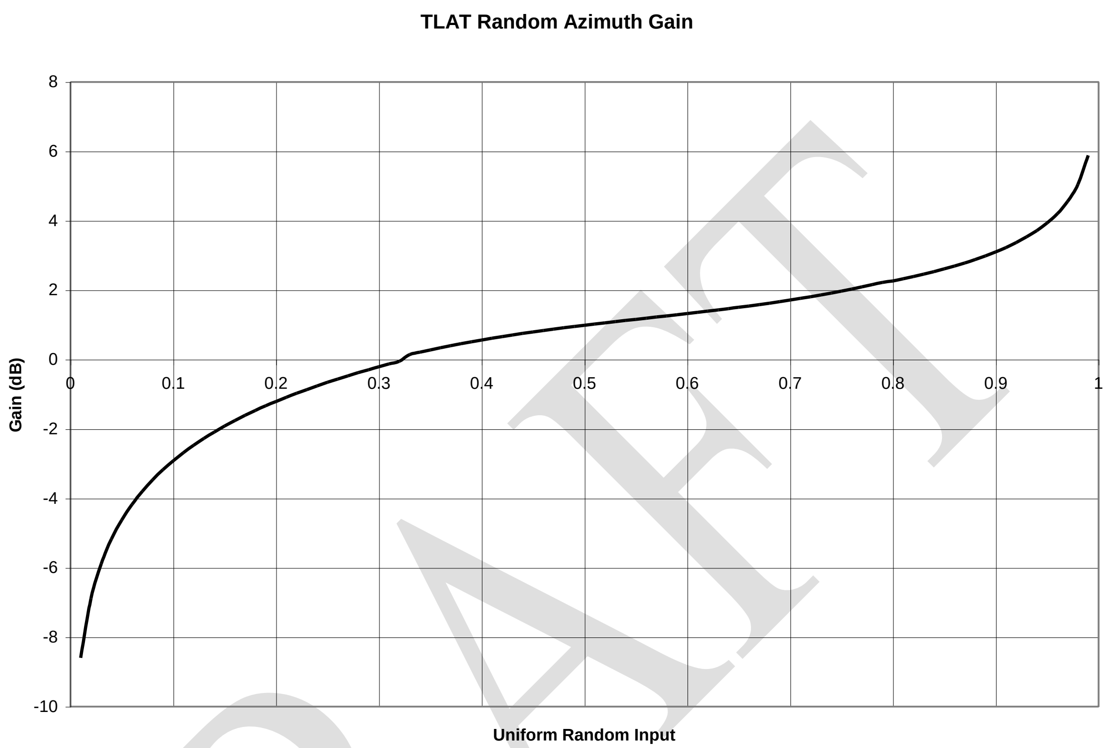


Figure K-2: TLAT Random Azimuth Gain

A uniform random variable on the x-axis is used to select a value that characterizes the azimuth variation in antenna gain. Note that approximately 1/3 of the time, the variation can be a loss of up to 8.6 dB. Approximately 2/3 of the time, the variation is an additional gain of up to 6 dB. Note that the median gain in the azimuthal direction is 1 dB.

The elevation and azimuth angles to other aircraft are constantly changing. To simulate this, the TLAT antenna model allows for a new random selection of the azimuth gain variation each time the relative azimuth between a pair of targets is altered by more than 5 degrees. This antenna gain model was used in the performance assessments of each of the three links treated in the TLAT report.

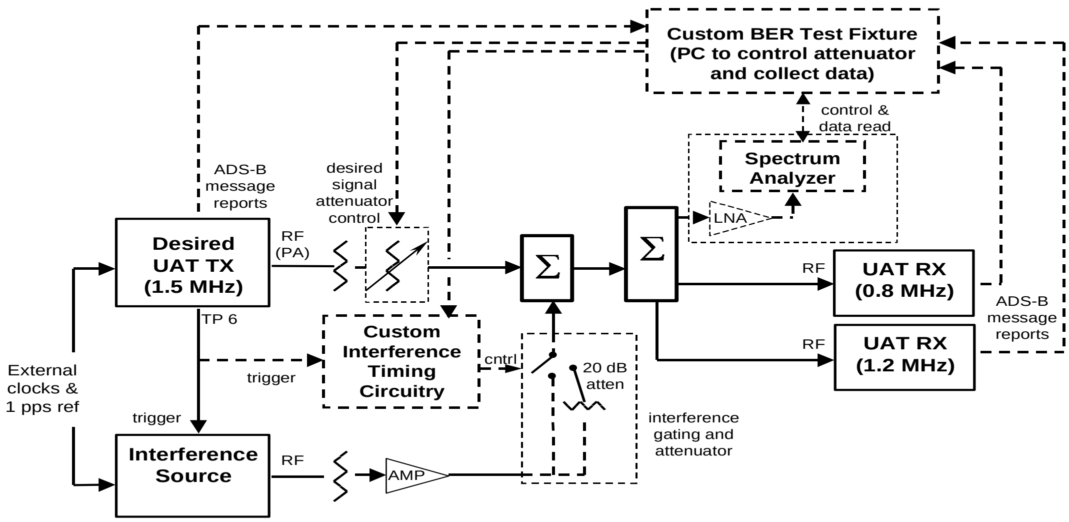
K.3 Receiver Performance Model

K.3.1 Measured Data

Measurements of the Bit Error Rate (BER) receive performance were made on two “Pre-MOPS” UAT transceivers, one with a nominal 1.2 MHz bandwidth and one with a nominal 0.8 MHz bandwidth. Simultaneous measurements were made while the same input signal was applied to both units. The input signal consisted of a Signal of Interest

(SOI), from a nominal 1.5 MHz bandwidth UAT transceiver, summed with an interference signal. The SOI was a Long ADS-B Message.

A BER test fixture was created in order to allow measuring the BER impact of pulsed interference as a function of time relative to the start of the pulse. It included circuitry for gating the test interference signal off during the UAT message synchronization header, and software for determining the position of every bit error in every received message payload or FEC. The test setup is shown in Figure K-3



Fixed attenuators and amplifiers are adjusted to provide:

- a desired-signal level at the UAT RX inputs of -20 dBm when signal attenuator is set to 0 dB, and

- a peak interference level at the UAT RX inputs of -20 dBm when interference is gated on and the 20 dB interference attenuator is bypassed.

Figure K-3: Test Setup for measuring BER

The interference signals used for the BER tests were the following:

1. No external interference (internal receiver noise only). SOI level was varied to achieve various Signal-to-Noise Ratios (SNRs). Note that SNR depends on the noise bandwidth used, which will be defined later in this section.
2. White Gaussian interference. SOI level was varied to achieve various SNRs.
3. A single UAT (1.5 MHz bandwidth) interferer. The levels of both SOI and interferer were independently varied to achieve various SNRs and various Interference-to-Noise Ratios (INRs).
4. A simulated combination of multiple UAT (1.5 MHz bandwidth) interferers. An Arbitrary Waveform Generator (AWG) produced these combination signals by playing back a variety of input data files. The input data files were generated from a set of single-UAT files recorded by a digital oscilloscope. These files were adjusted in level, offset in time and summed together to create the multi-UAT scenarios of interest, specifically:
   - Two UATs, both at the same level, and at various INRs.
   - Two UATs at high INR and at various relative levels.

- Three, five and ten UATs, all at the same level and at high INR.
- (As a check on the fidelity of the simulation, a single UAT at high INR was also simulated and measured and the BER was compared with the corresponding BER measured using an actual UAT at high INR. The discrepancy between the two was found to be less than 0.7 dB.)

5. A DME interferer emitting pulse pairs with 12-µsec separation. DME signals at two frequencies were used, at the SOI center frequency and one MHz above. The level of the SOI was varied to achieve a wide range of Signal-to-Interference Ratios (SIRs). The variation of BER with time during and shortly after the DME pulse pair was measured.
6. A Link 16 interferer, at various frequencies, at the SOI center frequency, three MHz higher, 6 MHz higher and so on up to 21 MHz higher. It was assumed that the corresponding lower frequency response would be similar. The level of the SOI was varied to achieve a wide range of Signal-to-Interference Ratios (SIRs). The variation of BER with time during and shortly after the Link 16 pulse pair was measured.

For all of the above interference conditions, bit errors were measured at every position in the message payload and FEC. Results from multiple messages were averaged together. Enough messages were measured to permit determining BER values down to about 10^{-5}. For the continuous interference conditions (no external interference or Gaussian noise), bit errors from all received payload and FEC bit were averaged together. For the UAT interferers, bit errors from all payload and FEC bits during interference transmission were averaged together.

For the pulsed interference conditions (DME and Link 16 signals), bit errors were averaged independently for each time offset after the start of the interference pulse (to a resolution of 0.5 UAT bit periods). This enabled determining BER values as a function of SIR, time and frequency offset. Sample plots of measured BER data for DME and Link 16 interferers are shown in Figure K-4 through Figure K-6.

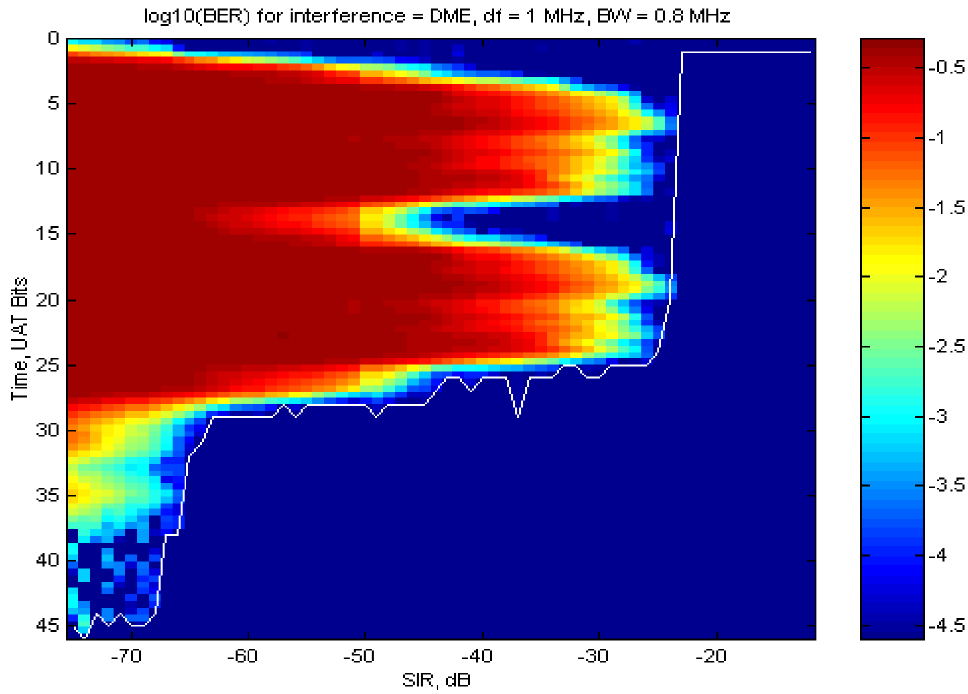


Figure K-4: **BER Due to DME interference**

(Frequency offset = 1 MHz, Receiver bandwidth = 0.8 MHz. log10 {BER} encoded as color)

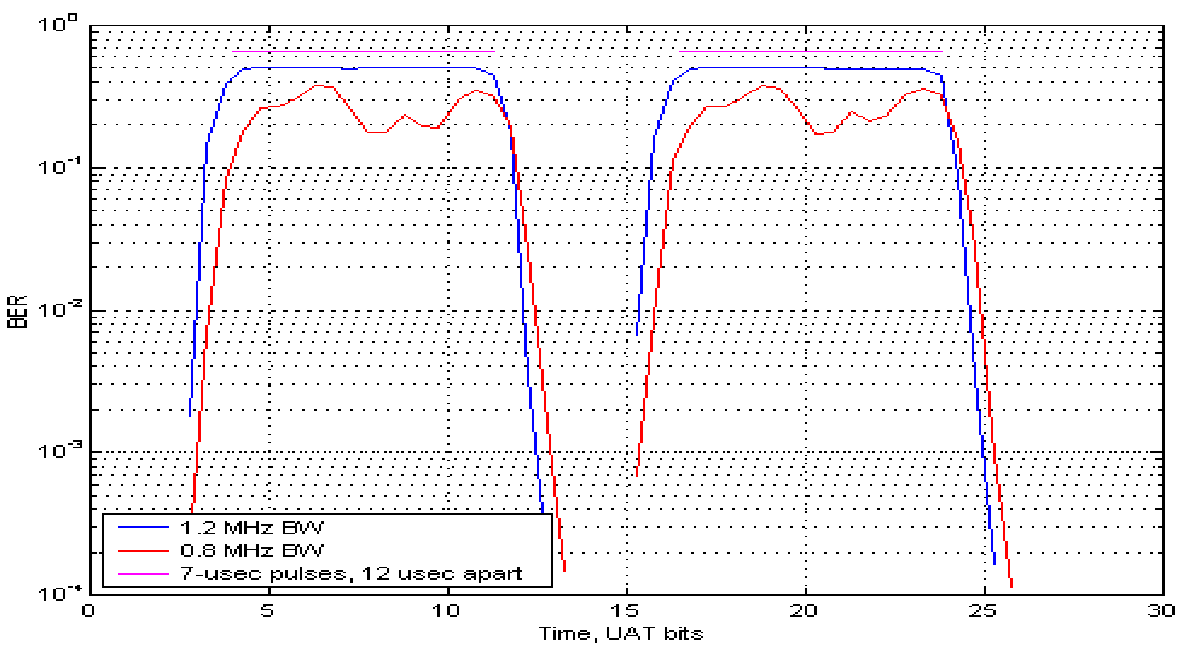
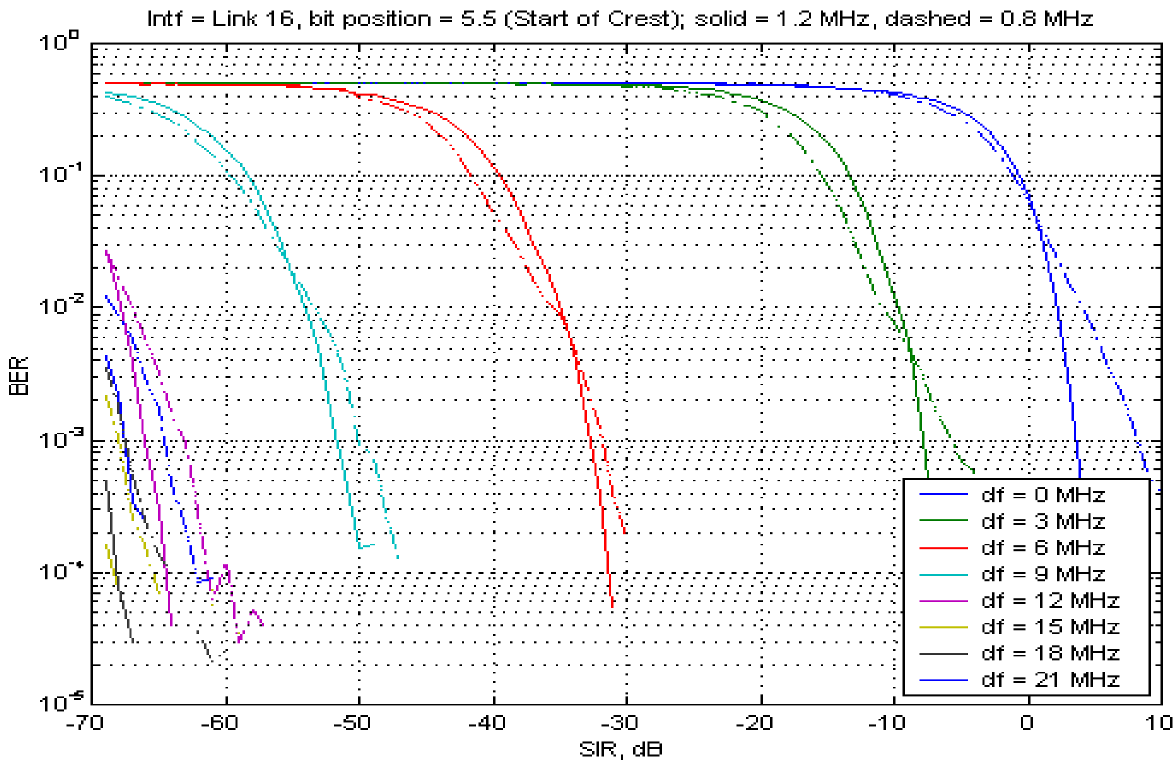


Figure K-5: **BER Due to DME Interference**

(Frequency offset = 1 MHz, Vertical Slice Through Color Plots Like Figure K-4 at SIR = -40 dB)



<u>Figure K-6:</u> Link 16 Interference

(Horizontal Slice Through Color Plots Like Figure K-4 at Bit Position 5.5)

K.3.2 Receiver Model Assumptions

Based on the above BER measurements, a computer program (the "UAT BER Model") was designed to estimate MOPS-compliant UAT BER performance under arbitrary combinations of UAT, DME and Link 16 interference. The UAT BER Model is incorporated within the Multi-Aircraft UAT Simulation (MAUS), which uses the BER estimates to evaluate the reception success of UAT messages.

The following simplifying assumptions were made in the UAT BER Model:

1. The variation of BER with Signal-to-Interference-Plus-Noise Ratio (SINR) for any given interference scenario is specified by just three parameters, B0, B1 and B2. In terms of the variable $\log_{10}(-\log_{10}(2*BER))$, called "llBER" in the following, every BER(SINR) relationship is specified by a 3-segment piecewise linear llBER Vs. SINR curve (for SINR specified in dB), as shown in Figure K-7. The parameters B1 and B2 are the SINR values at the llBER values of -0.5 for the first segment and +0.5 for the 3rd segment. The 1st and 3rd segments intersect at SINR = B0 with an llBER value of 0. The second segment simply rounds off the knee at B0 by connecting the points at llBER = -0.1 and +0.1. The corresponding BER Vs. SINR curve is shown in Figure K-8.

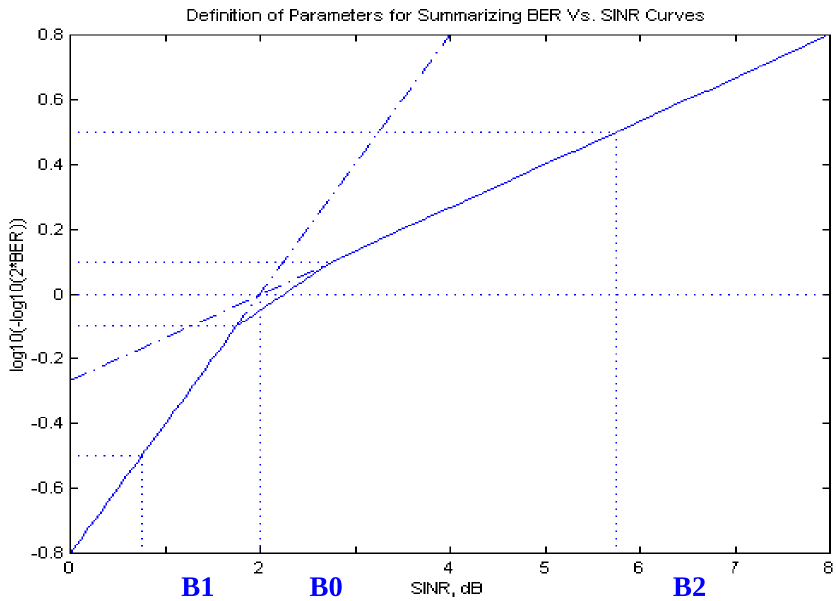


Figure K-7: **Assumed Piecewise Linear llBER Vs. SINR Curve (Typical)**

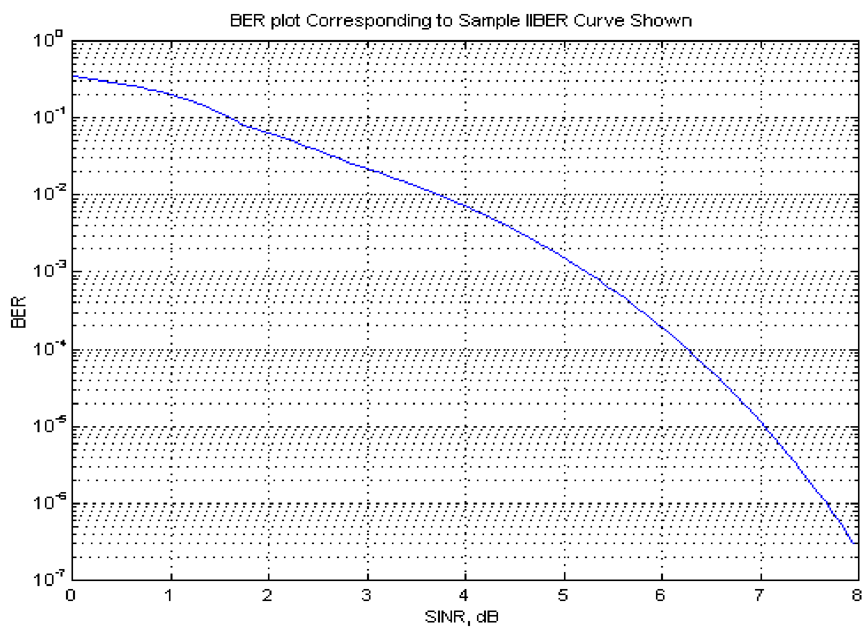


Figure K-8: **BER Vs. SINR Curve Corresponding to Figure K-7**

2. For multiple UAT interferers, the BER is determined only by the SINR, the INR, and the difference in level, dI, between the 2 strongest UAT interferers. If INR<<0 (INR specified in dB), BER is unaffected by dI. If there are more than two simultaneous UAT interferers, the 3rd strongest and all weaker ones have the same impact as noise sources of the same power levels (measured in a noise bandwidth yet to be specified), so their powers are understood to be included in the noise term for computing INR. The interference term in INR is the power sum of the two strongest interferers only.

3. For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with INR for any given value of dI follows a 4-parameter sigmoid curve of the form:

$$B = a + b \cdot \frac{INR - d}{\sqrt{c^2 + (INR - d)^2}} \ ,$$

   where the parameters a, b, c and d are given by:

   - a = {B(INR>>0) + B(INR<<0)}/2,
   - b = {B(INR>>0) - B(INR<<0)}/2,
   - d = INR at which B = a, and
   - c = b divided by the slope of the B(INR) curve at INR = d.

4. For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with dI follows a 3-parameter sigmoid curve of the form:

$$B = a + b \cdot \frac{dI}{\sqrt{c^2 + dI^2}} \ ,$$

   where the parameters a, b, and c are given by:

   - a = B(dI=0),
   - b = {B(dI>>0) - B(dI=0)}, and
   - c = b divided by the slope of the B(INR) curve at dI = 0.

5. Assumptions (2, 3 and 4) together mean that any of the three B parameters for any combination of Gaussian noise and multiple UAT interference may be specified by eight parameters (a0,b0,c0,d0 to describe B(INR) when dI>>0; b1,c1,d1 to describe B(INR) when dI=0; and c2 to describe B(dI) when INR>>0. The requirement of continuity of B(INR,dI) determines the remaining parameters:

   - a1 = (a0 - b0) + b1,
   - a2 = B(INR) for dI = 0, and
   - b2 = {B(INR) for dI>>0} - a2.

6. The BER impact of combining DME with other UAT interference and with receiver noise is the same as if the DME interference on any bit were replaced by an additional UAT interferer with a level such that it alone would produce the same BER as the DME interference alone.

7. The BER impact of combining Link 16 with other UAT interference and with receiver noise is the same as if the Link 16 interference on any bit were replaced by an additional Gaussian noise interferer with a level such that it alone would produce the same BER as the Link 16 interference alone.

With the above assumptions, BER is determined for every combination of Gaussian noise, multiple UAT, DME and Link 16 interference, by SINR, INR and dI, as defined above, together with 24 parameters. These parameters are then determined for each of the two Pre-MOPS UAT receive bandwidths as the values that best fit the measured Gaussian noise plus UAT interference data.

One additional parameter, the appropriate noise bandwidth must also be specified. This is conveniently represented as dN, the increase in effective noise power over that computed for a 1 MHz bandwidth. Initially, dN was chosen to equalize the SNR required for a given BER when interference was pure Gaussian noise with the SIR required when interference was ten equal-power UAT interferers. Subsequently, it was found that a better overall fit could be obtained with dN about 2 dB higher (bandwidth 60% larger). The dN values used are +1.5 dB for the 1.2 MHz bandwidth UAT and 0 dB for the 0.8 MHz bandwidth UAT.

K.3.3 Receiver Model Accuracy

Figure K-9 through Figure K-12 show the measured and modeled BER Vs. SINR curves for four sample subsets of the measured data. Figure K-11 and Figure K-12 show the BER modeling error for all the Gaussian noise plus UAT interference data so as to indicate the equivalent power error in dB. The BER-to-power curve used for Figure K-13 and Figure K-14 is the curve appropriate for pure Gaussian noise interference. With this measure, it can be seen that most of the data is modeled to + or – 1.5 dB accuracy.

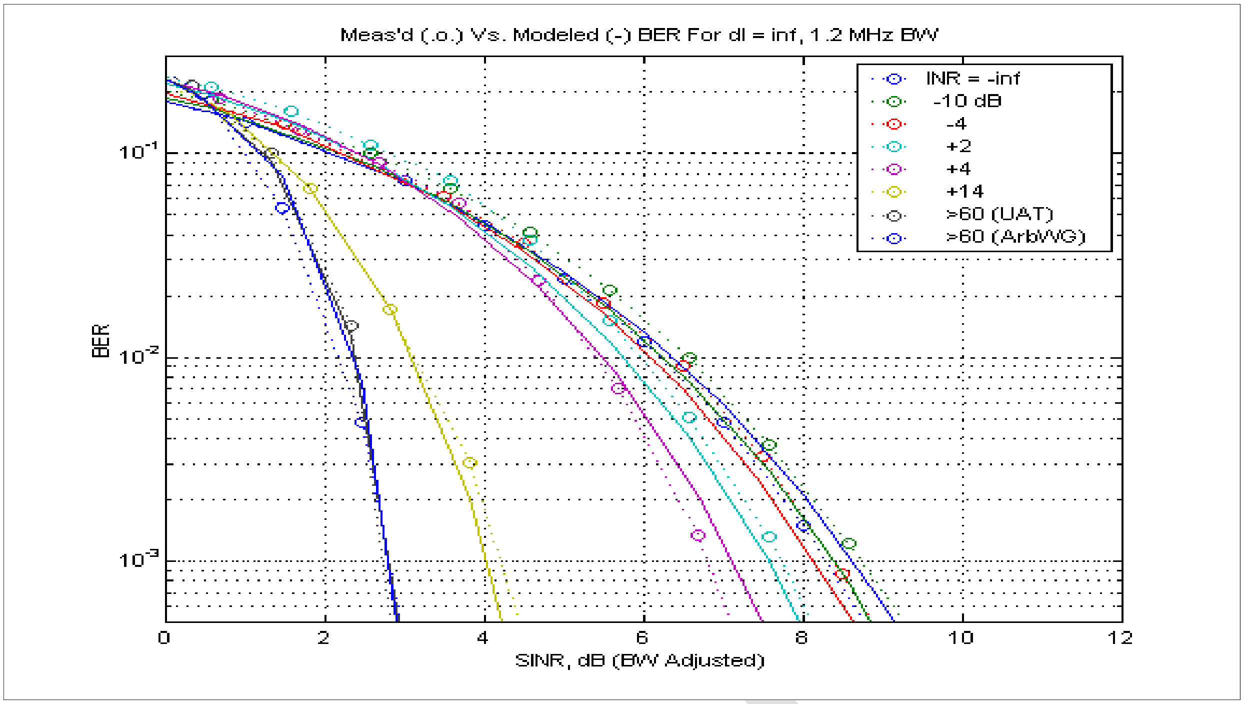


Figure K-9: **Gaussian Noise + Single UAT, 1.2 MHz Receiver**

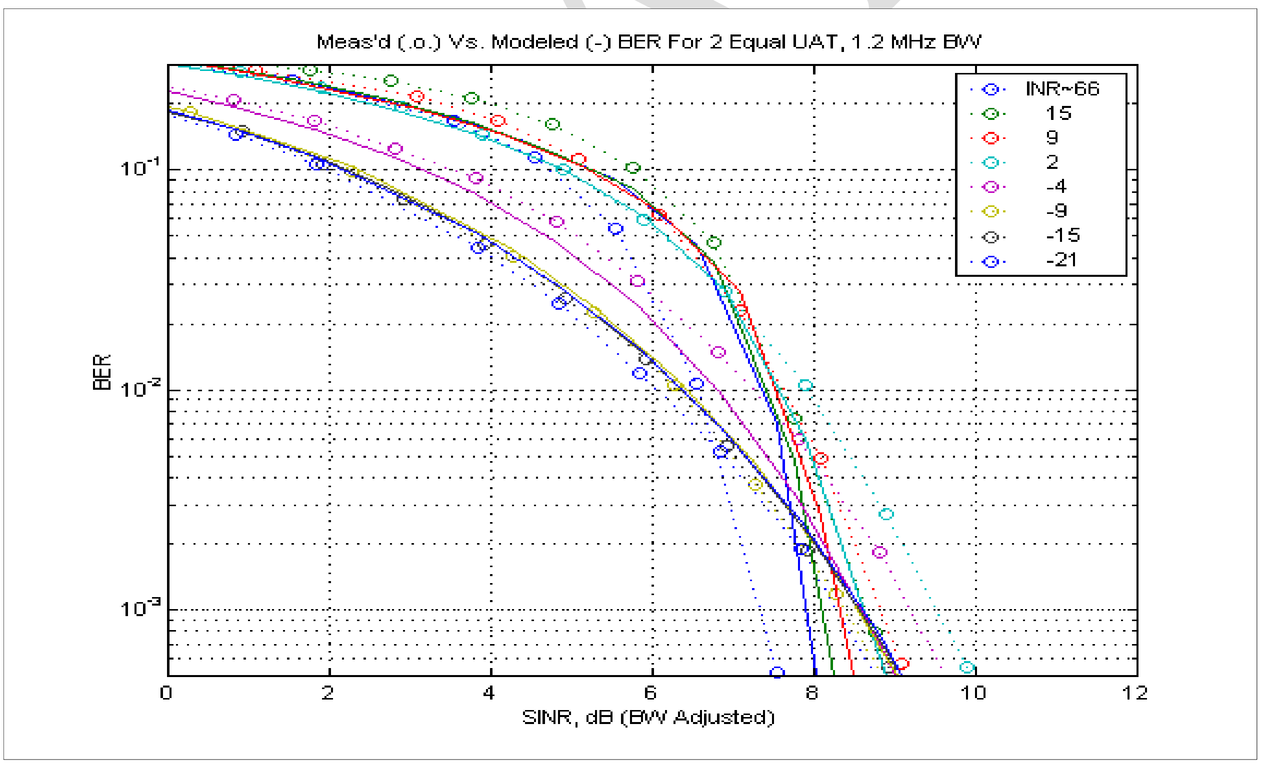


Figure K-10: **Gaussian Noise + Two Equal UATs, 1.2 MHz Receiver**

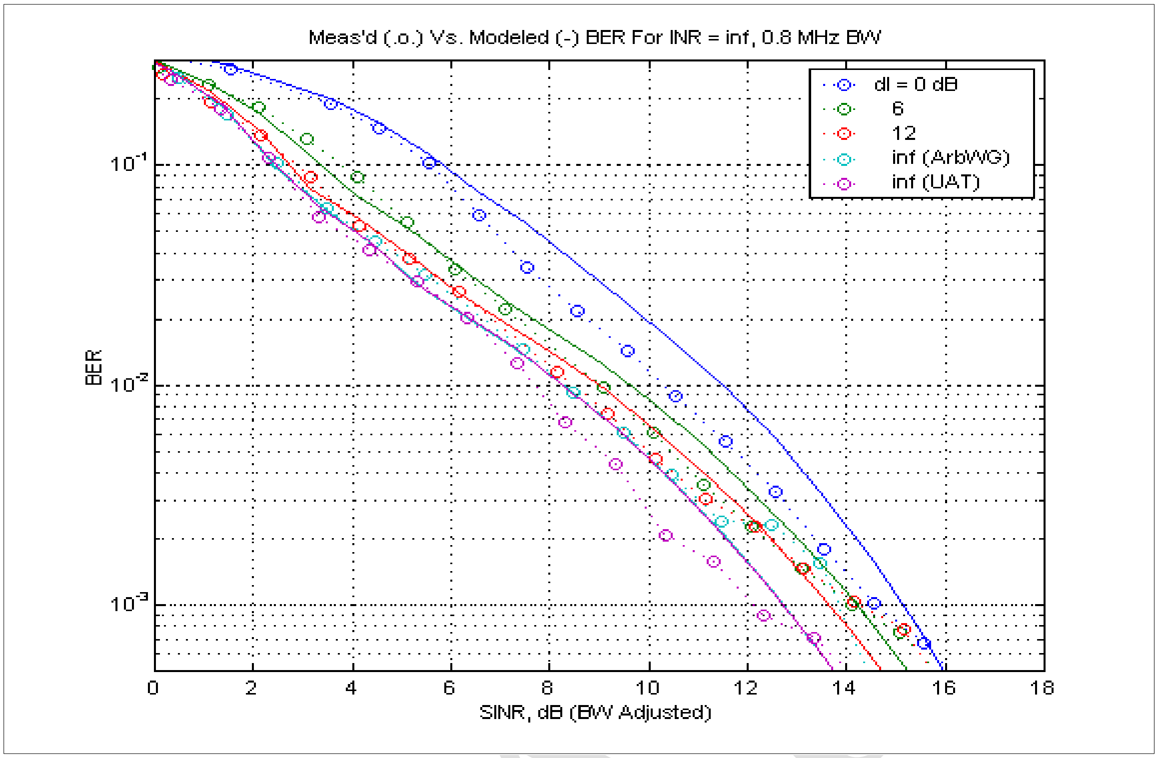


Figure K-11: Two Unequal UATs, INR >> 0 dB, 0.8 MHz Receiver

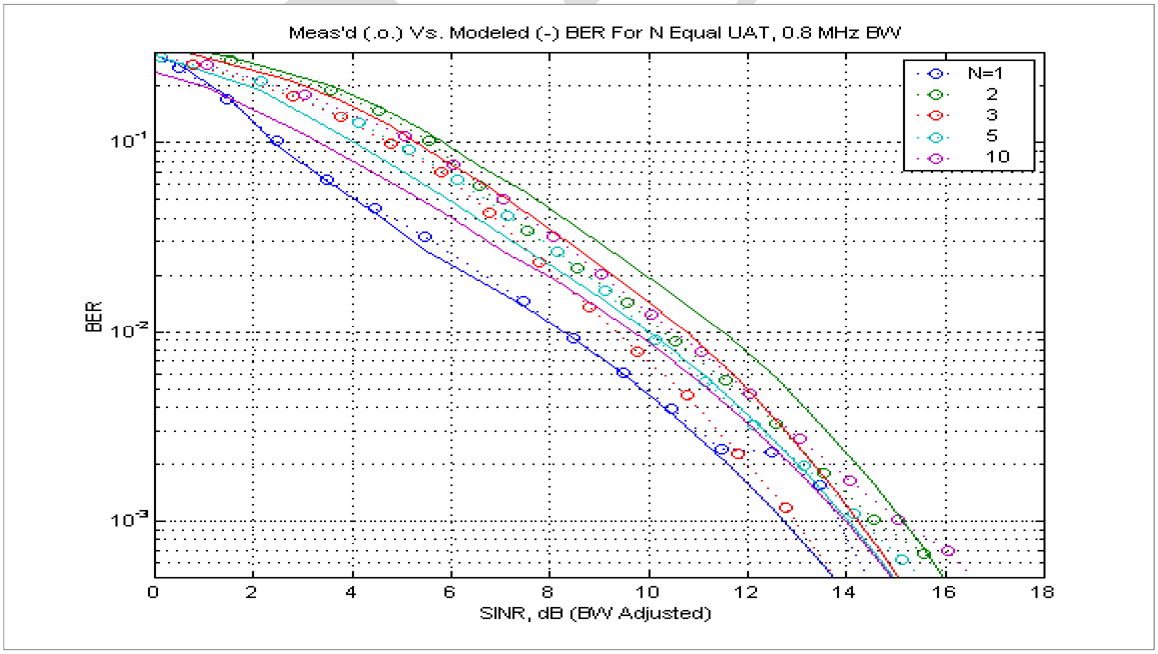


Figure K-12: N Equal UATs, INR >> 0, 0.8 MHz Receiver

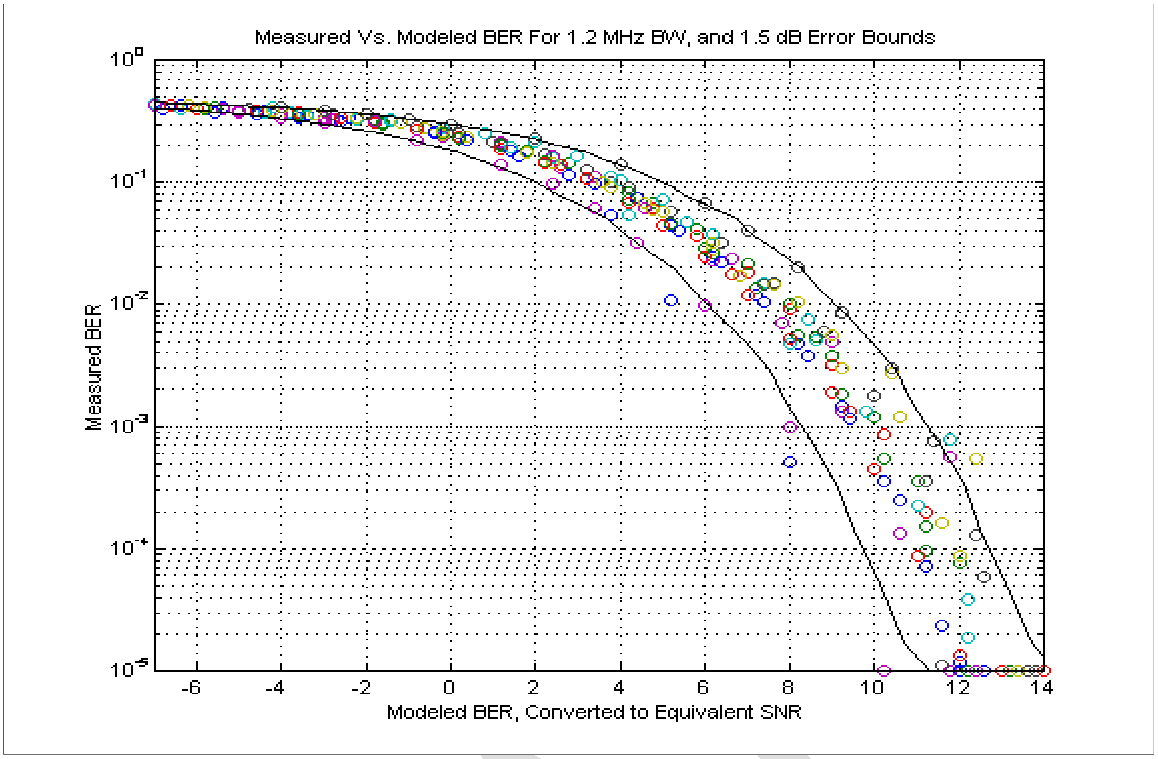


Figure K-13 **Model Errors for All Data, 1.2 MHz Receiver**

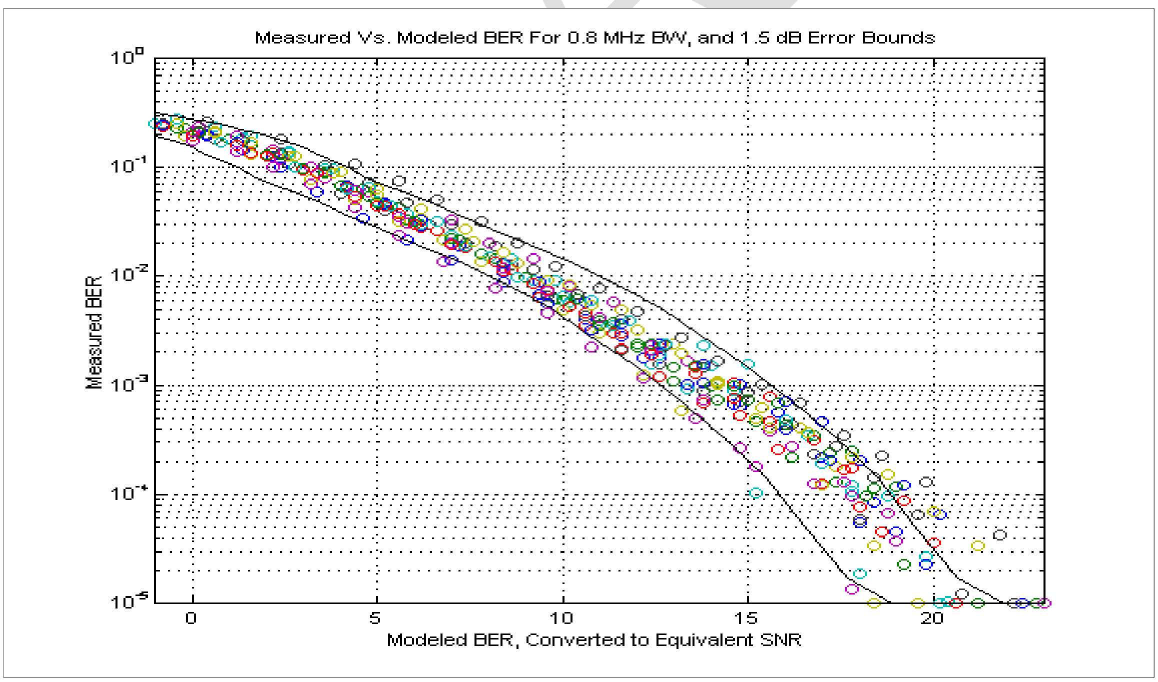


Figure K-14: Model Errors for All Data, 0.8 MHz Receiver

K.4 Multi-Aircraft Simulation (MAUS) Results

K.4.1 Los Angeles Basin 2020 (LA2020)

This scenario is based on the LA Basin 1999 maximum estimate. It is assumed that air traffic in this area would increase by a few percent each year until 2020, when it would be 50 % higher than in 1999. The distribution of aircraft in the scenario is based on approximations of measured altitude and range density distributions.

The following assumptions are made for the airborne and ground aircraft and ground vehicles for the LA Basin 2020 scenario:

- The density of airborne aircraft is taken to be:
  - Constant in range from the center of the area out to 225 nautical miles (5.25 aircraft/NM), (i.e., the inner circle of radius one NM would contain approximately five aircraft, as would the ring from 224 to 225 NM) and
  - Constant in area from 225 NM to 400 NM (.00375 aircraft/NM^2).
- There are assumed to be a fixed number of aircraft on the ground (within a circle of radius 5 NM at each airport), divided among LAX, San Diego, Long Beach, and five other small airports, totaling 225 aircraft. Half of the aircraft at each airport were assumed to be moving at 15 knots, while the other half were stationary. In addition, a total of 300 ground vehicles are distributed at these airports as well.
- The altitude distribution of the airborne aircraft is assumed to be exponential, with a mean altitude of 5500 feet. This distribution is assumed to apply over the entire area.
- The airborne aircraft are assumed to have the following average velocities, determined by their altitude. The aircraft velocities for aircraft below 25000 feet are uniformly distributed over a band of average velocity +/- 30 percent.
  - 0-3000 feet altitude 130 knots
  - 3000-10000 ft 200 knots
  - 10000-25000 ft 300 knots
  - 25000-up 450 knots
- The aircraft are all assumed to be moving in random directions.
- ADS-B MASPS equipage class A0 (and A1L as defined in §2.1.11) are restricted to fly below 18000 feet. All other aircraft are assumed to be capable of flying at any altitude. The aircraft in the LA2020 scenario are assumed to be in the following proportions:
  - A3 30%
  - A2 10%
  - A1 40%
  - A0 20%

For the LA2020 scenario, the A1 equipage was assumed to include two subclasses: A1H (high) and A1L (low). These subclasses are defined in Section 2.1.11.

The scenario for the 2020 high density LA Basin case contains a total of 2694 aircraft: 1180 within the core area of 225 NM, 1289 between 225-400 NM, and 225 on the ground. This represents a scaling of the estimated maximum 1999 LA Basin levels upward by 50 percent. Of these aircraft, 471 lie within 60 NM of the center. (This includes aircraft on the ground.) Around ten percent of the total number of aircraft are above 10000 ft in altitude, and more than half of the aircraft are located in the outer (non-core) area of the scenario.

An attempt was made to at least partially account for the expected lower aircraft density over the ocean. In the third quadrant (between 180 degrees and 270 degrees), for distances greater than 100 NM from the center of the scenario, the density of aircraft is reduced to 25 % of the nominal value used. The other 75 % of aircraft that would have been placed in this area are distributed uniformly among the other three quadrants at the same range from the center. This results in relative densities of 1:5 between the third quadrant and the others.

The ADS-B MASPS requirements for ADS-B air-to-air surveillance range and report update interval are used to assess how the candidate links perform in relation to the free flight operational enhancements identified by the SF21 Steering Committee. These requirements specify the minimum range for acquisition of the state vector and the mode-status and TC and TS reports where applicable, as well as the maximum update periods allowed for this information. (See RTCA Document No. DO-242A, §3.3.3.1.4)

Eurocontrol criteria augment those of the ADS-B MASPS with specific air/ground performance characteristics. These air/ground criteria specify ranges, use of intent information (TC and TS reports), and update times. Additionally, Eurocontrol criteria extend existing ADS-B MASPS air-to-air requirements for long-range deconfliction.

Results are presented as a series of plots of 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. Each point on the plot represents the performance of Aircraft/Vehicles within a 10 NM bin centered on the point. The ADS-B MASPS requirements are also included on the plots for reference. Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types. In addition, performance of different transmit-receive pairs is shown at several different altitudes, where appropriate. The first altitude considered is “high altitude”, which is defined to be the aircraft near the center of the scenario with the largest number of other aircraft in view. This is invariably an aircraft in the range of FL 350 – FL 400, and applies to A3, A2, and A1H equipage. The other altitude used is FL150 at the center of the scenario, and applies to all equipage classes.

Results for all of these cases are shown in Figure K-15 through Figure K-41 and conclusions are presented below. The ADS-B MASPS requirements for state vector, and preliminary requirements for TSR, and TCR+0 updates are shown as black lines on the plots. Although results for TCR+1 transmissions are shown, there are currently no requirements that have been set for TCR+1 reception. The ADS-B MASPS specify that the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. This does not include all of the potential Eurocontrol requirements. Air-ground requirements are defined to 150 NM for all aircraft equipage classes. Performance in compliance with MASPS requirements is indicated by results that are below the black line. Note that the ADS-B MASPS range limitations for A3 transmitters are indicated on the plots by a solid vertical line, while desired range limitations are indicated by a dashed vertical line.

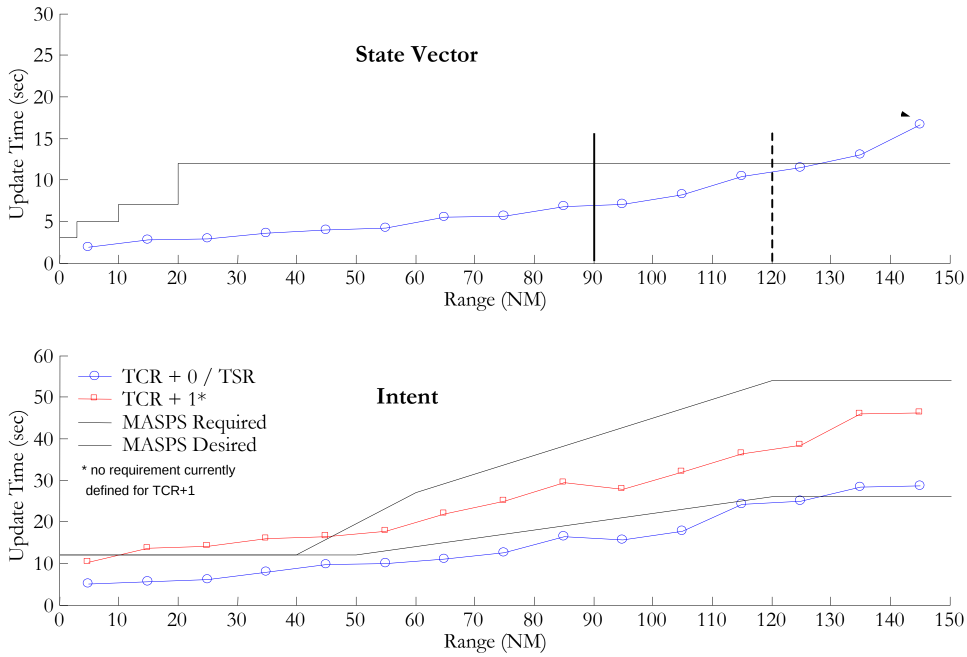


Figure K-15: **A3 Receiver in LA2020 at High Altitude Receiving A3 Transmissions**

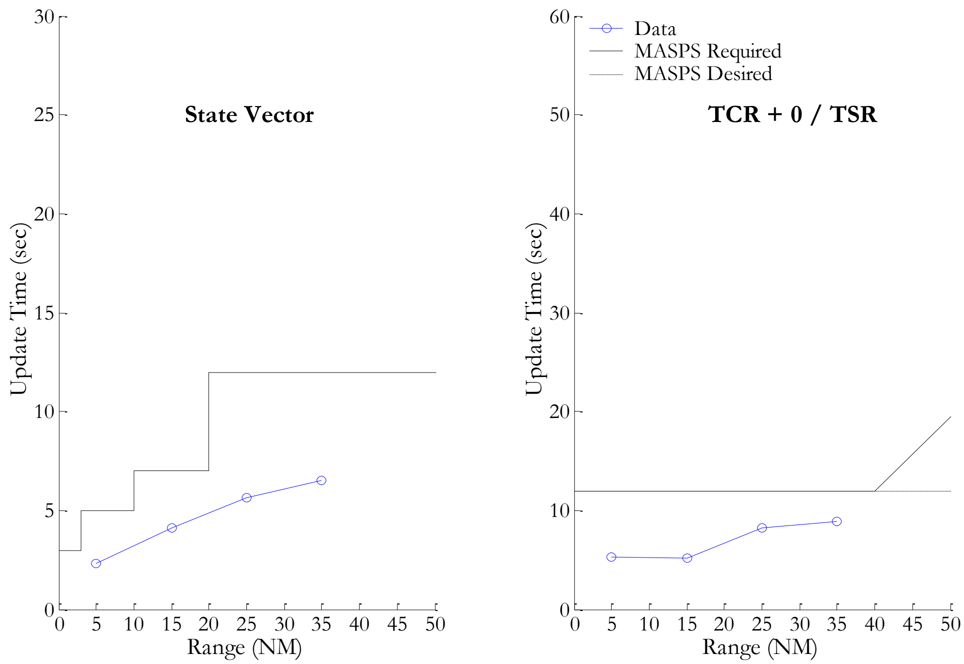


Figure K-16: **A3 Receiver in LA2020 at High Altitude Receiving A2 Transmissions**

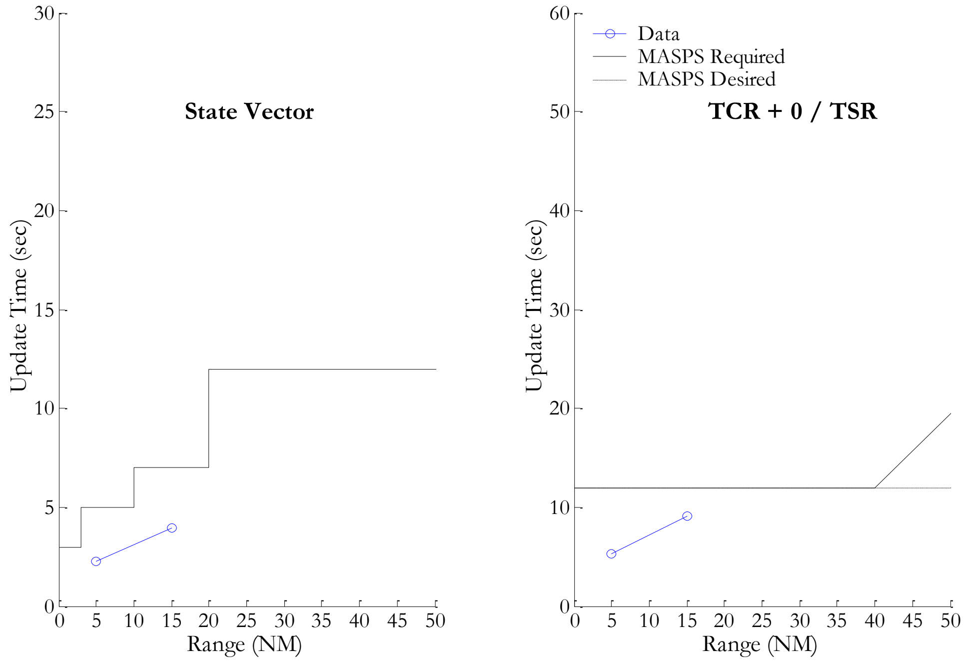


Figure K-17: A3 Receiver in LA2020 at High Altitude Receiving A1H Transmissions

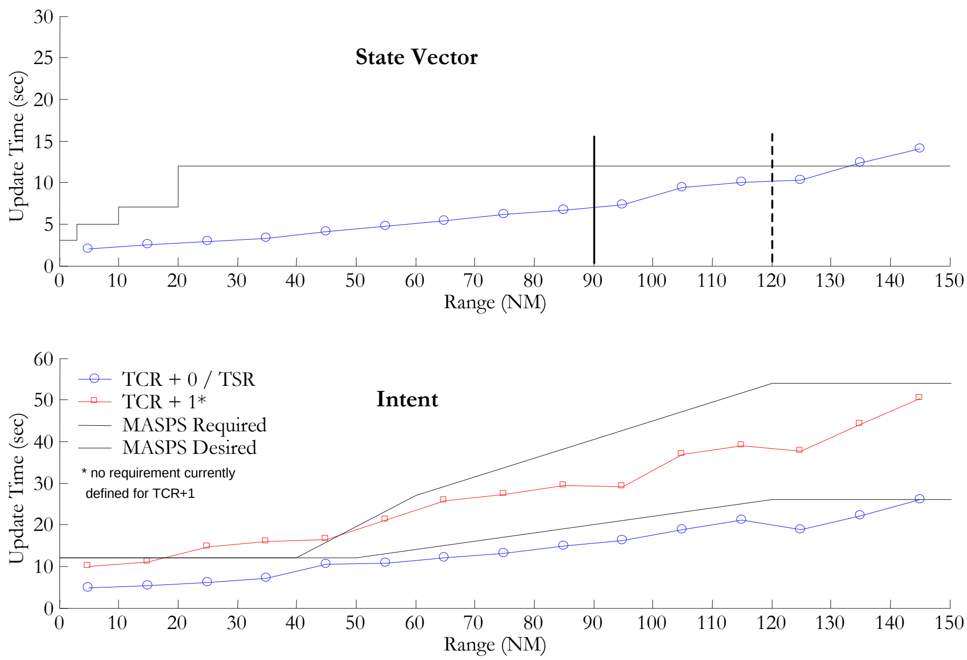
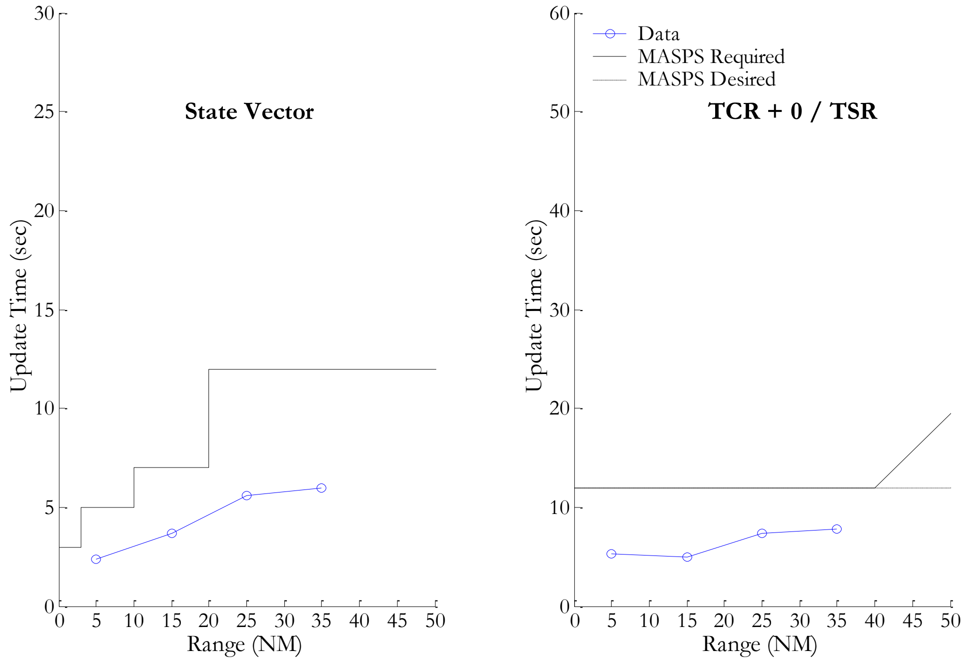
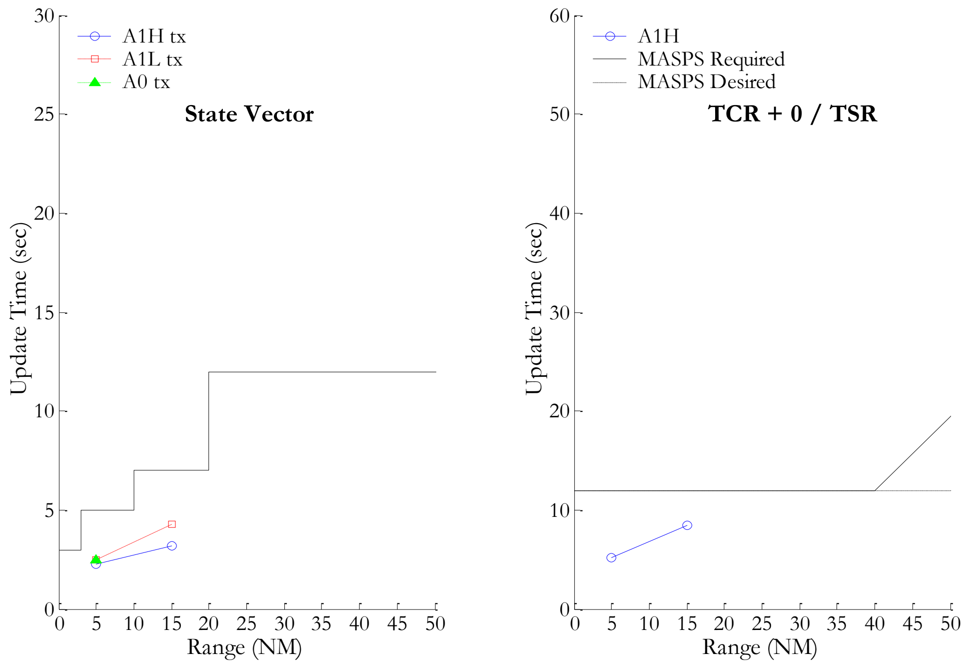


Figure K-18: A3 Receiver in LA2020 at FL 150 Receiving A3 Transmissions



<u>Figure K-19:</u> A3 Receiver in LA2020 at FL 150 Receiving A2 Transmissions



<u>Figure K-20:</u> A3 Receiver in LA2020 at FL 150 Receiving A1 and A0 Transmissions

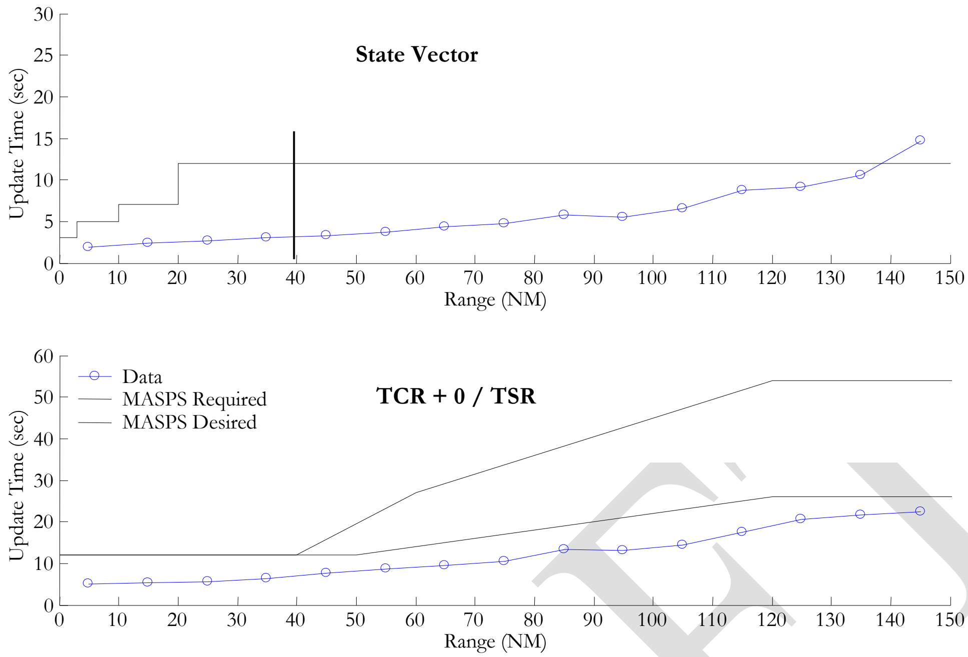


Figure K-21: A2 Receiver in LA2020 at High Altitude Receiving A3 Transmissions

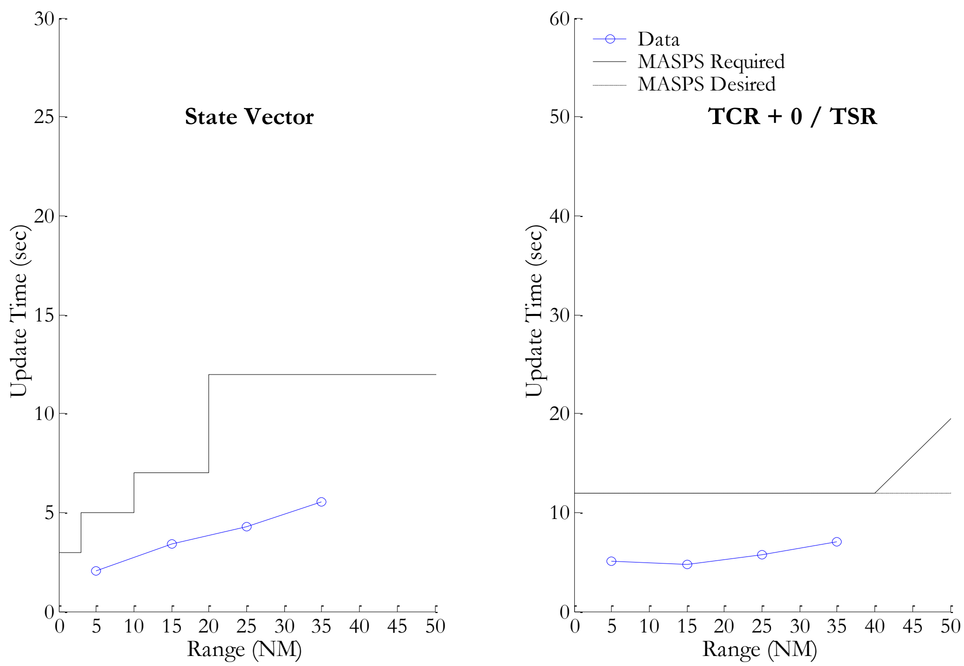
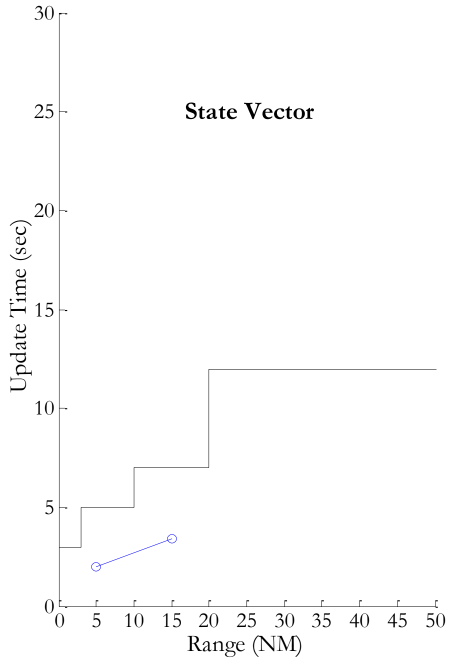
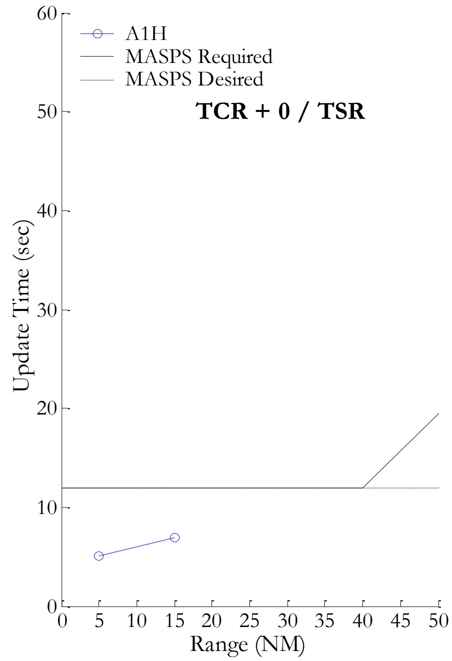
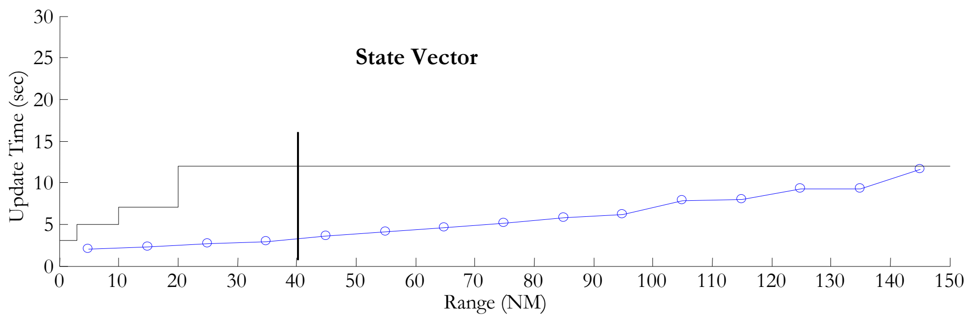


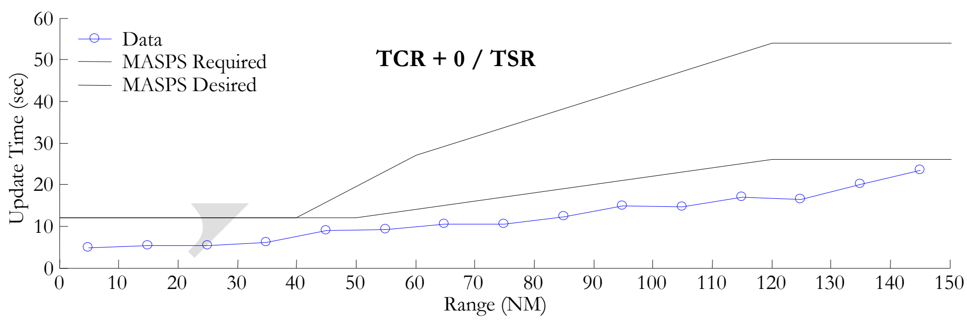
Figure K-22: A2 Receiver in LA2020 at High Altitude Receiving A2 Transmissions





<u>Figure K-23:</u> A2 Receiver in LA2020 at High Altitude Receiving A1H Transmissions





<u>Figure K-24:</u> A2 Receiver in LA2020 at FL 150 Receiving A3 Transmissions

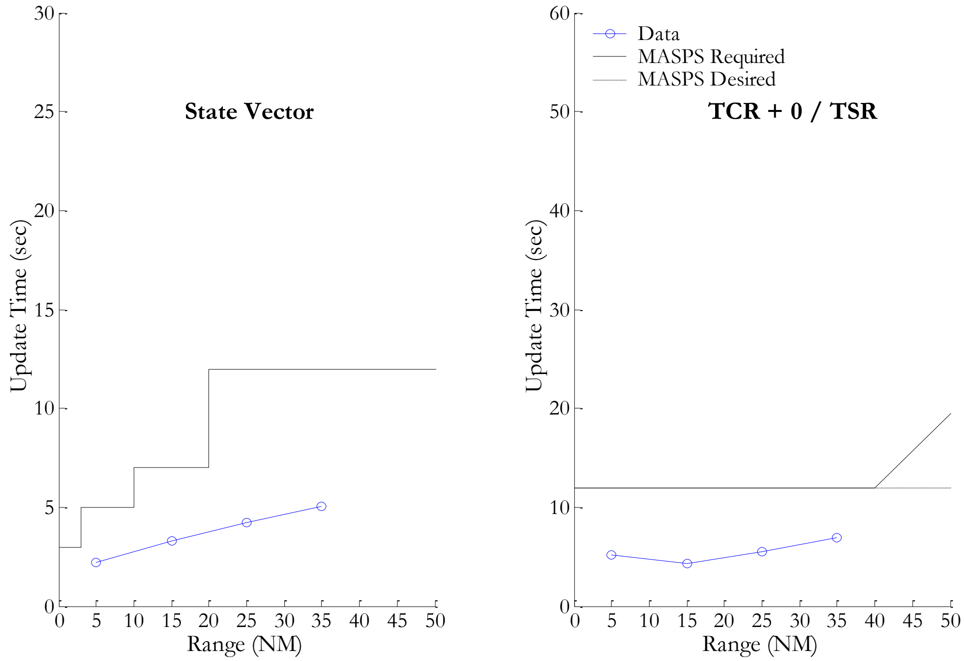


Figure K-25: **A2 Receiver in LA2020 at FL 150 Receiving A2 Transmissions**

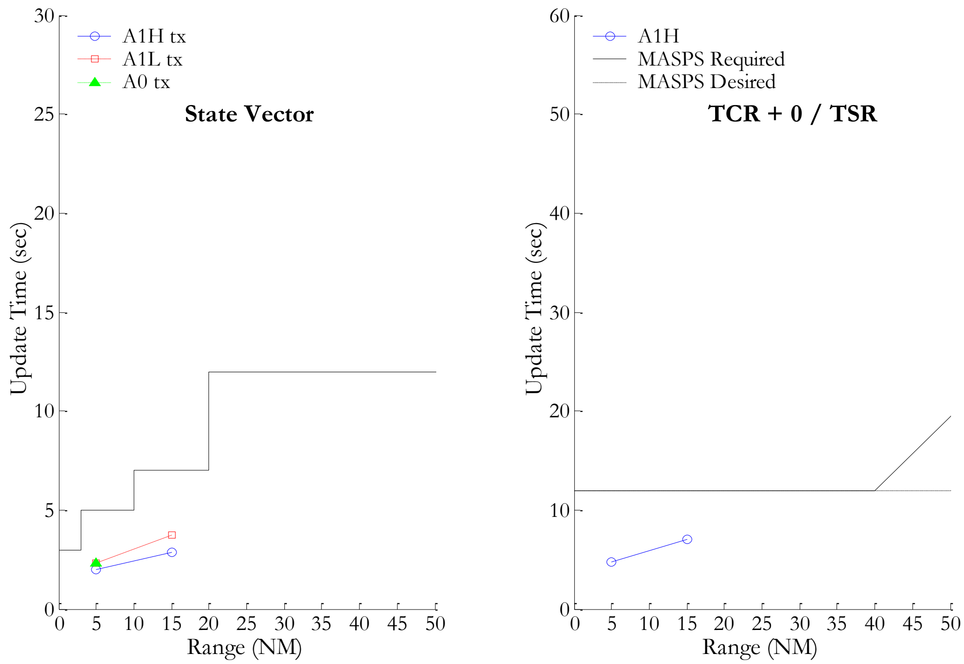


Figure K-26: **A2 Receiver in LA2020 at FL 150 Receiving A1 and A0 Transmissions**

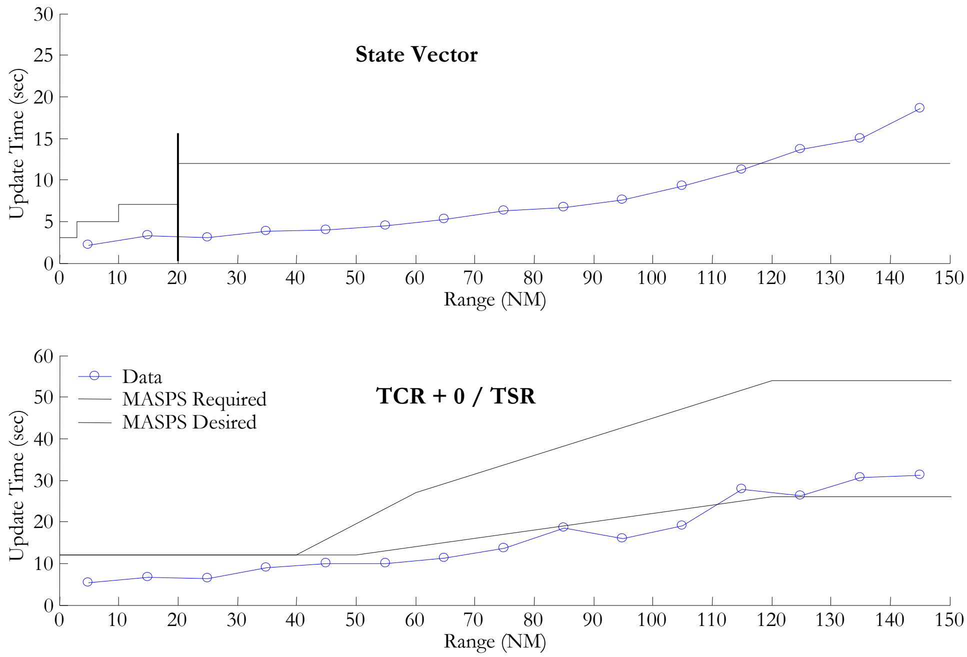


Figure K-27: **A1H Receiver in LA2020 at High Altitude Receiving A3 Transmissions**

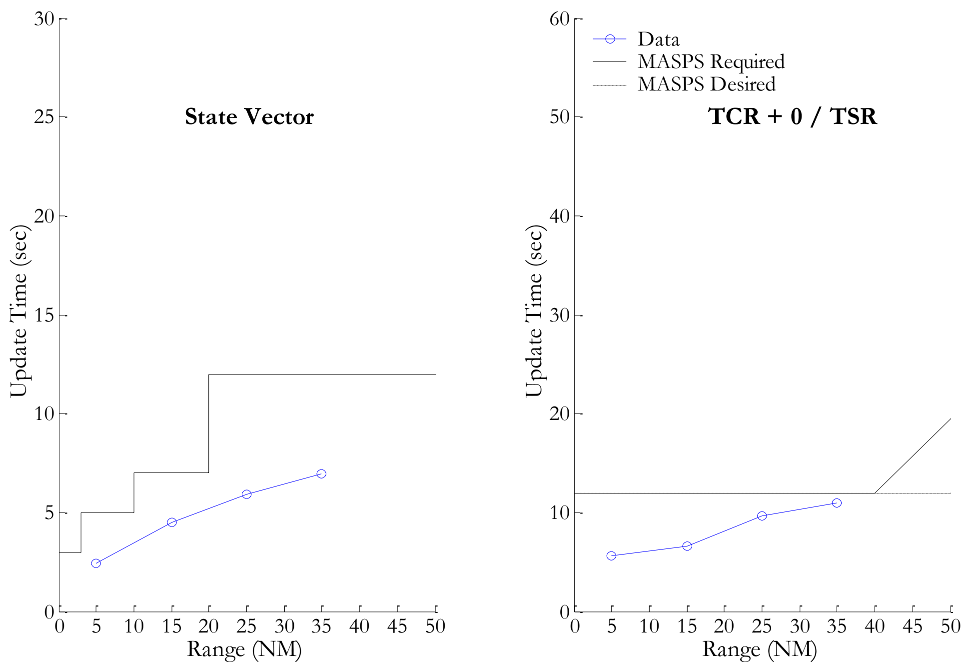


Figure K-28: **A1H Receiver in LA2020 at High Altitude Receiving A2 Transmissions**

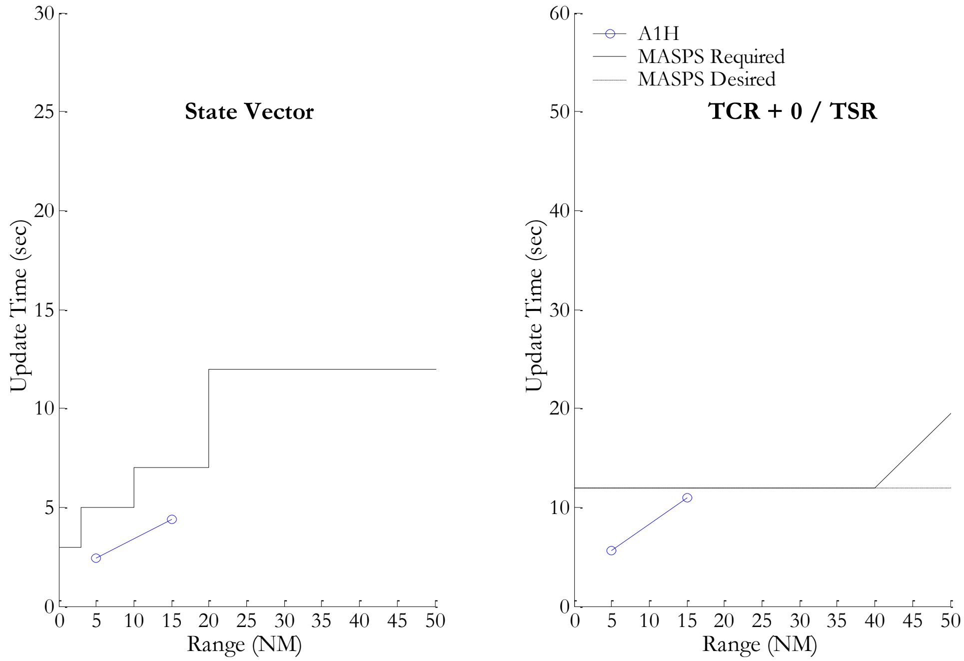


Figure K-29: A1H Receiver in LA2020 at High Altitude Receiving A1H Transmissions

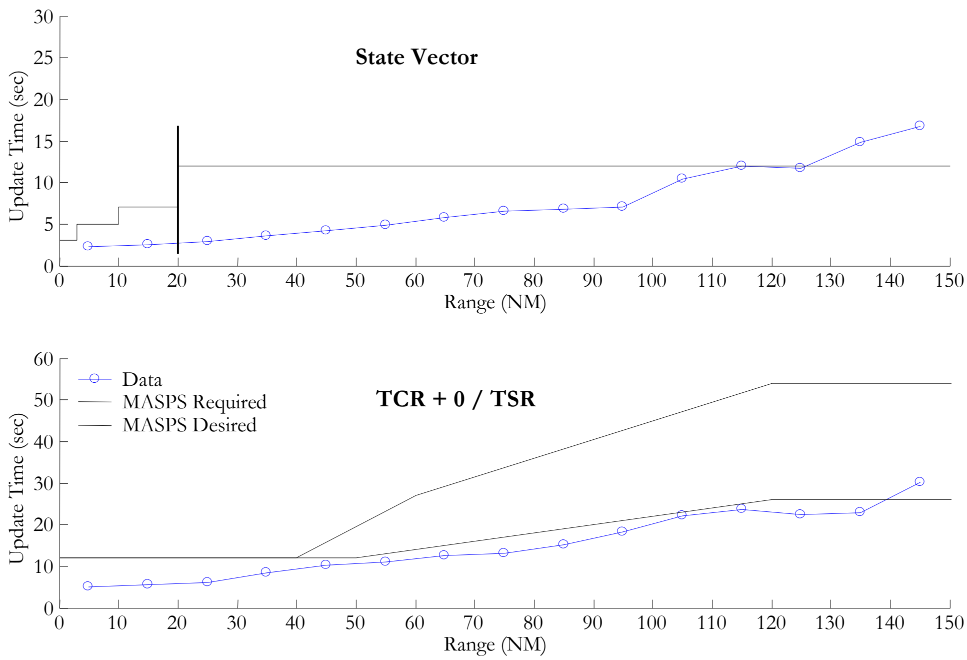


Figure K-30: A1 Receiver in LA2020 at FL 150 Receiving A3 Transmissions

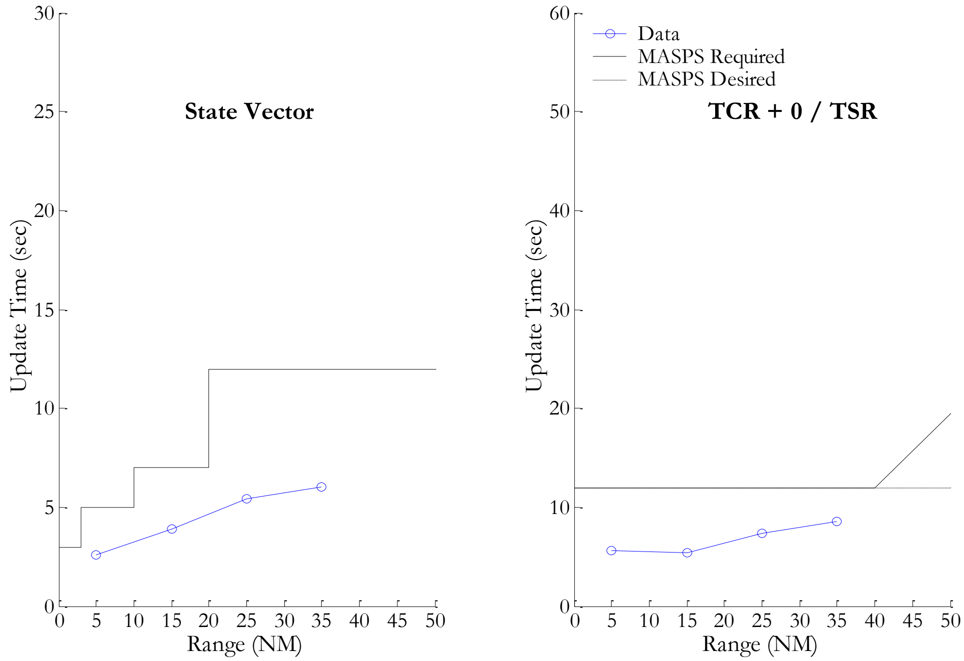


Figure K-31: A1 Receiver in LA2020 at FL 150 Receiving A2 Transmissions

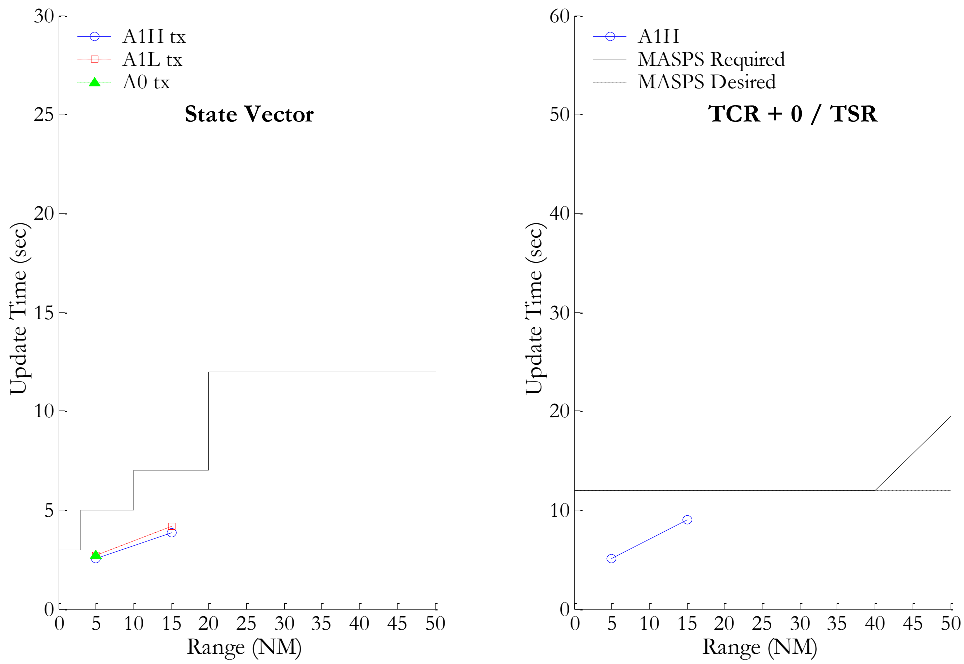


Figure K-32: A1 Receiver in LA2020 at FL 150 Receiving A1 and A0 Transmissions

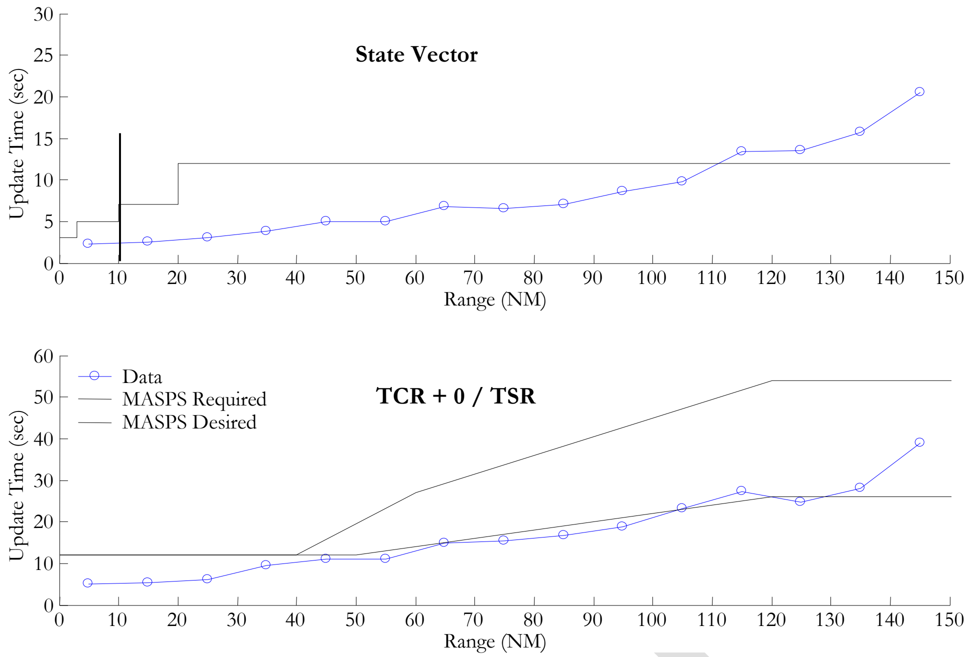


Figure K-33: A0 Receiver in LA2020 at FL 150 Receiving A3 Transmissions

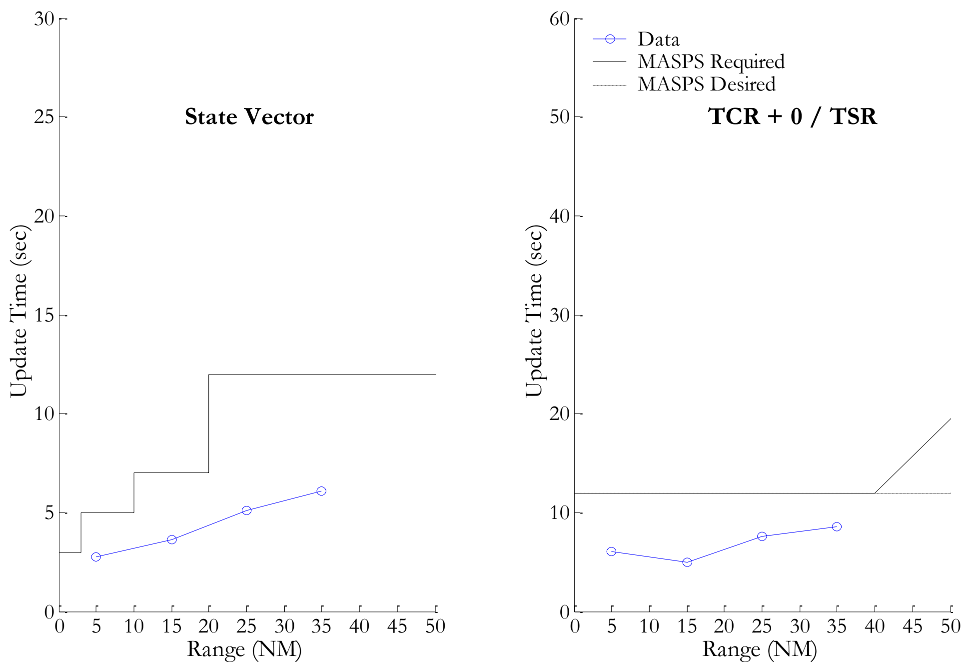


Figure K-34: A0 Receiver in LA2020 at FL 150 Receiving A2 Transmissions

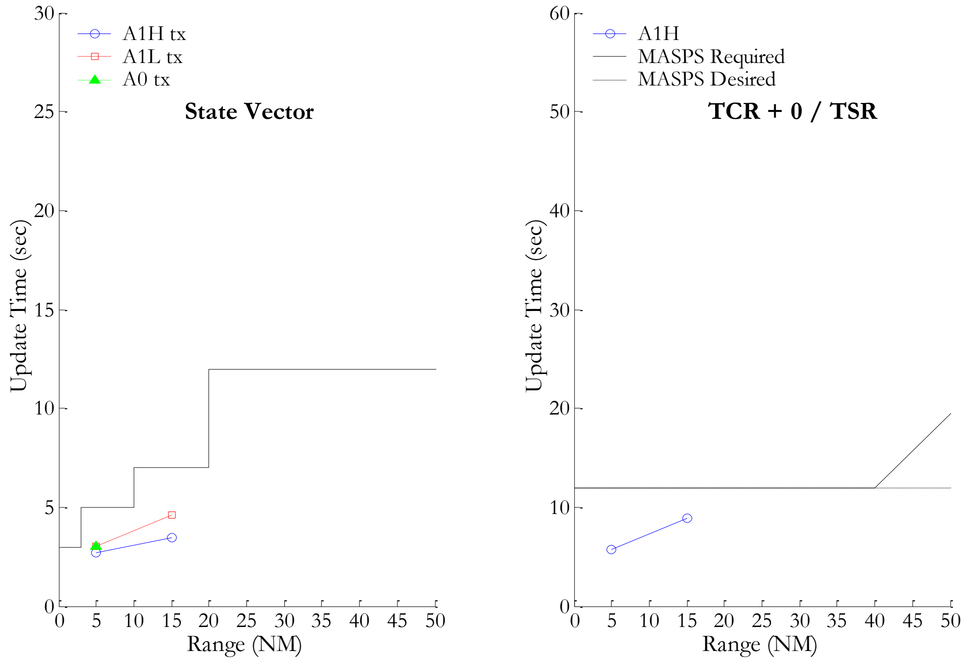


Figure K-35: **A0 Receiver in LA2020 at FL 150 Receiving A1 and A0 Transmissions**

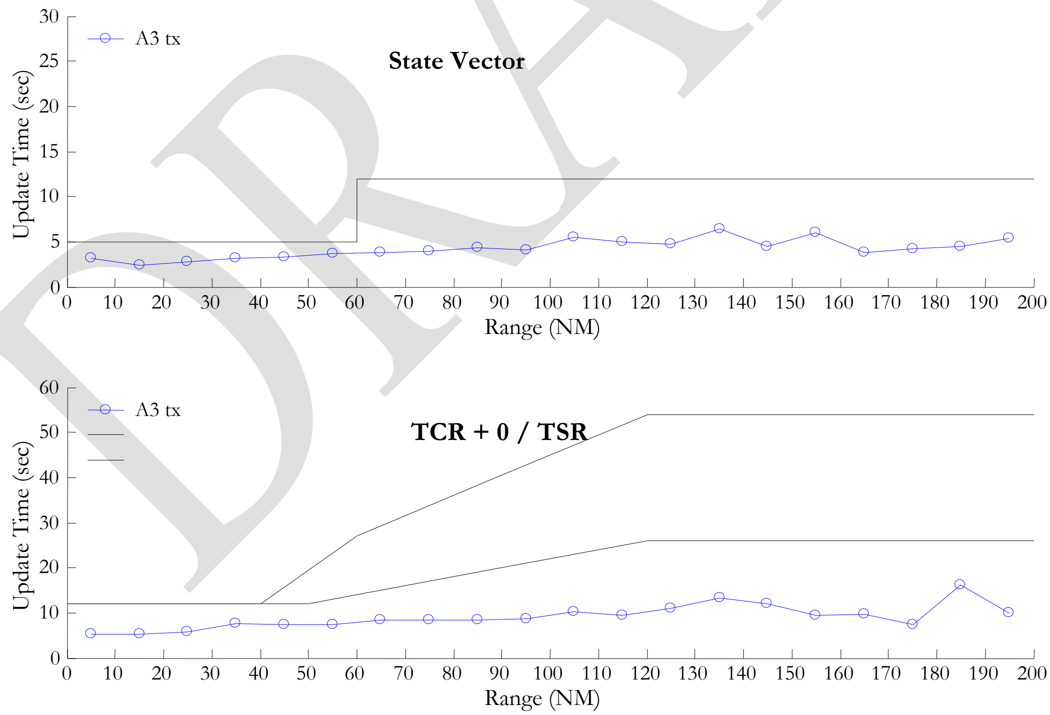


Figure K-36: **Ground Receiver in LA2020 Receiving A3 Transmissions**

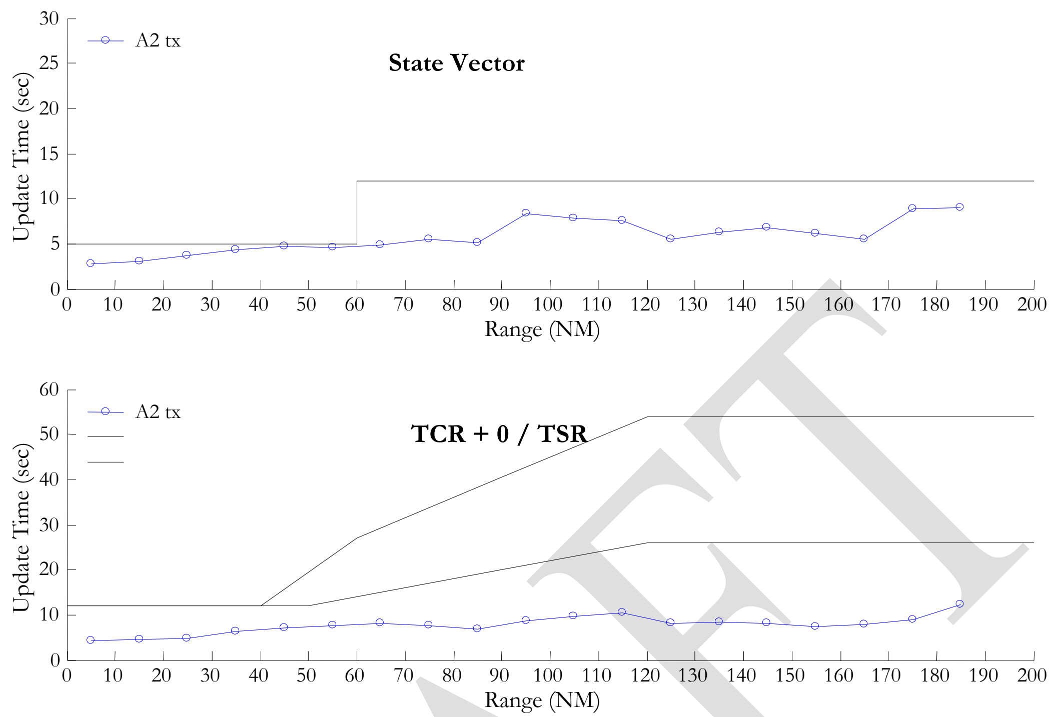


Figure K-37: Ground Receiver in LA2020 Receiving A2 Transmissions

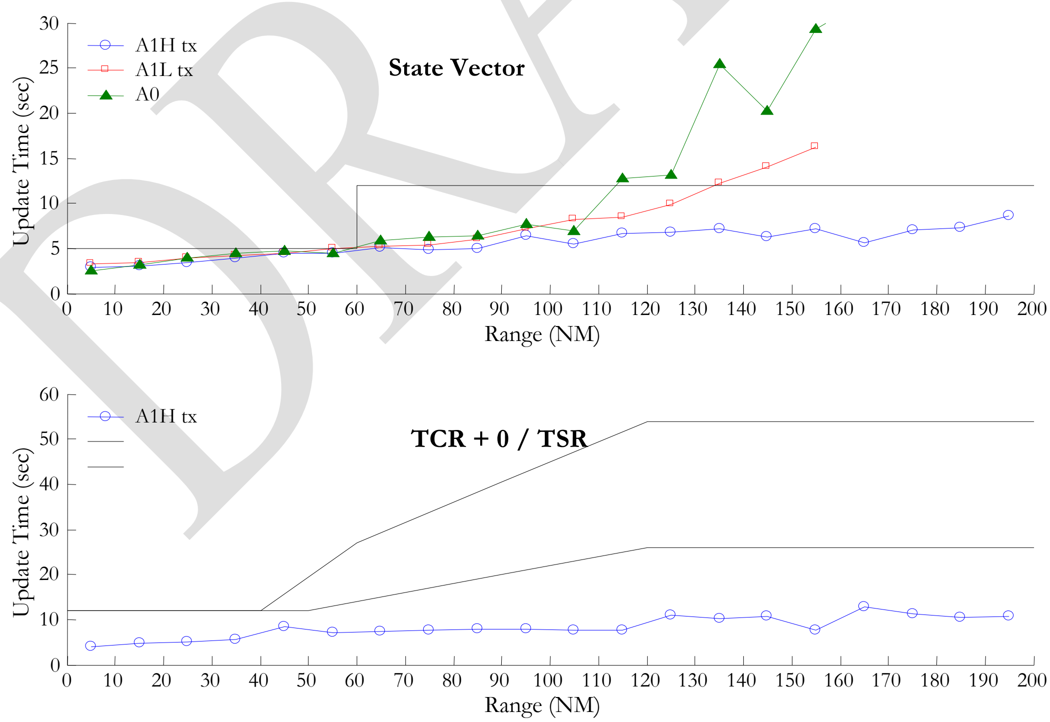
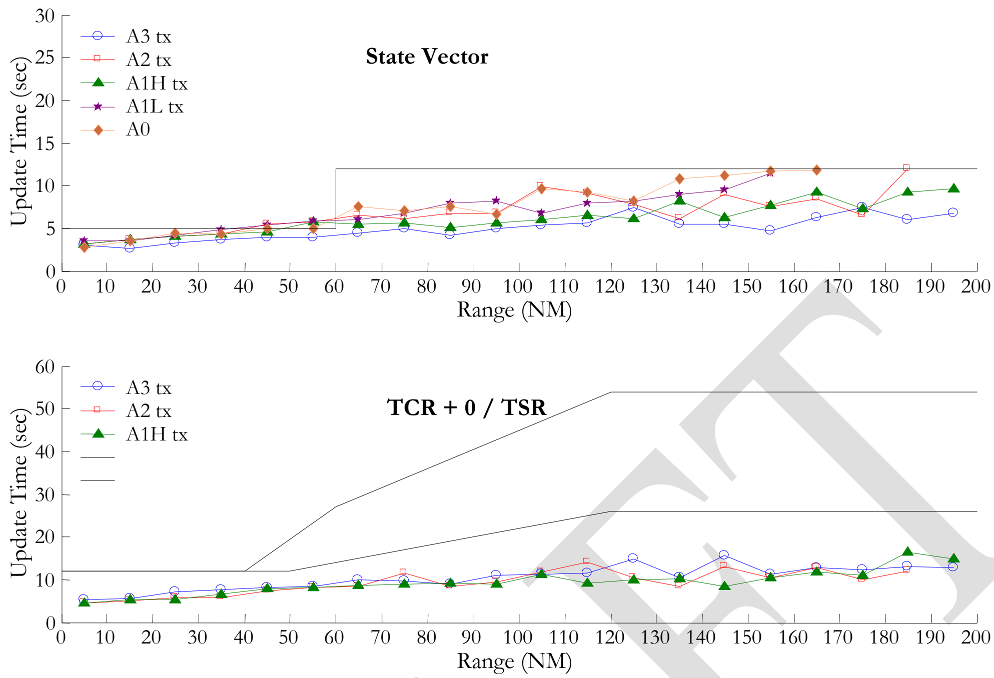
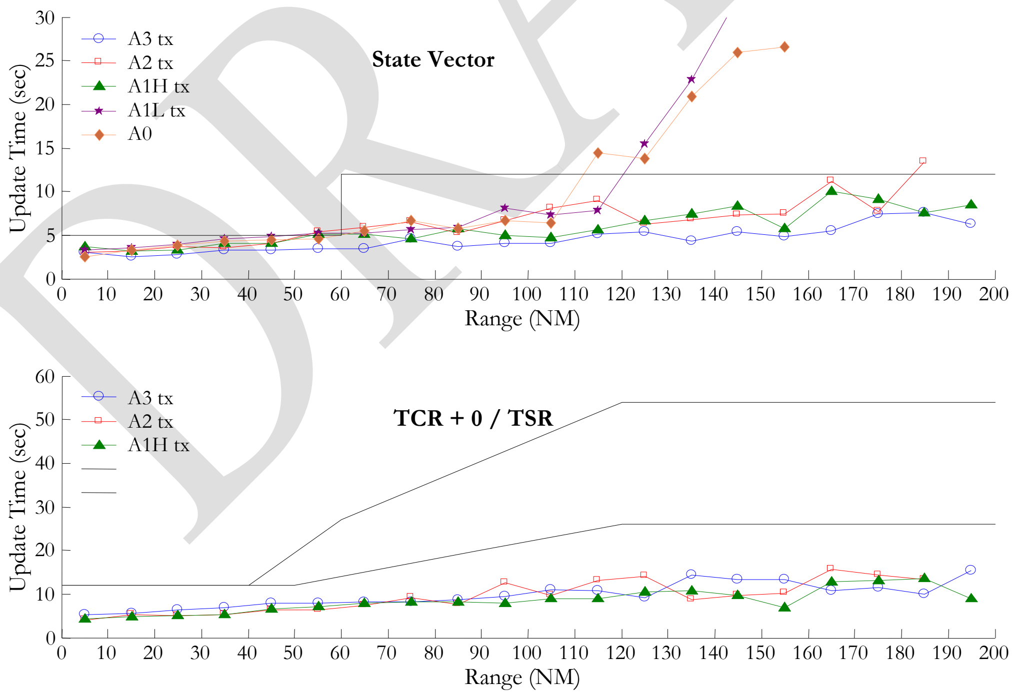


Figure K-38: Ground Receiver in LA2020 Receiving A1 and A0 Transmissions



<u>Figure K-39:</u> Ground Receiver in LA with Sectorized Antenna with a 10 kW TACAN at 980 MHz located 1000' away



<u>Figure K-40:</u> Standard Ground Receiver in LA with TACAN that delivers –90 dBm at 980 MHz to the UAT Ground Antenna

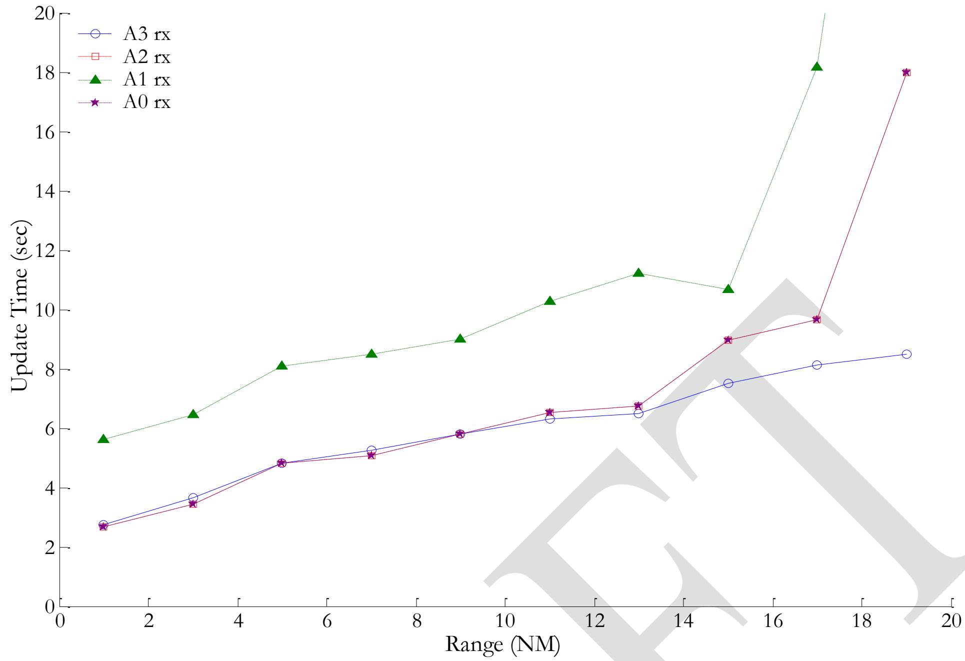


Figure K-41: State Vector Updates from Ground Vehicle Transmitters for all Types of Receivers at 2000 feet Altitude

Recall that the LA2020 scenario includes 2694 aircraft and 300 ground vehicles transmitting on UAT. In addition, a baseline Link 16 scenario is also included as co-channel interference.

The results for LA2020 UAT air-air system performance shown in Figure K-15 to Figure K-35 are summarized in Table K-1 below. This summary indicates that the UAT System is projected to be fully compliant with the ADS-B MASPS (DO-242A) air-to-air report update requirements at both the required and desired ranges.

Table K-1: Ranges of ADS-B MASPS Compliance for UAT Transmit-Receive Combinations in the LA2020 Scenario

	RECEIVER			
TRANSMITTER	**A3**	**A2**	**A1**	**A0**
A3	130	40+	20+	10+
A2	40+	40+	20+	10+
A1H	20+	20+	20+	10+
A1L	20+	20+	20+	10+
A0	10+	10+	10+	10+

The results for the LA2020 scenario shown in Figure K-15 through Figure K-41 may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs in the LA2020 scenario for both state vector and intent update rates at all ranges specified by the MASPS. Performance for receivers located at FL 150 tends to be better in general than the corresponding receivers at high altitude, due primarily to the lower levels of self-interference encountered at lower altitudes.

- The Eurocontrol extension to 150 NM for A3 class equipage is only met for LA2020 at the 95% level out to 130-135 NM, but the 95th percentile update rate at 150 NM is 14-17 seconds, depending on the altitude of the receiving aircraft.

- Air-ground update requirements are met to 150 NM for a standard ground receiver located at LAX in the LA2020 scenario for equipages A3, A2, and A1H. A1L and A0 equipage met requirements out to 135 and 110 NM, respectively. A test case was run for the case of a 980 MHz DME/TACAN co-located with the ground receiver. The results of the test case show that, in the presence of a 5 kw TACAN at 980 MHz located 50 feet away from the ground receiver at LAX in the LA2020 scenario, a three-sector antenna allows the update requirements to be met for all aircraft equipages to 150 NM. Another test case was run for the case of the co-located 980 MHz TACAN with a standard ground receiver, to see what level of power at the UAT antenna could be supported without degradation in performance. The results show that –90 dBm TACAN power at the UAT antenna at 980 MHz does not significantly change the standard ground performance in LA2020: A3, A2, and A1H performance meet the MASPS requirements out to 150 NM, and A1L and A0 meet the requirements out to 120 and 110 NM, respectively. This means that, if the TACAN were located 1000 feet from the ground receive antenna, an additional 30 dB of isolation would be required in order to assure MASPS compliance. This could be achieved by increasing the separation distance, for example.

- System performance results are presented for state vector updates of ground vehicles to an aircraft on approach to LAX in the LA2020 scenario. There is no specific update rate requirement in the ADS-B MASPS for this situation.

K.4.2 Core Europe Scenarios

Two cases were considered for Core Europe: a current scenario, and one that focuses on 2015. The reason these two cases were considered is that the operation of UAT in Core Europe 2015 is based on the premise that the existing on-channel DME/TACANs will be moved from 978 MHz to other available frequencies. Therefore, the future scenario assumes that there will be no DME/TACANs on 978 MHz, but that all existing and planned DME/TACANs at 979 MHz will be operational and running at full allowed power levels, no matter how close they are to one another. This condition was chosen in order to provide a conservatively severe estimate of the DME/TACAN interference environment.

The current Core Europe scenario was also considered, in order to provide an estimate of UAT performance in the transitional period until the current transmitters at 978 MHz could be moved to other frequencies. For both scenarios, two sub-cases were analyzed: worst-case traffic density (over the center of the scenario at Brussels, selected to provide the highest UAT self-interference levels) and worst-case DME/TACAN environment (location selected to provide the highest interference from DME/TACANs). The worst-case DME/TACAN environment selection required moving a high-power mobile 979 MHz TACAN to a particular location near several other 979 MHz TACANs.

For the Core Europe 2015 scenario, the distributions and assumptions made were taken directly from the Eurocontrol document entitled “High-Density 2015 European Traffic Distributions for Simulation,” dated August 17, 1999. This scenario is well-defined and straightforward to apply. This scenario includes a total of 2091 aircraft (both airborne and ground) and 500 ground vehicles, and is based on the following assumptions:

- There are five major TMAs (Brussels, Amsterdam, London, Paris, and Frankfurt), each of which is characterized by:
  - The inner region (12 NM radius) contains 29 aircraft at lower altitudes,
  - The outer region (50 NM radius) contains 103 aircraft at mid to higher altitudes.
  - There are 25 aircraft on the ground within a 5 NM radius of each TMA. Additionally, there are 25 aircraft not associated with a TMA randomly distributed through the scenario.
  - There are assumed to be 100 ground vehicles equipped with transmit-only UAT equipment.
- These aircraft are assumed to be symmetrically distributed azimuthally, and the aircraft in an altitude band are assumed to be uniformly distributed throughout the band. However, all aircraft in the same band are assumed to be traveling at the same band-dependent velocity.
- Superimposed over these aircraft is a set of airborne en route aircraft, which are distributed over a circle of radius 300 NM. These aircraft are distributed over four altitude bands, ranging from low to upper altitudes. They also travel at velocities that are altitude band dependent.
- As in the LA Basin 2020 scenario, for the Core Europe 2015 scenario all aircraft are assumed to be ADS-B equipped. The equipage levels have been adjusted to be:
  - 30 % A3
  - 30% A2
  - 30% A1
  - 10% A0

Aircraft equipage is assigned according to altitude. The lower percentages of A0 and A1 aircraft than those found in the LA Basin scenarios reflect differences in operating conditions and rules in European airspace.

The current Core Europe scenario is defined by using the same algorithm for generating the aircraft as for Core Europe 2015, but reducing the total number of aircraft proportionally, to reflect today's maximum value of 1200 for the number of aircraft in operation. A test case was also run at the worst-case DME/TACAN location, in order to evaluate a partial equipage scenario that could be supported by UAT with no movement of DME/TACAN assignments.

The two geographical areas that underlie the scenarios discussed above (LA Basin and Core Europe) correspond to very different types of situations for an aircraft to operate in, and thus should provide two diverse environments for evaluation. The LA Basin scenario contains only about 14% of all airborne aircraft at altitudes above 10000 ft, while the Core Europe scenario has around 60% above 10000 ft. Thus, there will be vastly different numbers of aircraft in view for the two scenarios. Additionally, the aircraft density distributions are also quite different, which will place different stresses on the data link systems.

K.4.2.1 Current Core Europe

The current Core Europe air traffic scenario is described in Section K.4.2. This section presents the results of simulation runs which correspond to the assumptions stated in K.4.2 for 1200 aircraft, the estimated number of aircraft today in the Core Europe scenario. Recall that DME/TACANs on 978 MHz are not assumed to have been moved; therefore, there are a number of strong emitters at the nominal UAT frequency. Two locations are considered for current Core Europe: one in the midst of worst-case UAT self-interference, in the center of the scenario over Brussels; the other in a location that is thought to represent the worst-case DME/TACAN environment, over western Germany. In addition, the Baseline B Link 16 scenario is also assumed to interfere with UAT transmissions for all Core Europe cases.

Results are presented as a series of plots in Figure K-42 to Figure K-62 for 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. Each point on the plot represents the performance of Aircraft/Vehicles within a 10 NM bin centered on the point. The ADS-B MASPS requirements for state vector, and preliminary requirements for TSR, and TCR+0 updates are shown as black lines on the plots. The ADS-B MASPS specify that the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. This does not include all of the potential Eurocontrol requirements, since the Eurocontrol requirement for four Trajectory Change Points to be broadcast was not addressed. Although results are presented here for A1L equipment, it is not likely that this equipage class will be implemented in Europe. Air-ground requirements are defined to 150 NM for all aircraft equipage classes. Performance in compliance with MASPS requirements is indicated by results that are below the black line. Note that the ADS-B MASPS range limitations for A3 transmitters are indicated on the plots by a solid vertical line, while desired range limitations are indicated by a dashed vertical line, and Eurocontrol extension to 150 NM are indicated by a dotted vertical line.

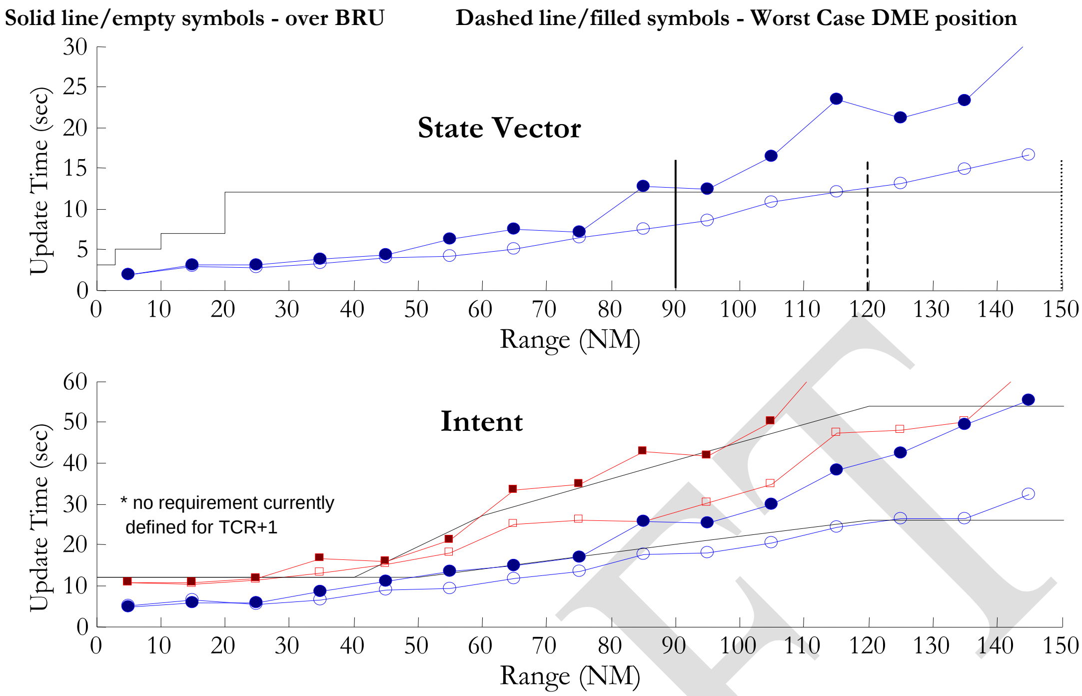


Figure K-42: A3 Receiver at High Altitude in Current Europe Receiving A3 Transmissions

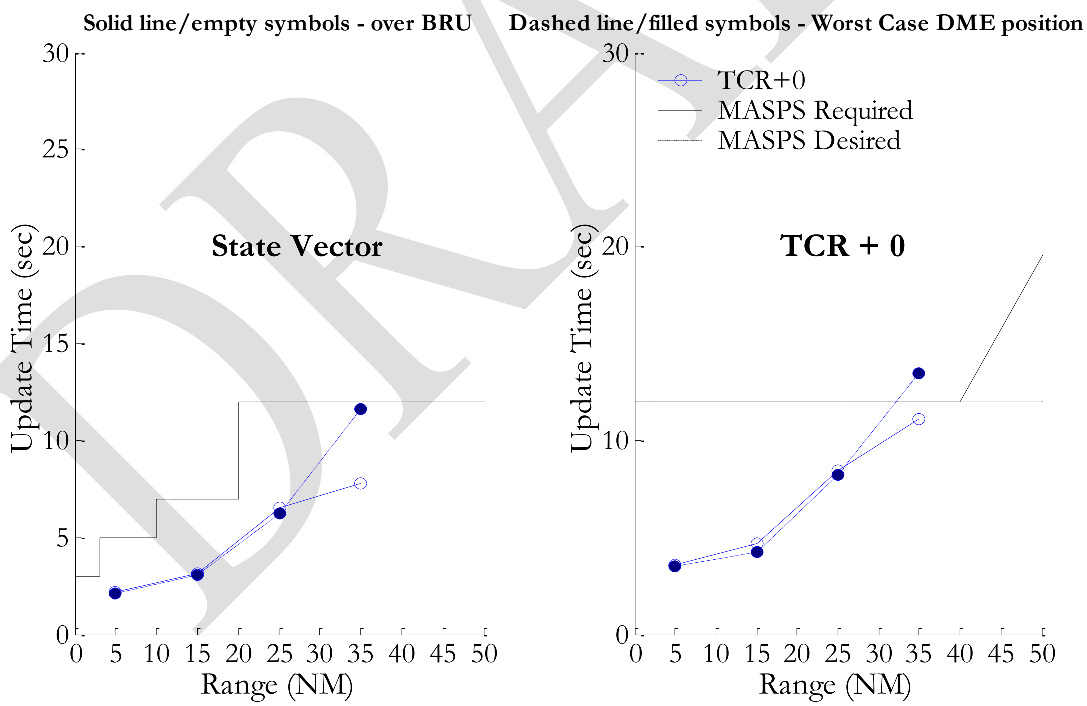


Figure K-43: A3 Receiver at High Altitude in Current Europe Receiving A2 Transmissions

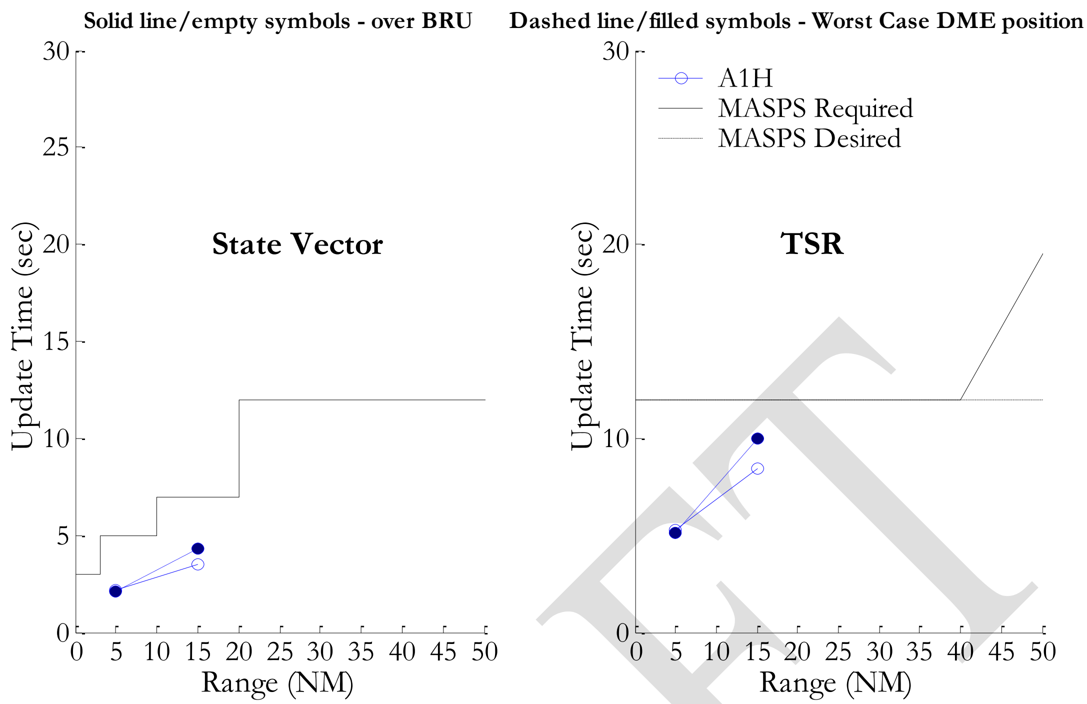


Figure K-44: A3 Receiver at High Altitude in Current Europe Receiving A1H Transmissions

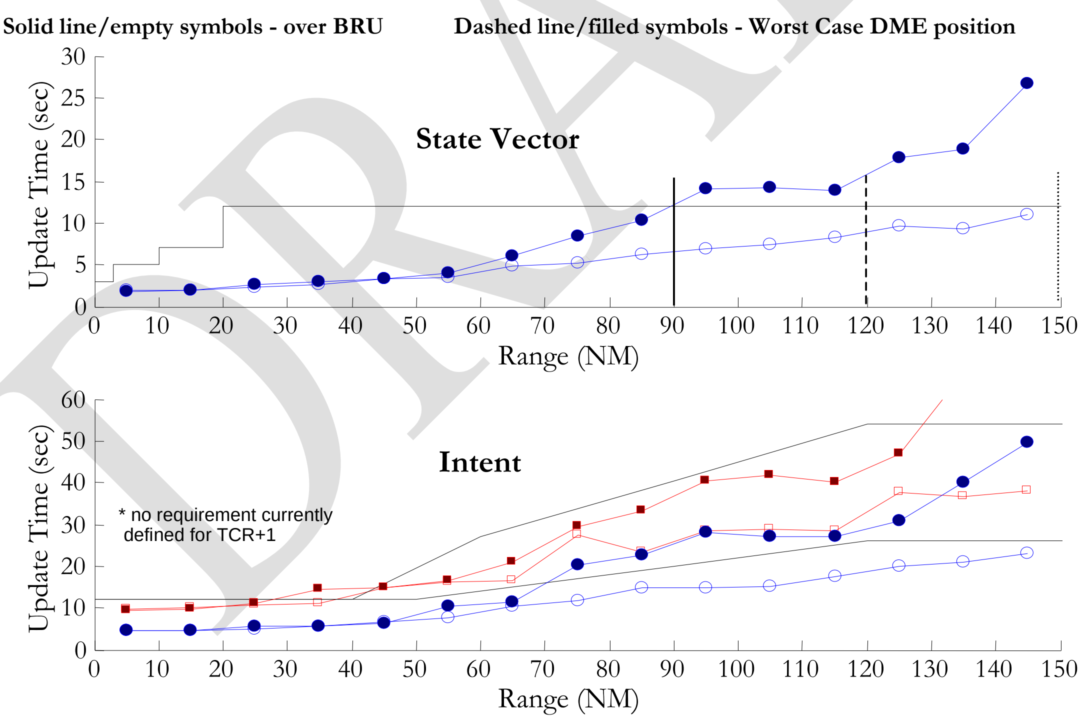


Figure K-45: A3 Receiver at FL 150 in Current Europe Receiving A3 Transmissions

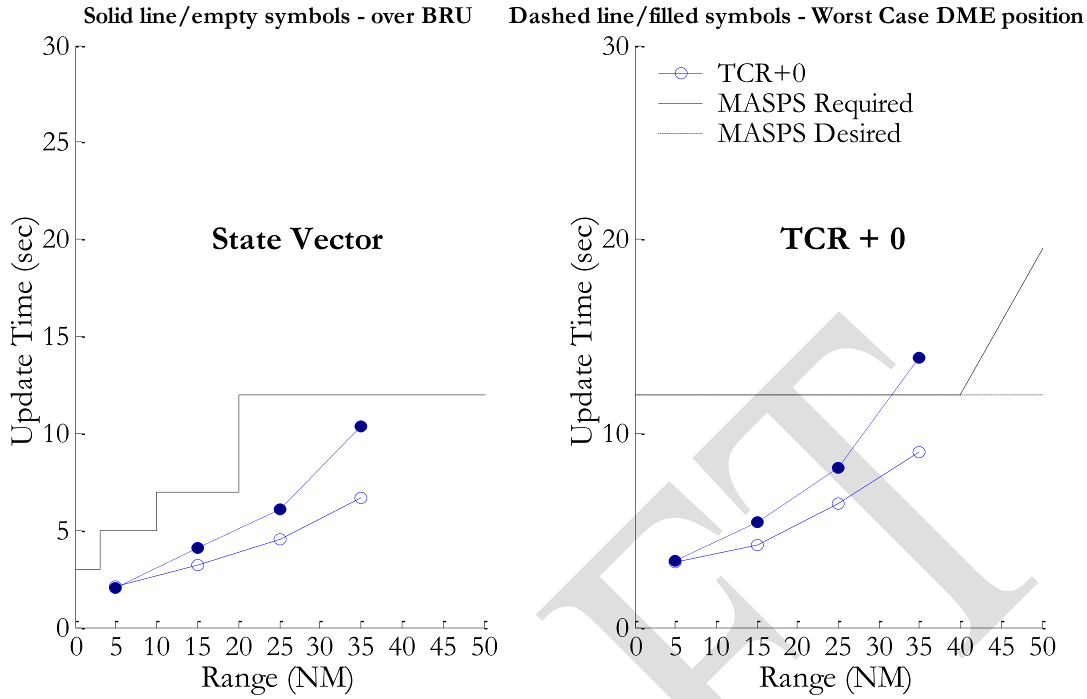


Figure K-46: **A3 Receiver at FL 150 in Current Europe Receiving A2 Transmissions**

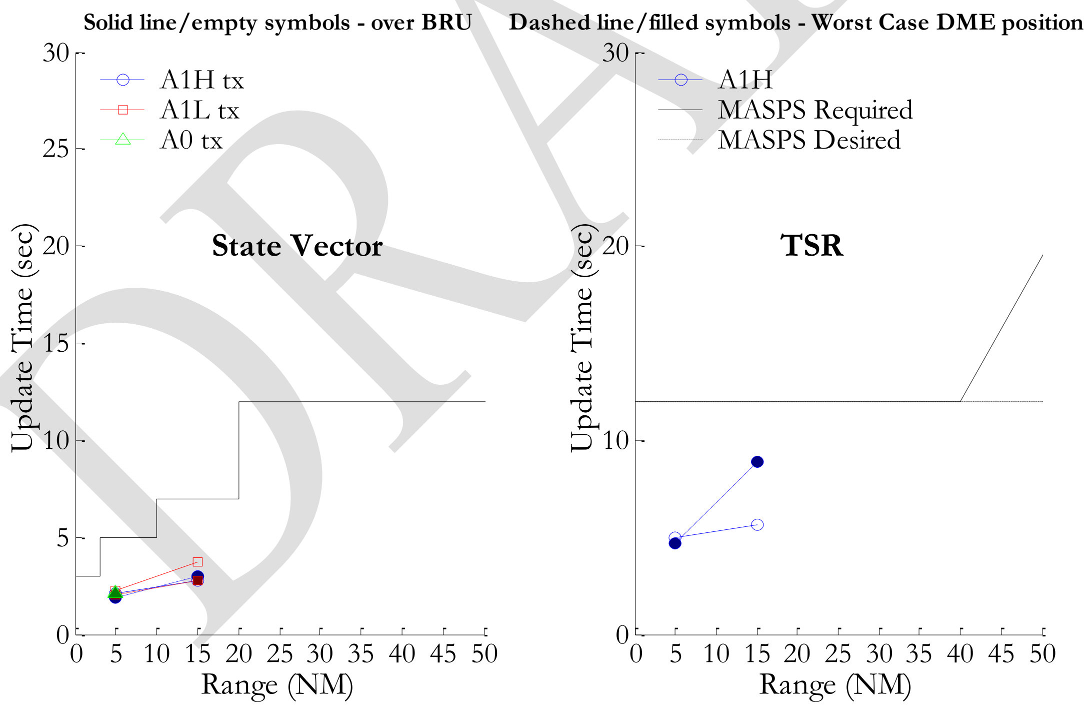


Figure K-47: **A3 Receiver at FL 150 in Current Europe Receiving A1 and A0 Transmissions**

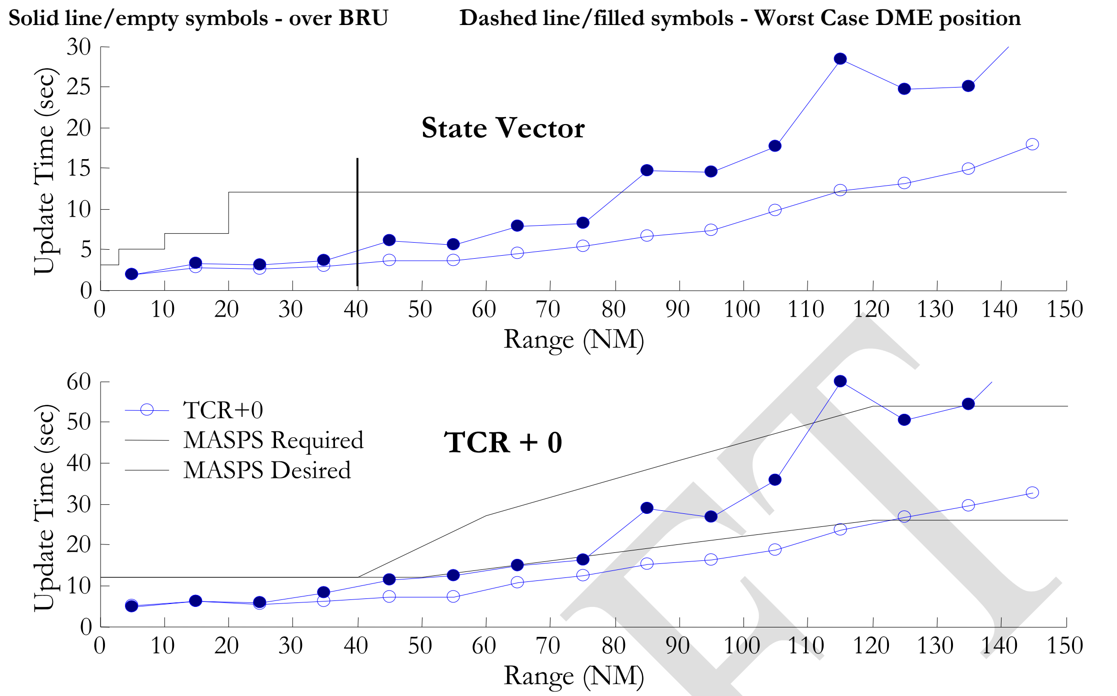


Figure K-48: A2 Receiver at High Altitude in Current Europe Receiving A3 Transmissions

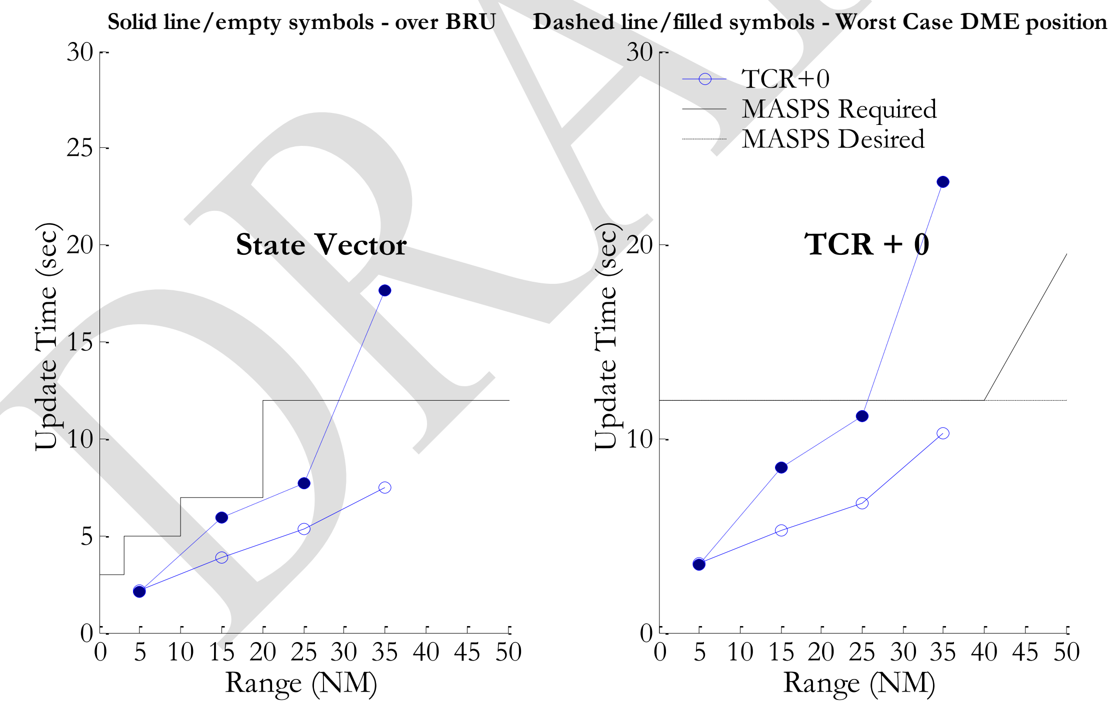


Figure K-49: A2 Receiver at High Altitude in Current Europe Receiving A2 Transmissions

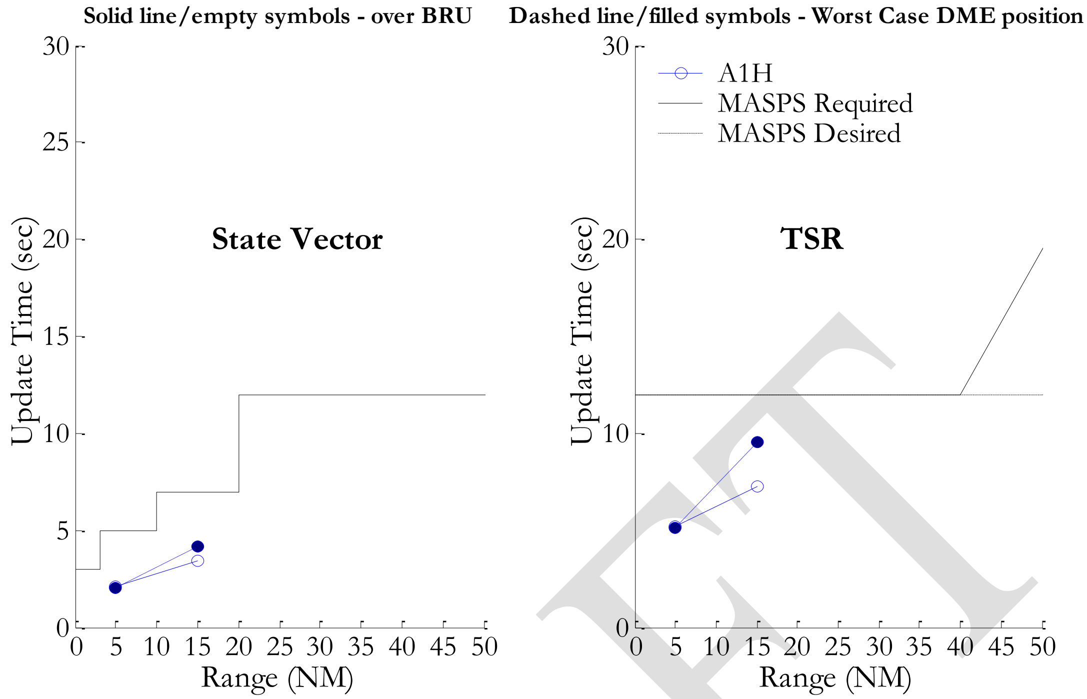


Figure K-50: **A2 Receiver at High Altitude in Current Europe Receiving A1H Transmissions**

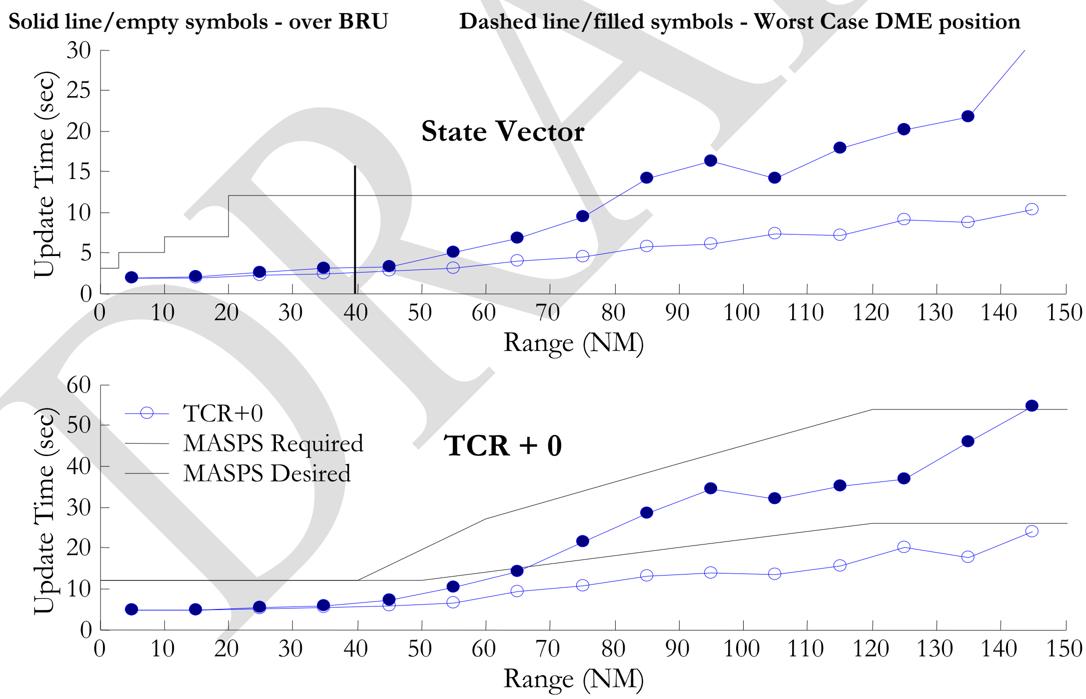
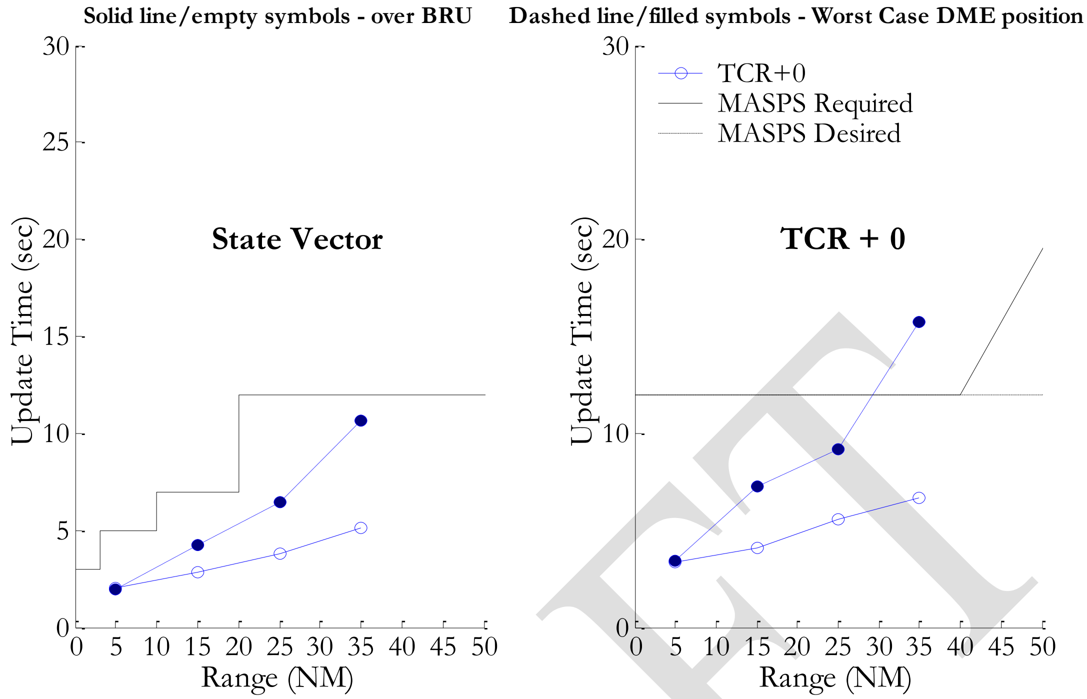
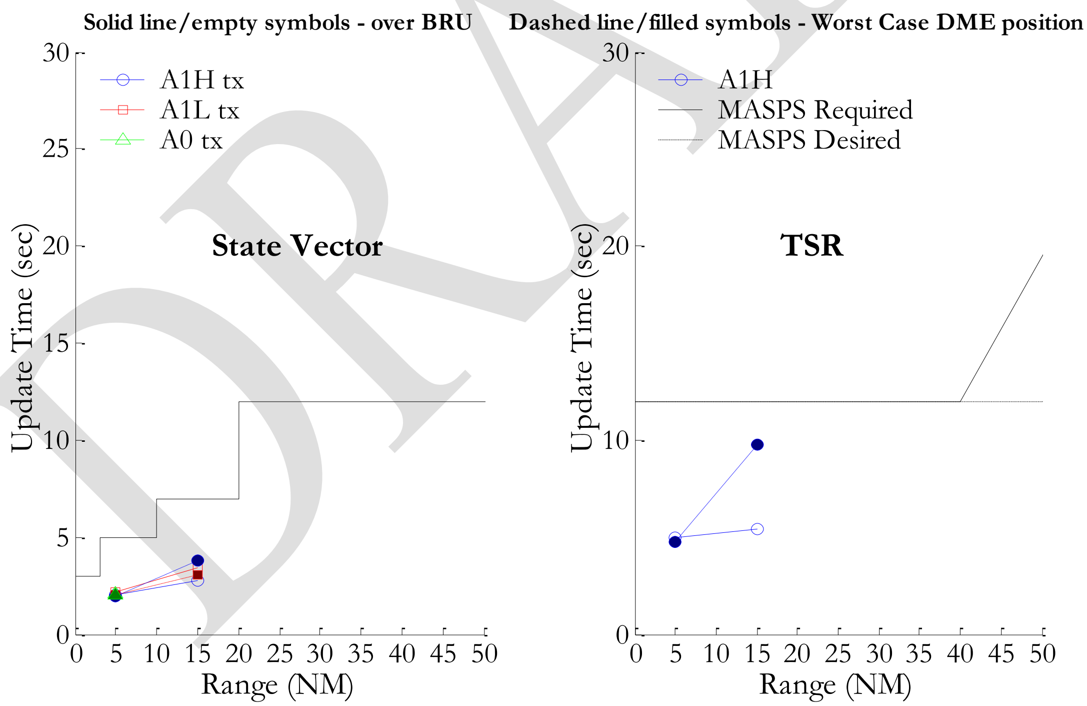


Figure K-51: **A2 Receiver at FL 150 in Current Europe Receiving A3 Transmissions**



<u>Figure K-52:</u> A2 Receiver at FL 150 in Current Europe Receiving A2 Transmissions



<u>Figure K-53:</u> A2 Receiver at FL 150 in Current Europe Receiving A1 and A0 Transmissions

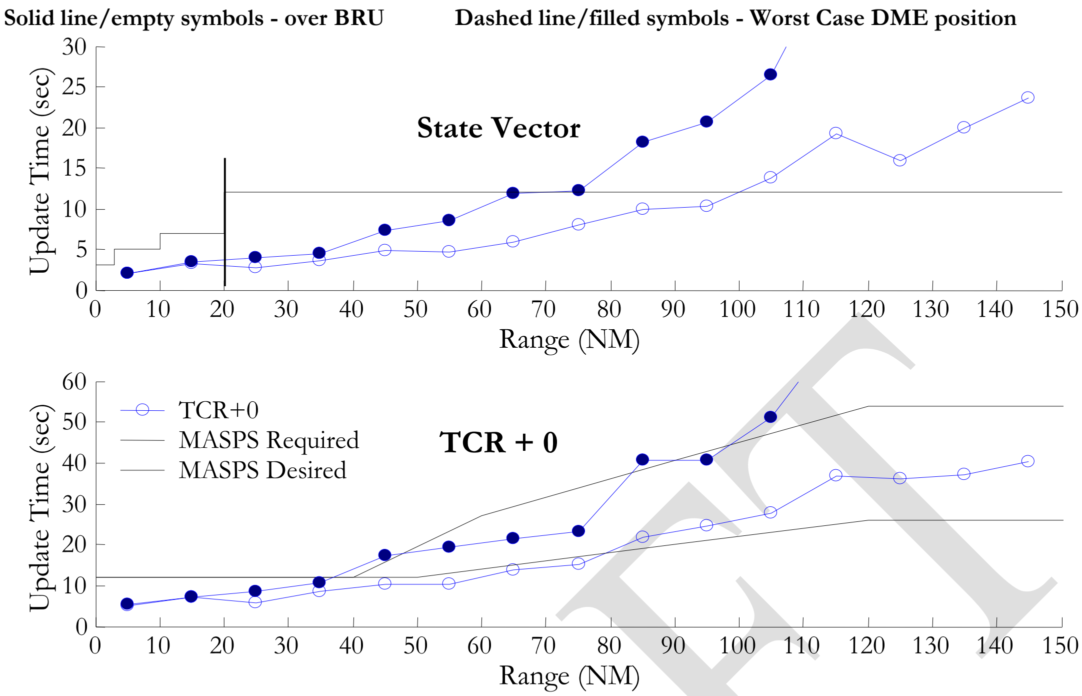


Figure K-54: **A1H Receiver at High Altitude in Current Europe Receiving A3 Transmissions**

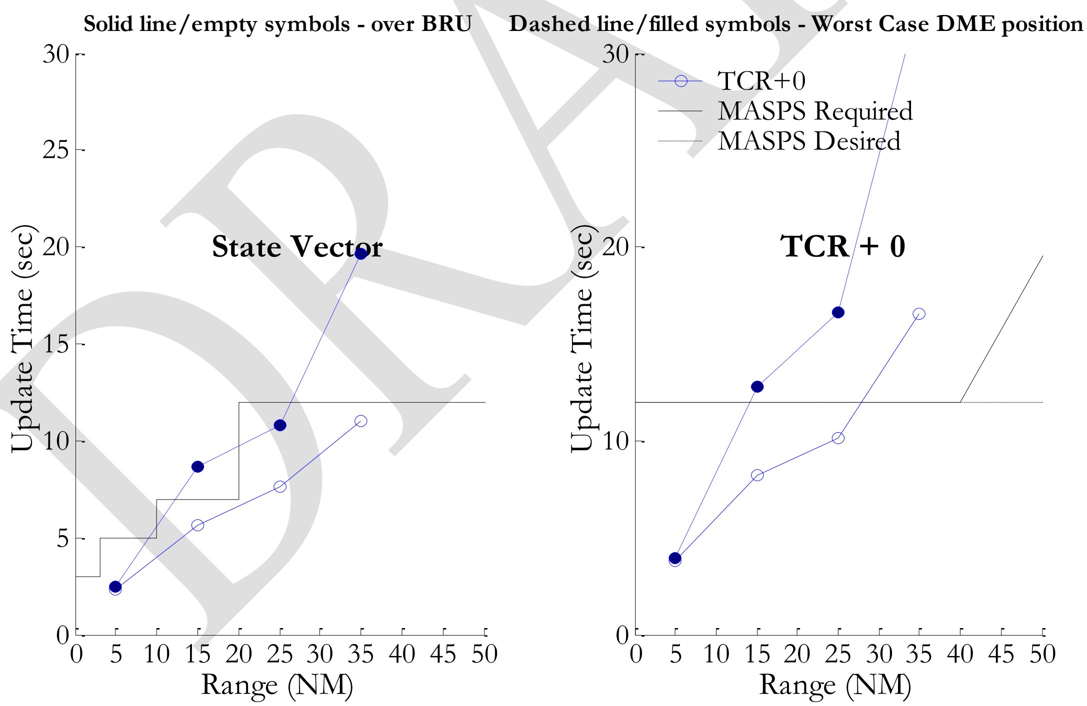


Figure K-55: **A1H Receiver at High Altitude in Current Europe Receiving A2 Transmissions**

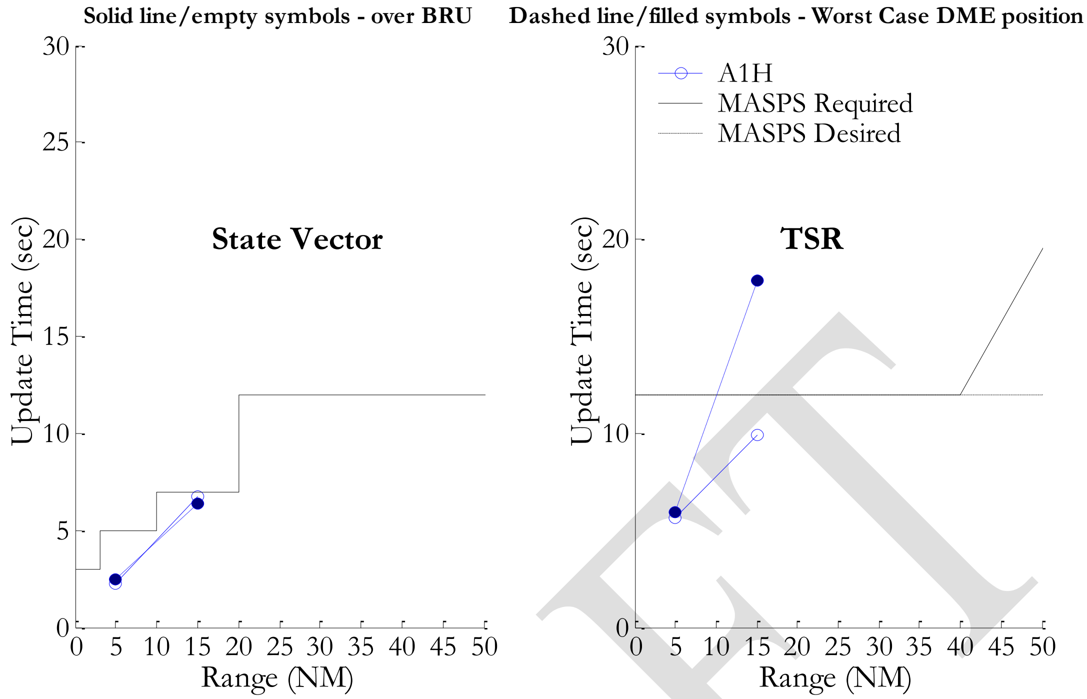


Figure K-56: A1H Receiver at High Altitude in Current Europe Receiving A1H Transmissions

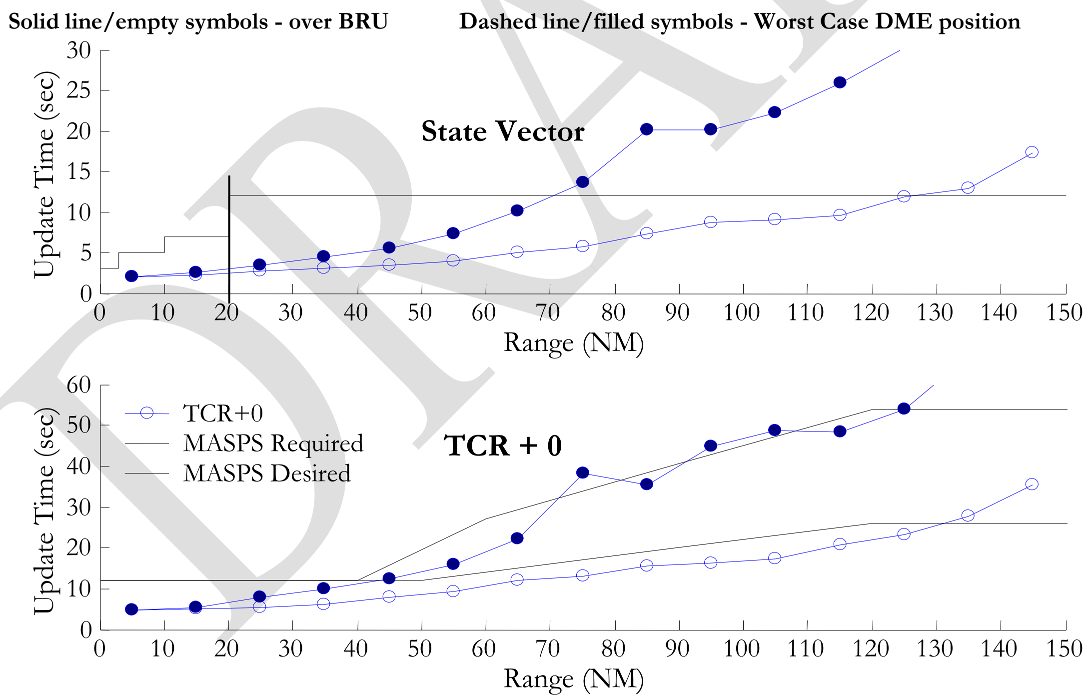
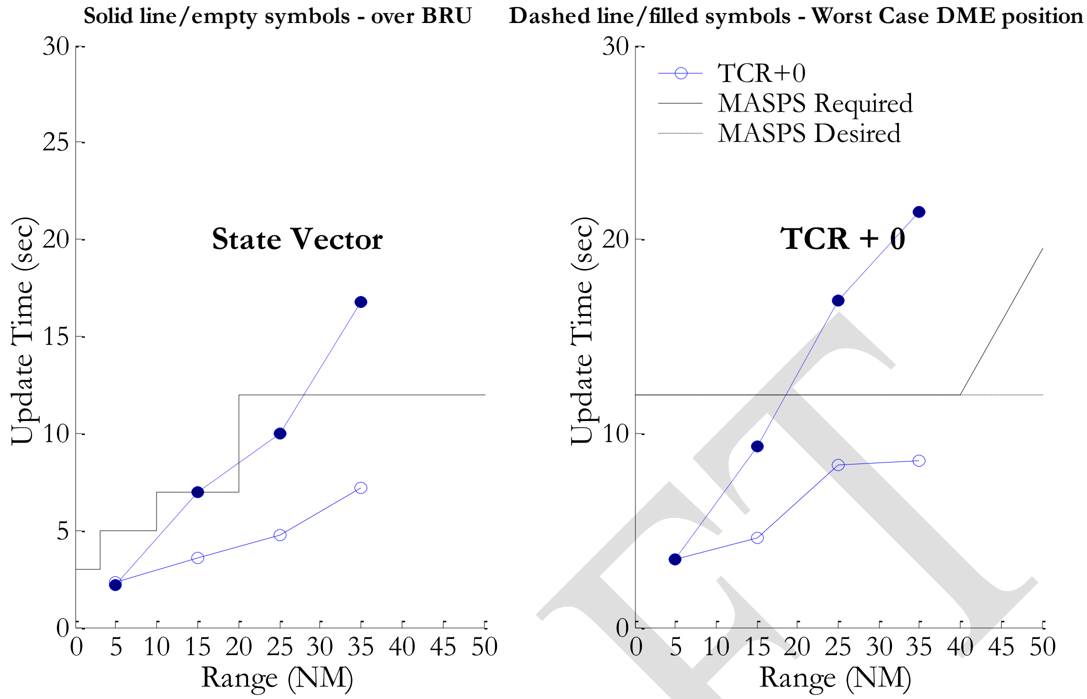
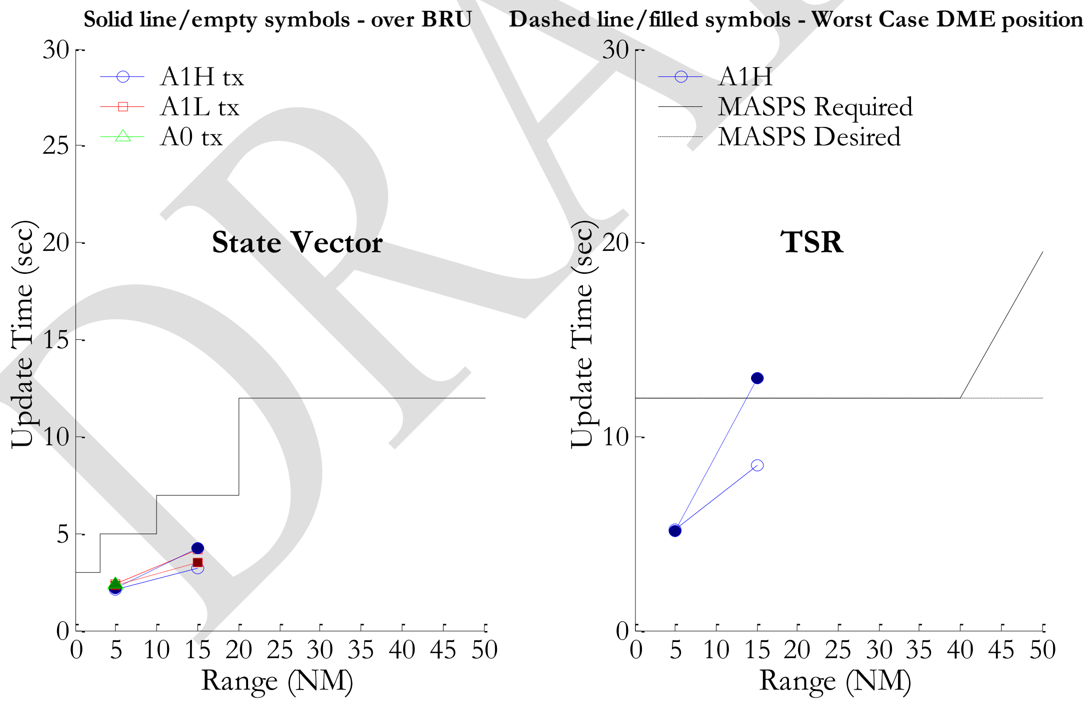


Figure K-57: A1 Receiver at FL 150 in Current Europe Receiving A3 Transmissions



<u>Figure K-58:</u> A1 Receiver at FL 150 in Current Europe Receiving A2 Transmissions



<u>Figure K-59:</u> A1 Receiver at FL 150 in Current Europe Receiving A1 and A0 Transmissions

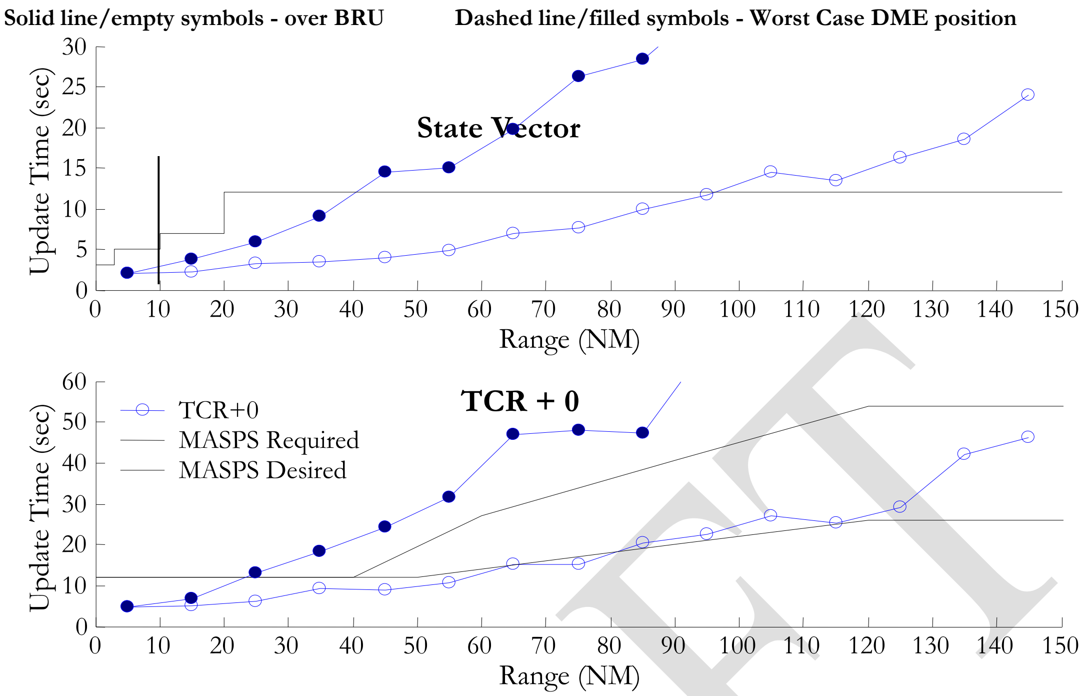


Figure K-60: A0 Receiver at FL 150 in Current Europe Receiving A3 Transmissions

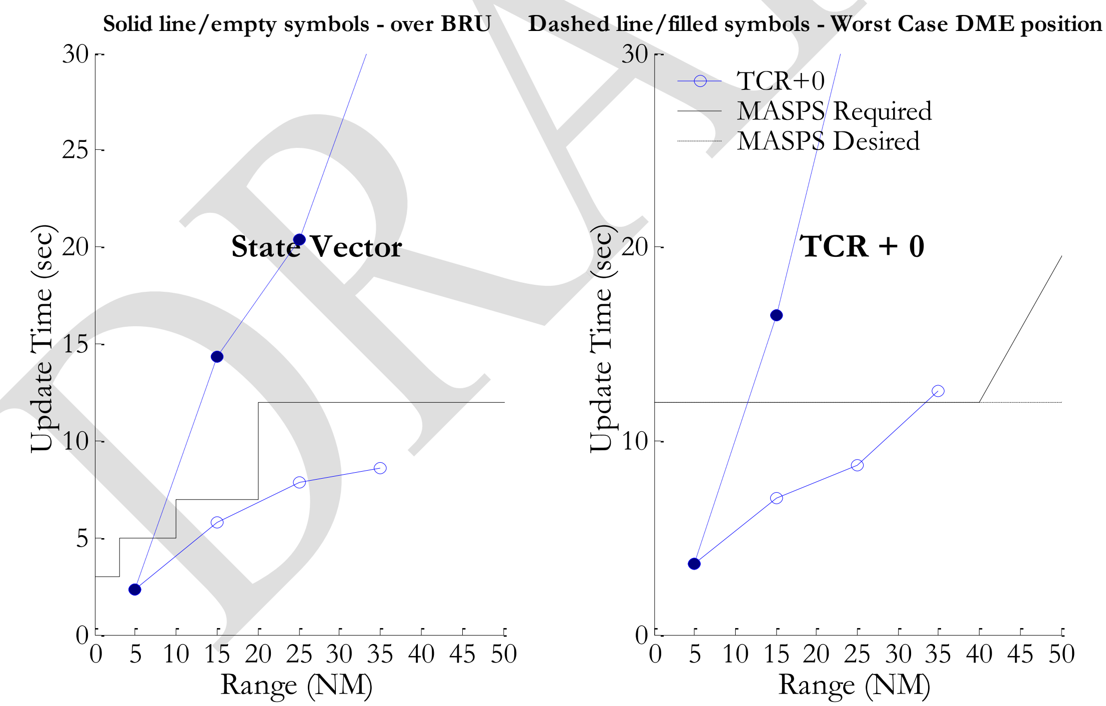
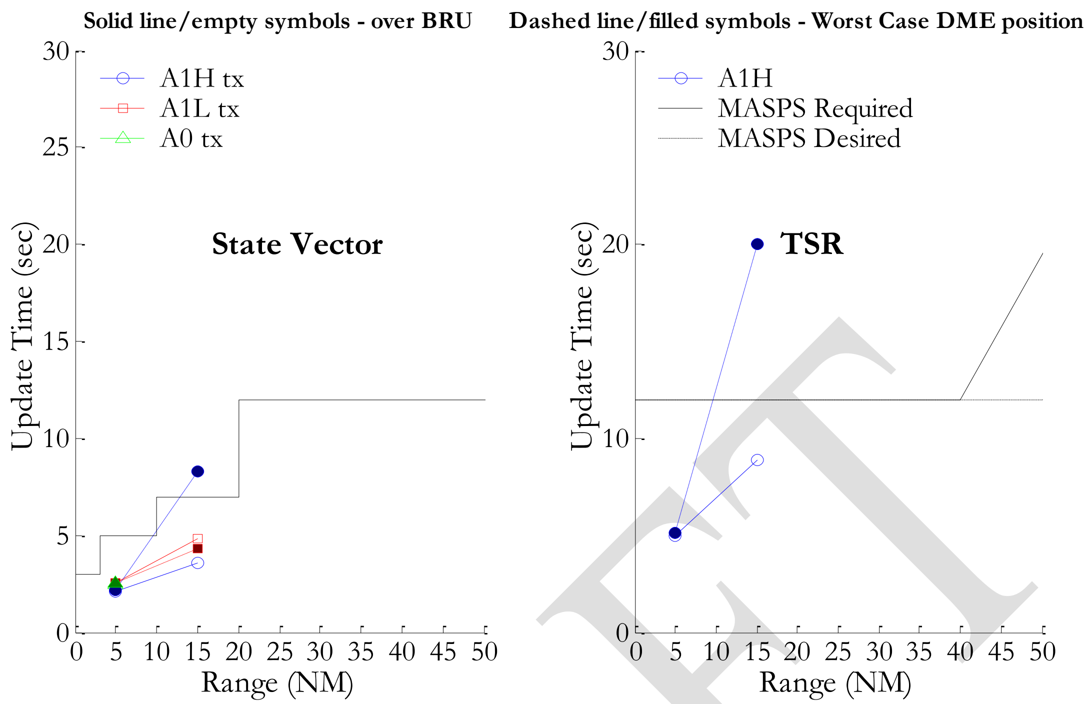


Figure K-61: A0 Receiver at FL 150 in Current Europe Receiving A2 Transmissions



<u>Figure K-62:</u> A0 Receiver at FL 150 in Current Europe Receiving A1 and A0 Transmissions

Recall that the current Core Europe scenario includes 1200 aircraft transmitting on UAT. The DME/TACAN interference environment is characterized by three on-channel plus two adjacent-channel emitters, all at the maximum allowable powers. In addition, a baseline Link 16 scenario is also included as co-channel interference.

The results for the case of an aircraft over Brussels (highest levels of UAT self-interference) in the current Core Europe scenario, which were shown in Figure K-42 through Figure K-62, may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs for both state vector and intent update rates at all ranges specified by the ADS-B MASPS.
- The Eurocontrol extension to 150 NM for A3 equipage is not met at the 95% level at the highest receiver altitude, but the 95% level is achieved to a range of 115 NM. At 150 NM the 95th percentile update time is 17 seconds. At FL 150 the Eurocontrol extension to 150 NM is met at the 95% level. As in the LA2020 case, the results at FL 150 tend to be better than those at high altitude, due to reduced self-interference at lower altitudes.
- Discussion of the air-ground coverage will be deferred to the CE2015 scenario. It is felt that the future case, with many more aircraft, is a worst-case scenario.
- Ground vehicle visibility will also be presented and discussed for the CE2015 case only, for the same reasons.

The results for the case of an aircraft in the location representing the highest levels of DME/TACAN interference in the current Core Europe scenario, which were also shown in Figure K-42 through Figure K-62, may be summarized as follows:

- Some of the ADS-B MASPS air-air requirements and desired criteria are met for some of the aircraft equipage transmit-receive pairs for both state vector and intent update rates at ranges specified by the ADS-B MASPS, but there are a number of cases where the requirements are not met.

Due to the failure to meet all of the ADS-B MASPS update requirements in the worst case DME/TACAN environment, a test case was run to examine the performance at this receiver point for a reduced rate of equipage, in order to determine a level of equipage that could be supported in the current severe DME/TACAN environment. The scenario that was used included 154 aircraft, generated in a manner identical to the other Core Europe scenarios. The location of the victim receiver remained at the worst case DME/TACAN interference location. The results are shown below in Figure K-63 through Figure K-83.

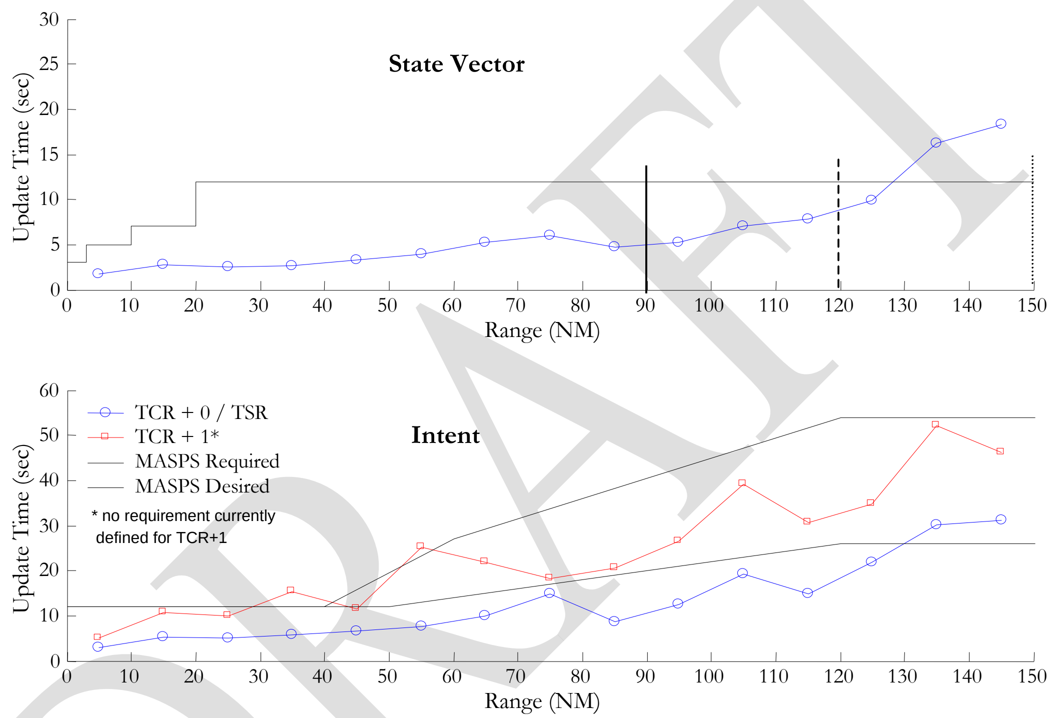


Figure K-63: A3 Receivers in the Worst-Case Current DME Position (154 equipped aircraft) at High Altitude Receiving A3 Transmissions

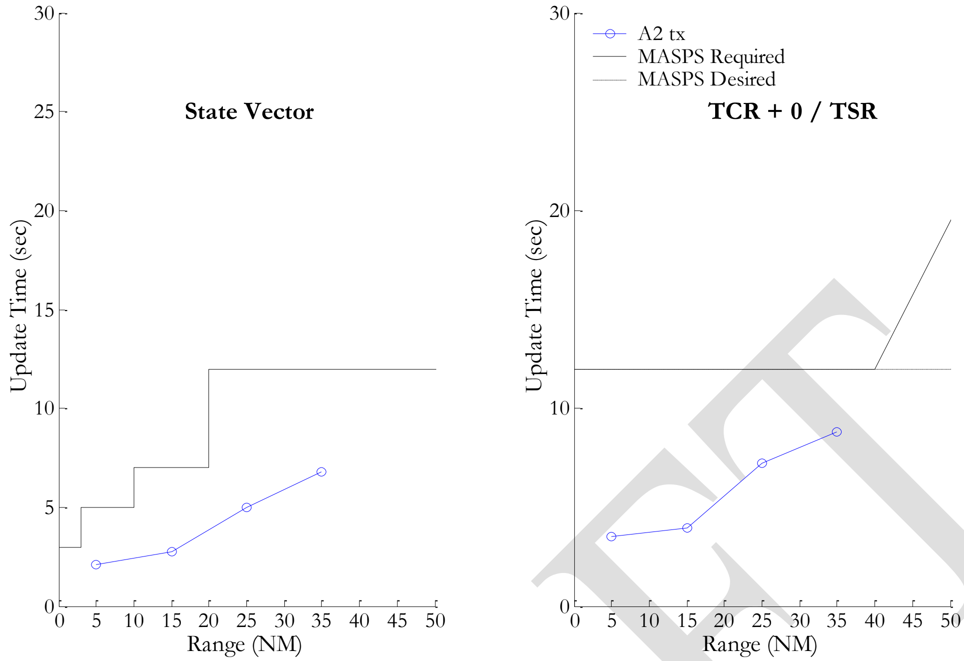


Figure K-64: **A3 Receivers in the Worst-Case Current DME Position (154 equipped aircraft) at High Altitude Receiving A2 Transmissions**

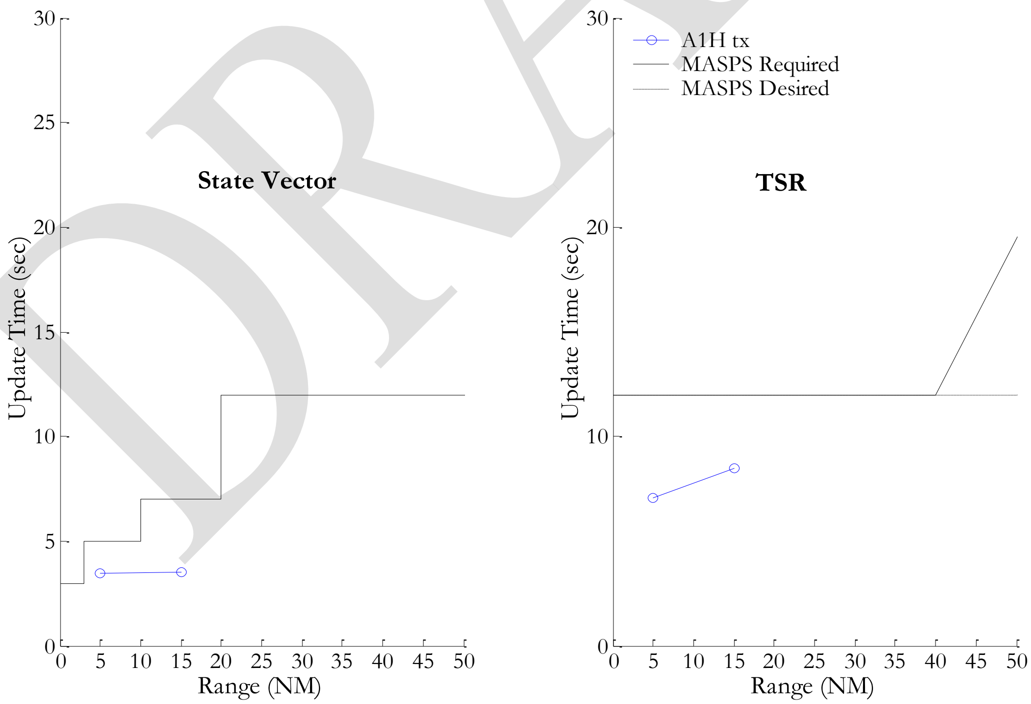


Figure K-65: **A3 Receivers in the Worst-Case Current DME Position (154 equipped aircraft) at High Altitude Receiving A1H Transmissions**

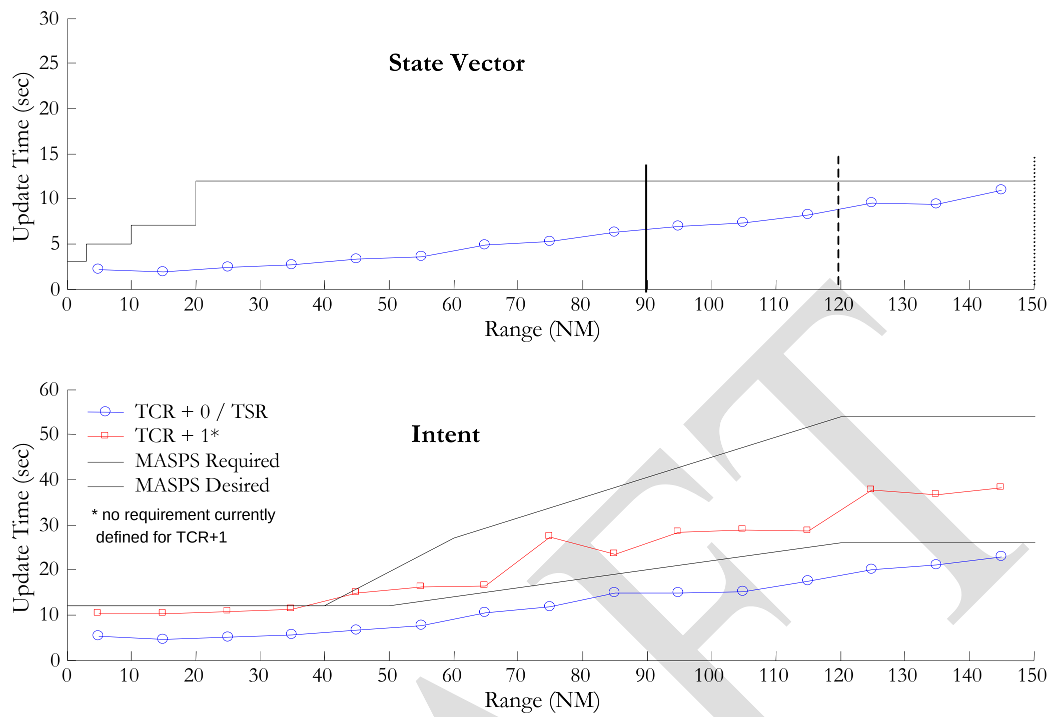


Figure K-66: A3 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions

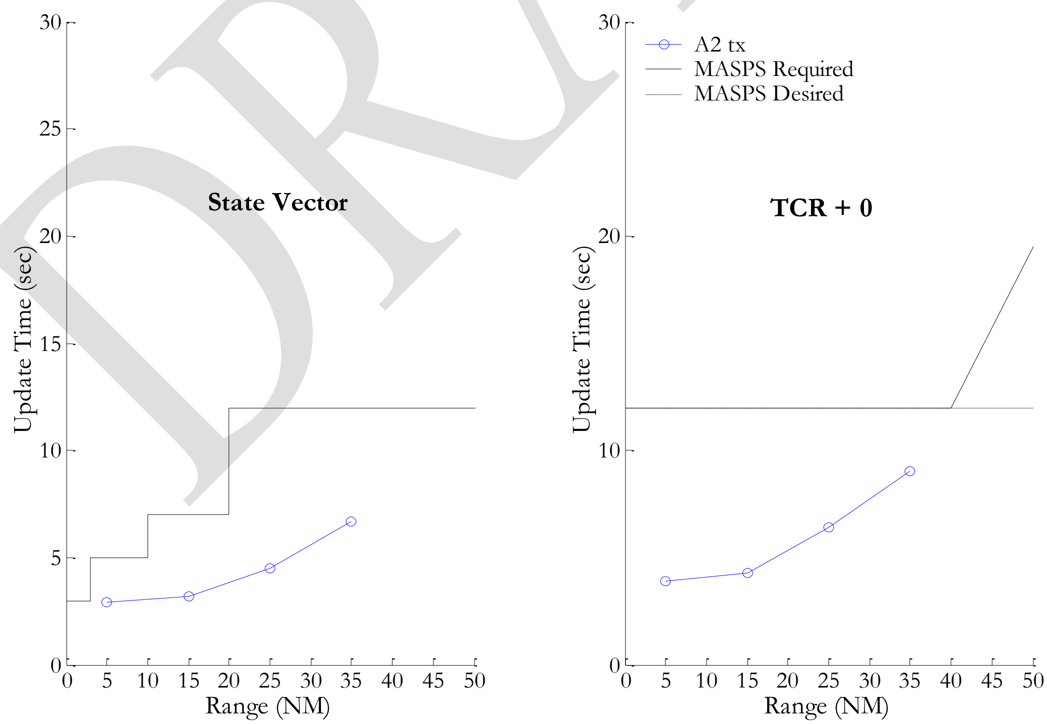


Figure K-67: A3 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A2 Transmissions

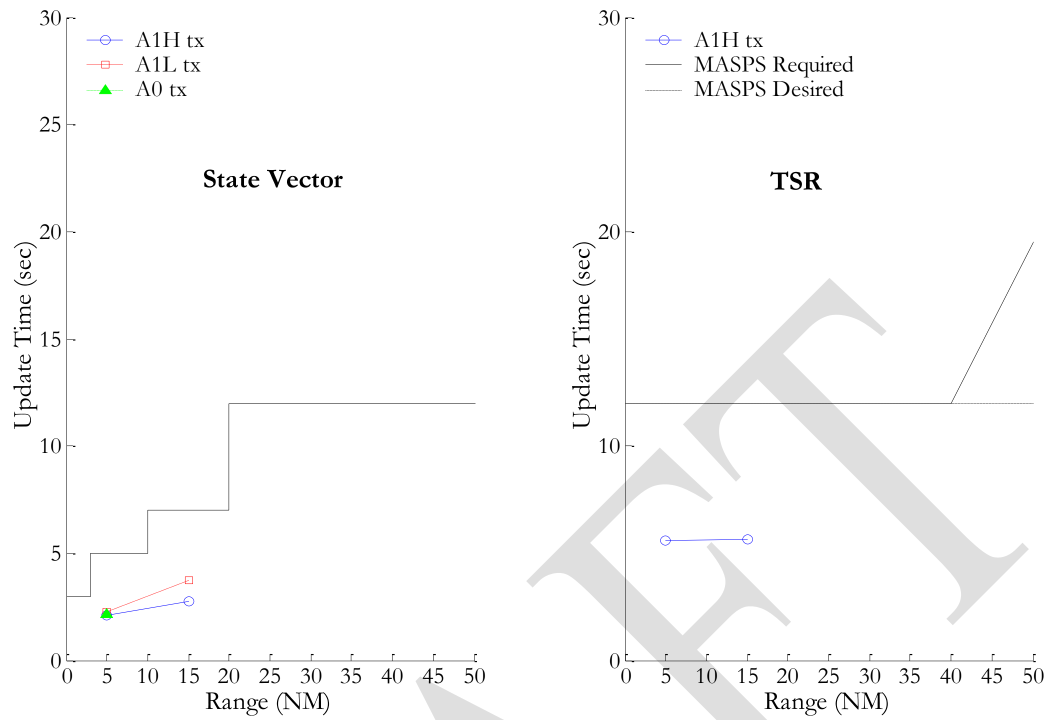


Figure K-68: **A3 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1 and A0 Transmissions**

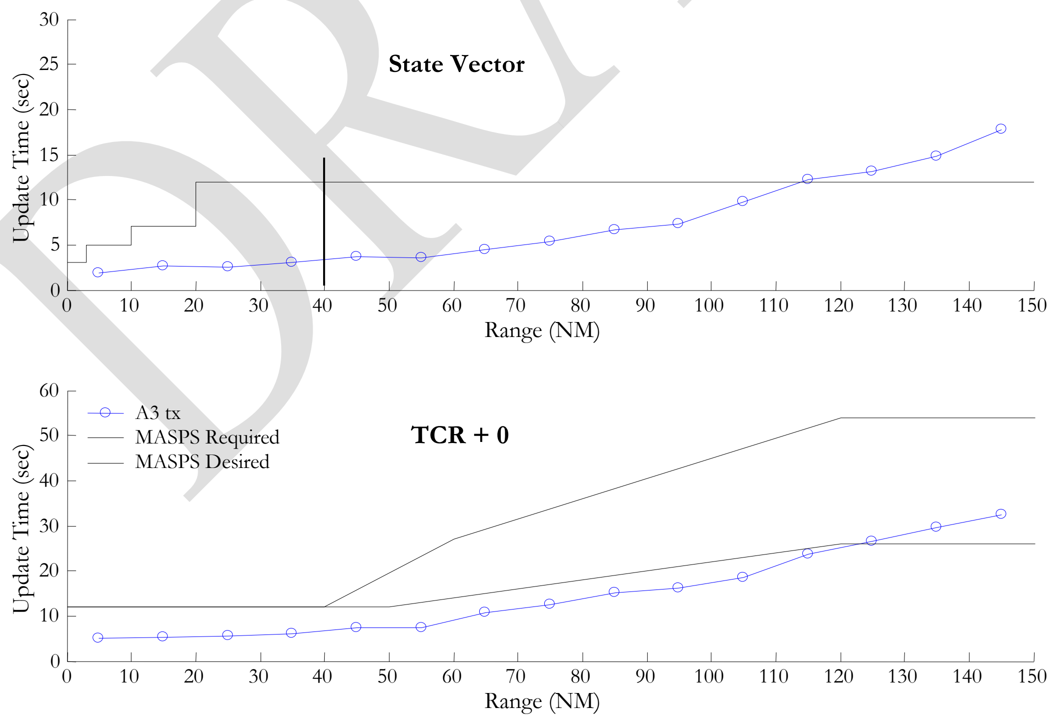
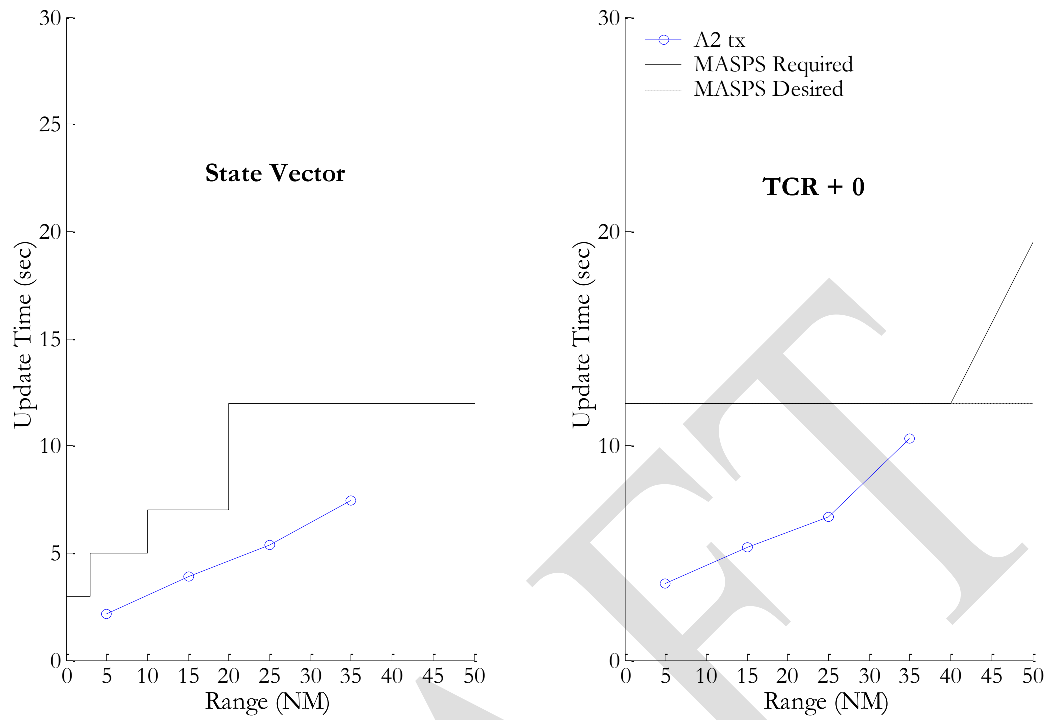
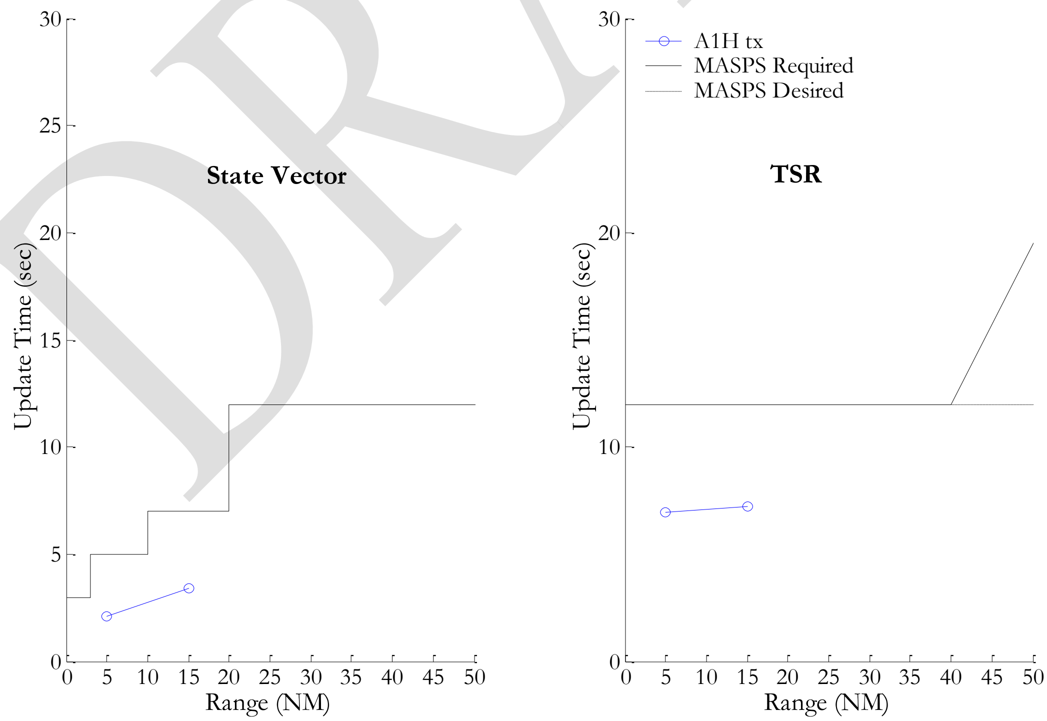


Figure K-69: **A2 Receiver at High Altitude in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions**



<u>Figure K-70:</u> A2 Receiver at High Altitude in the Current Worst-Case DME Position (154 equipped aircraft) Receiving A2 Transmissions



<u>Figure K-71:</u> A2 Receiver at High Altitude in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1H Transmissions

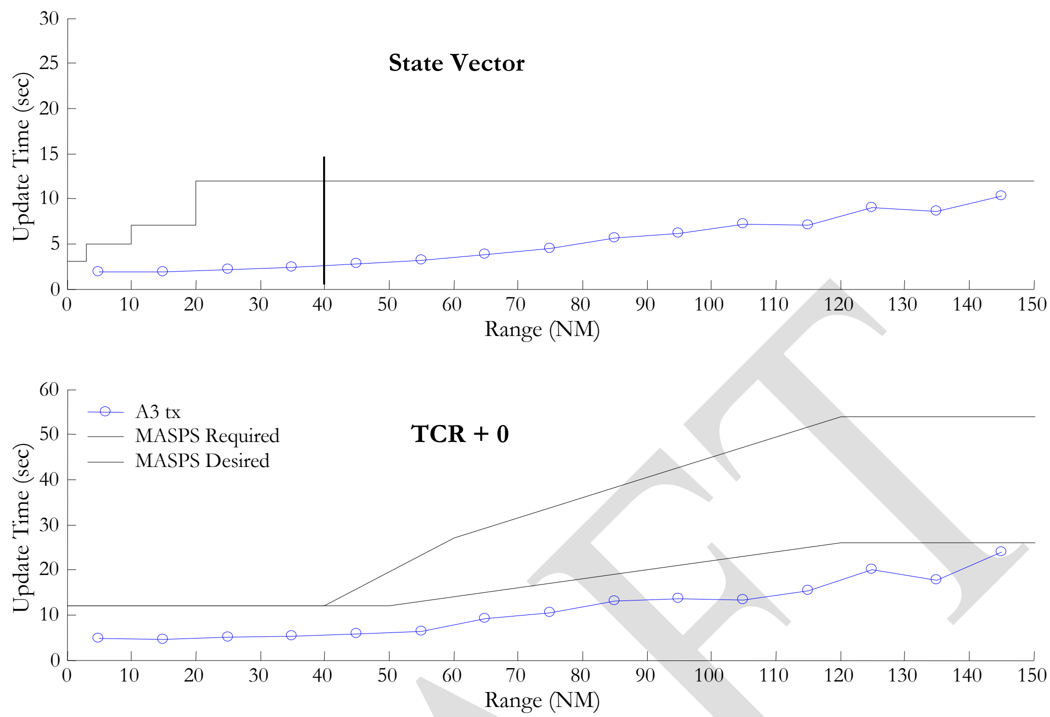


Figure K-72: A2 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions

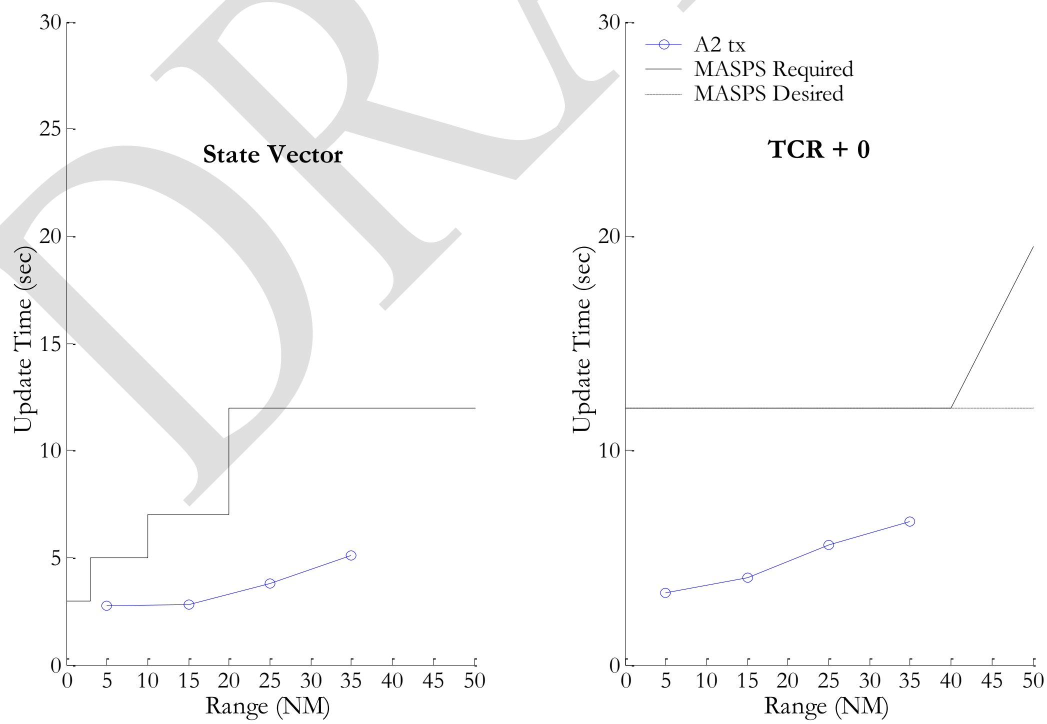
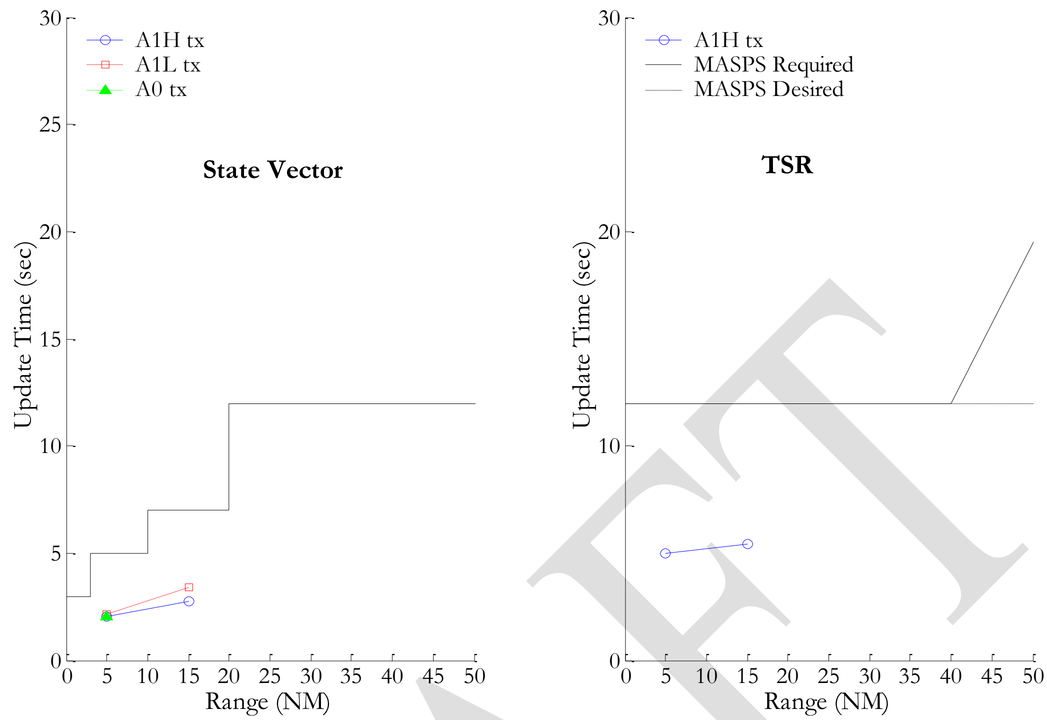
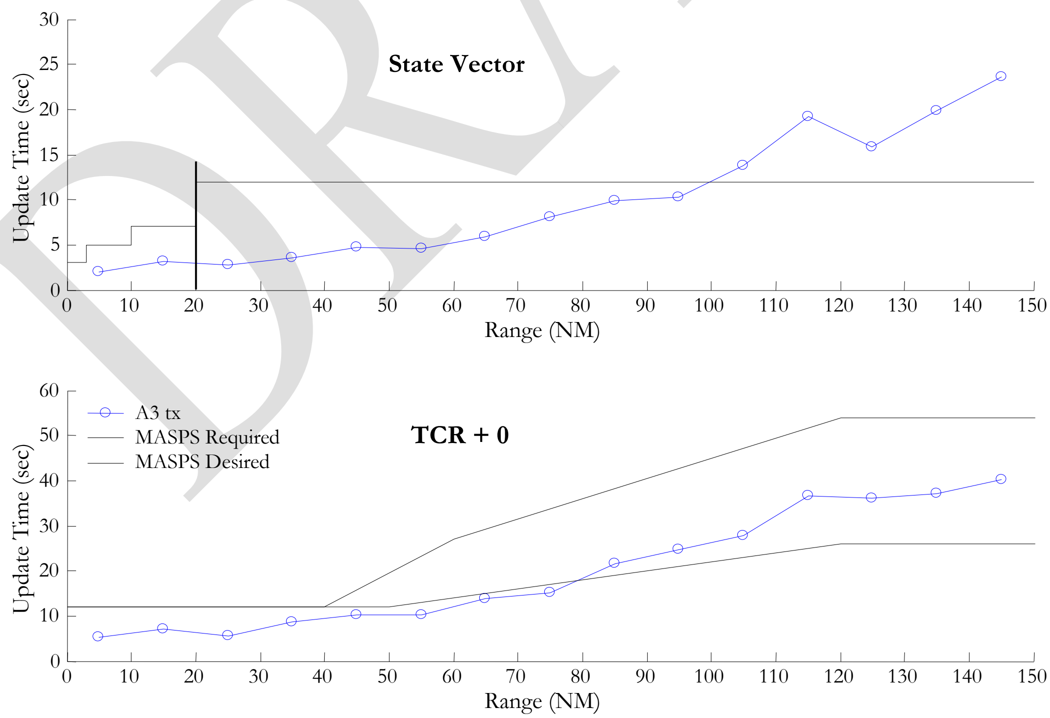


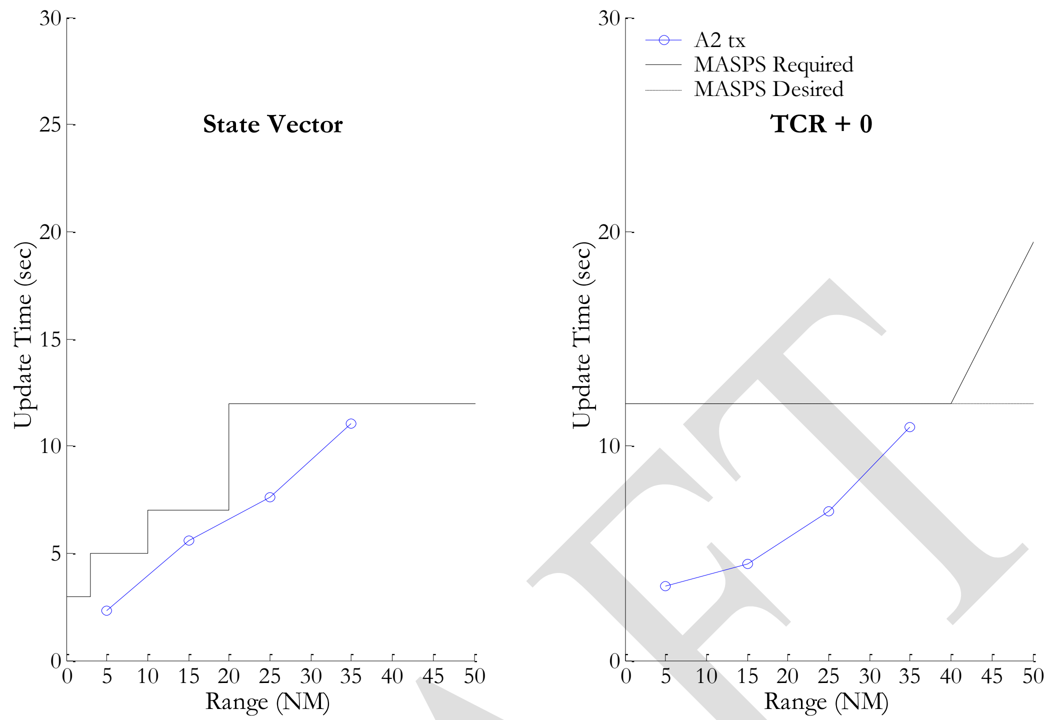
Figure K-73: A2 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A2 Transmissions



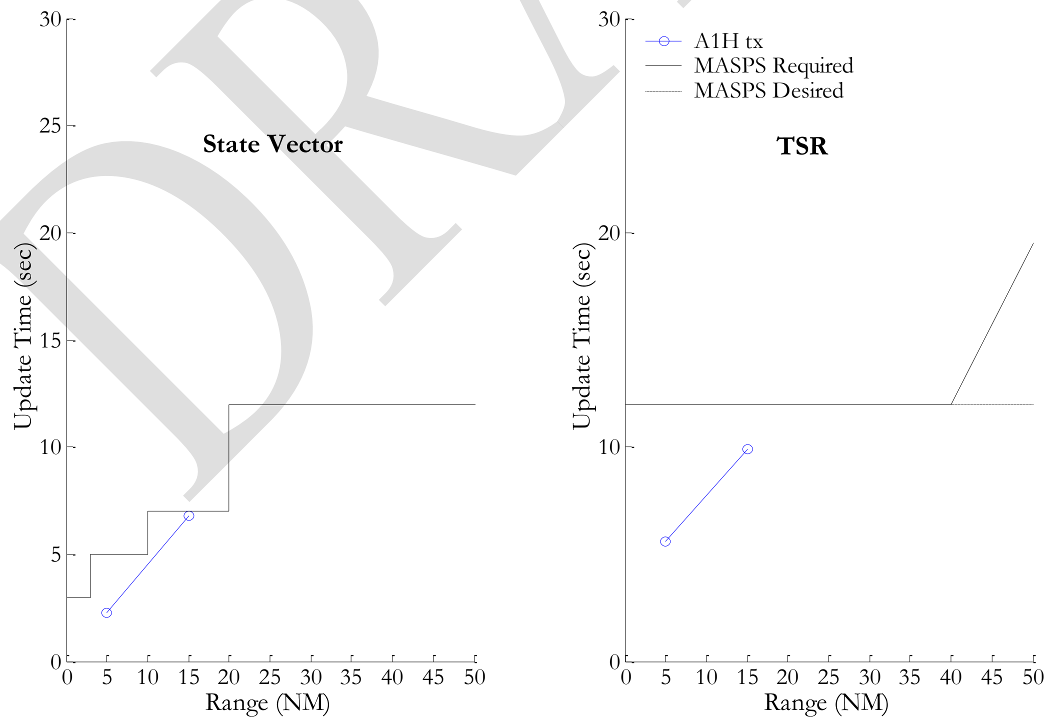
<u>Figure K-74:</u> A2 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1 and A0 Transmissions



<u>Figure K-75:</u> A1H Receiver at High Altitude in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions



<u>Figure K-76:</u> A1H Receiver at High Altitude in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A2 Transmissions



<u>Figure K-77:</u> A1H Receiver at High Altitude in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1H Transmissions

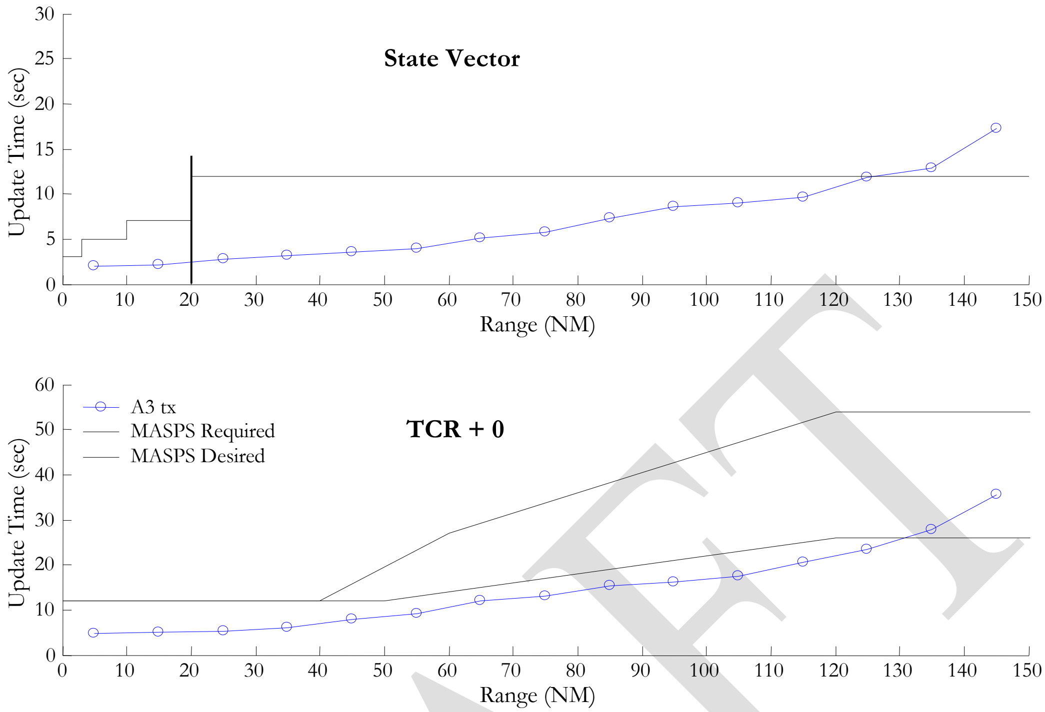


Figure K-78: **A1 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions**

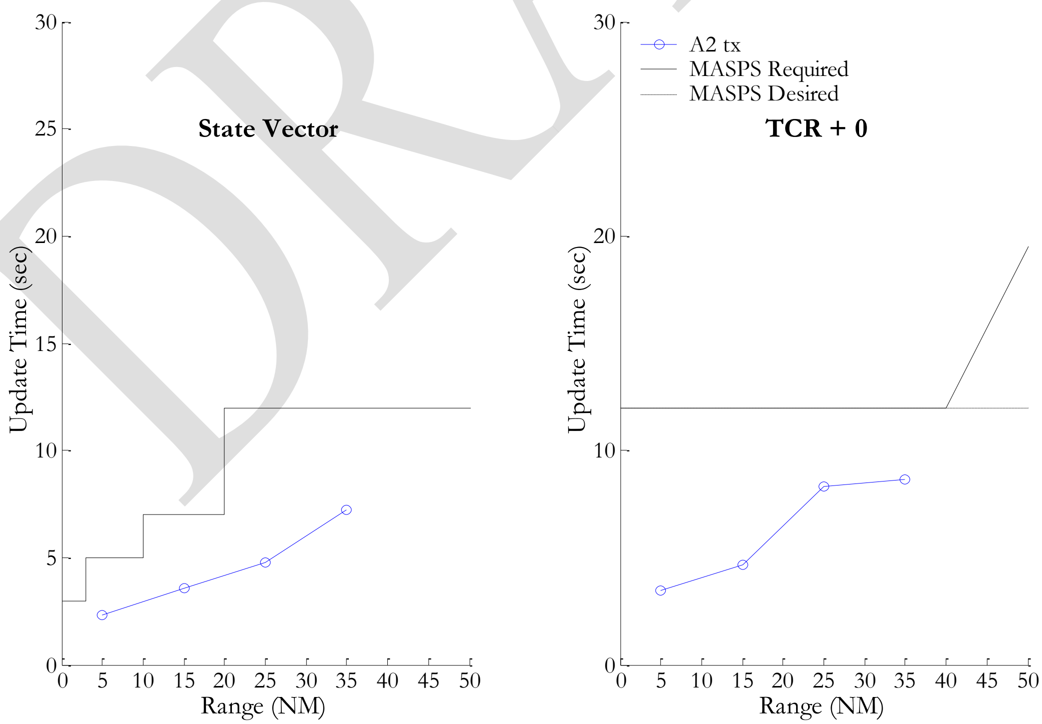


Figure K-79: **A1 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A2 Transmissions**

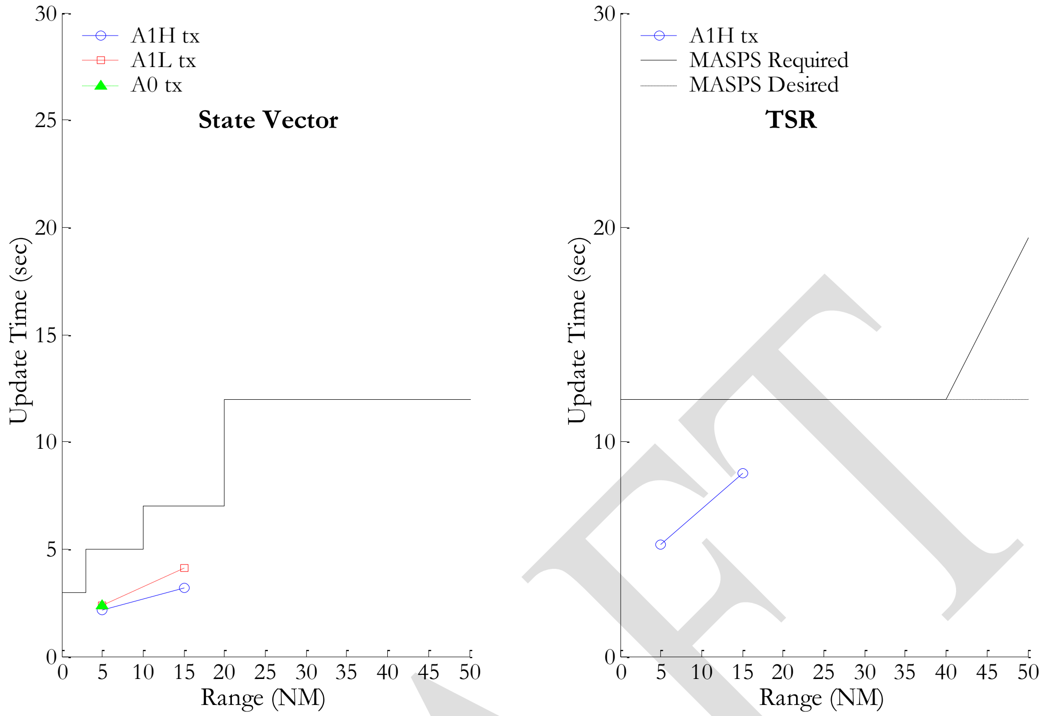


Figure K-80: A1 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1 and A0 Transmissions

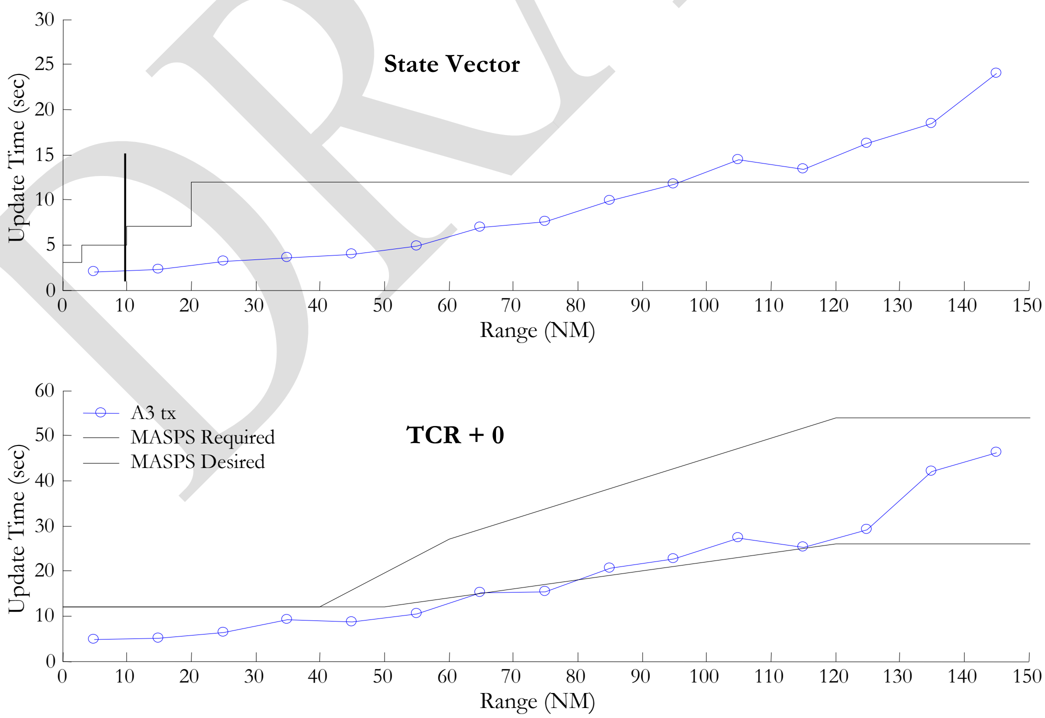


Figure K-81: A0 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A3 Transmissions

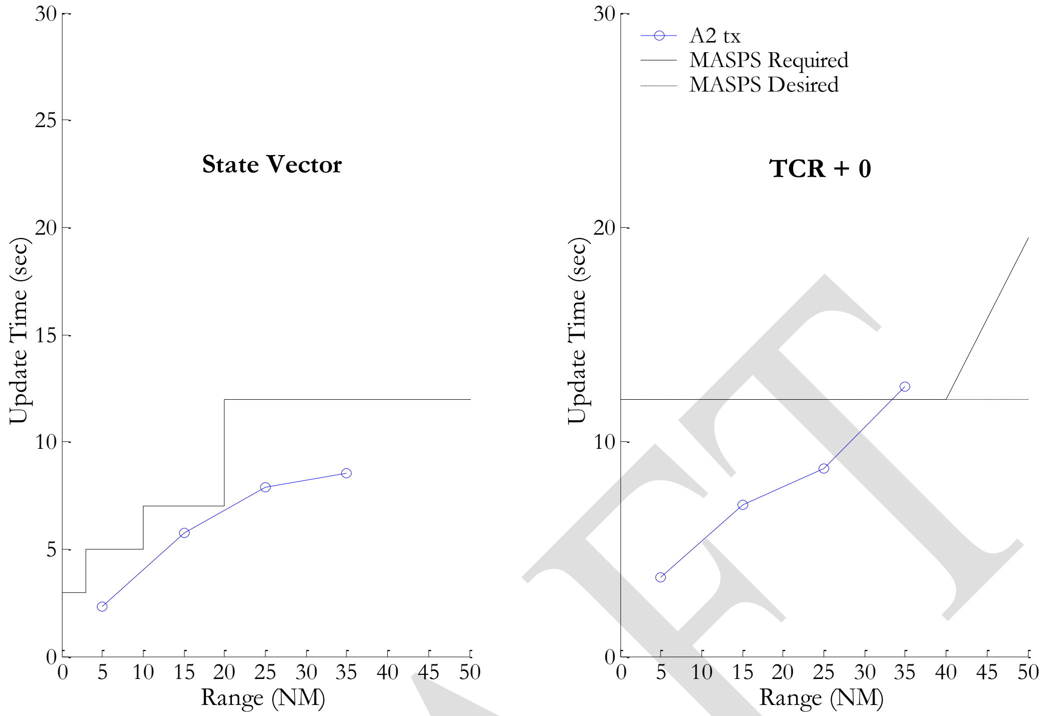


Figure K-82: **A0 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A2 Transmissions**

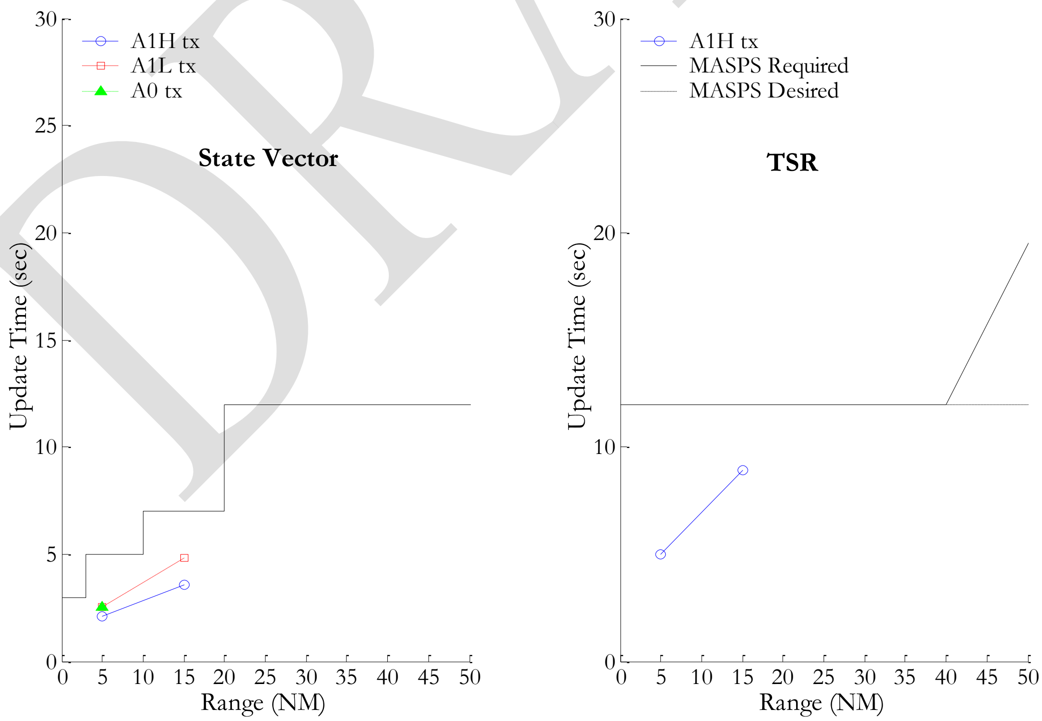


Figure K-83: **A0 Receiver at FL 150 in the Worst-Case Current DME Position (154 equipped aircraft) Receiving A1 and A0 Transmissions**

Recall that the Core Europe test case scenario includes 154 aircraft transmitting on UAT. The DME/TACAN interference environment is characterized by three on-channel plus two adjacent-channel emitters, all at the maximum allowable powers. In addition, a baseline Link 16 scenario is also included as co-channel interference.

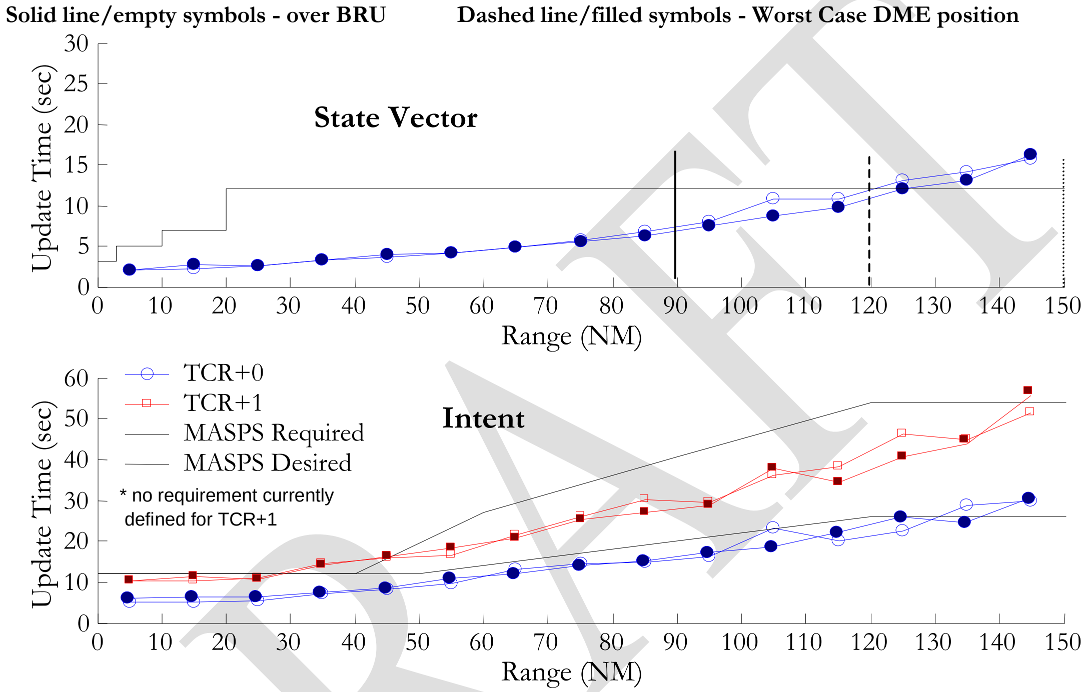
The results for the case of an aircraft in the location representing the highest levels of DME/TACAN interference in the Core Europe test case scenario with current DME/TACAN assignments, which were shown in Figure K-63 through Figure K-83, may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs for both state vector and intent update rates at all ranges specified by the MASPS.
- The Eurocontrol extension to 150 NM for A3 is not met at the 95% level at the highest receiver altitude, but the state vector 95% update time at 150 NM is 18 seconds. The 95% level is achieved to a range of 130 NM.
- The conclusion for this excursion is that, if UAT were implemented in all aircraft in Core Europe today, performance would be satisfactory in all areas, with the exception of areas that are characterized by high levels of multiple DME/TACAN transmissions on the UAT operating frequency. In those areas, at least some of the DME/TACANs would have to be moved off the UAT frequency when equipage levels reached the 12-15% levels, in order to achieve ADS-B MASPS-compliant performance.

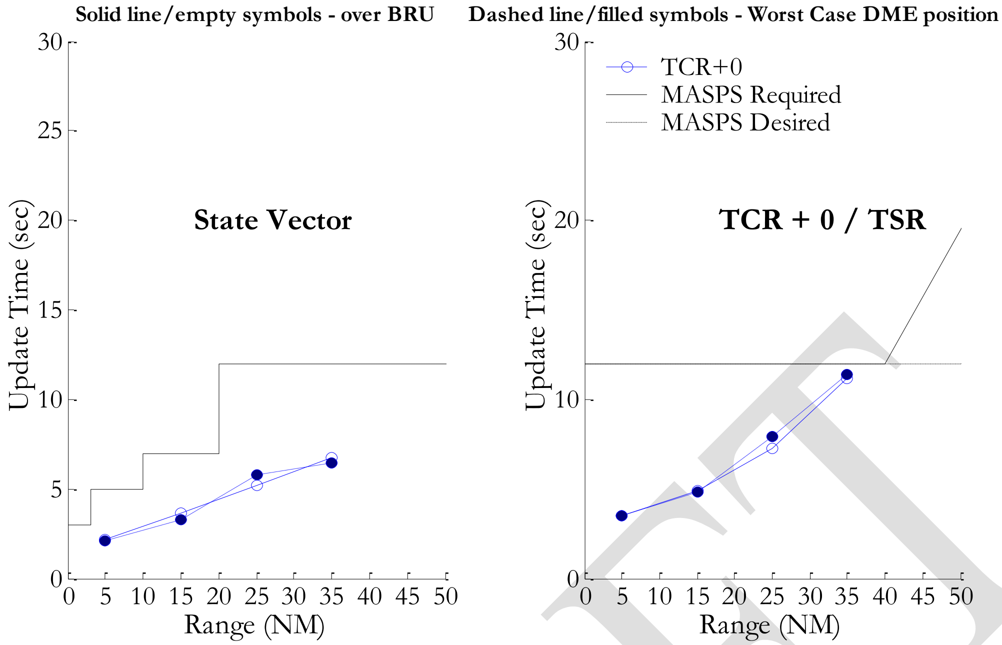
K.4.2.2 Core Europe 2015

The future Core Europe scenario (CE2015) is defined in Section K.4.2. This section presents the results of simulation runs which correspond to the assumptions stated in Section K.4.2 for the full complement of 2091 aircraft and 500 ground vehicles. Recall that DME/TACANs on 978 MHz are assumed to have been moved, and that all potential and planned DME/TACANs on 979 MHz are assumed to have been implemented and transmit at maximum allowed powers. Two locations are considered for CE2015: one in the midst of worst-case UAT self-interference, in the center of the scenario over Brussels; the other in a location that is thought to represent the worst-case DME environment, over western Germany. In addition, the Baseline B Link 16 scenario is also assumed to interfere with UAT transmissions in the CE2015 environment. Results are presented as a series of plots of 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. The ADS-B MASPS requirements are also included on the plots for reference. Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types. In addition, performance of different transmit-receive pairs is shown at several different altitudes, where appropriate.

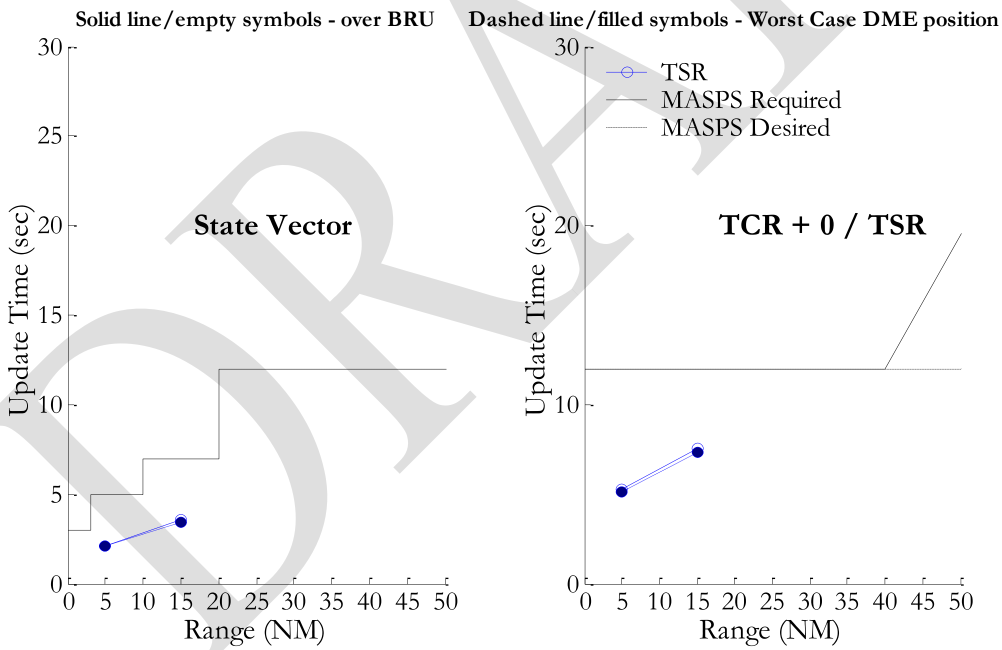
Results are presented as a series of plots in Figure K-84 to Figure K-107 for 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. Each point on the plot represents the performance of Aircraft/Vehicles within a 10 NM bin centered on the point. The ADS-B MASPS requirements for state vector, and preliminary requirements for TSR, and TCR+0 updates are shown as black lines on the plots. The ADS-B MASPS specify that the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. This does not include all of the potential Eurocontrol requirements, since the Eurocontrol requirement for four Trajectory Change Points to be broadcast was not addressed. Air-ground requirements are defined to 150 NM for all aircraft equipage classes. Performance in compliance with MASPS requirements is indicated by results that are below the black line. Note that the ADS-B MASPS range limitations for A3 transmitters are indicated on the plots by a solid vertical line, while desired range limitations are indicated by a dashed vertical line, and Eurocontrol extension to 150 NM are indicated by a dotted vertical line.



<u>Figure K-84:</u> A3 Receiver in CE2015 at High Altitude Receiving A3 Transmissions



<u>Figure K-85:</u> A3 Receiver in CE2015 at High Altitude Receiving A2 Transmissions



<u>Figure K-86:</u> A3 Receiver in CE2015 at High Altitude Receiving A1H Transmissions

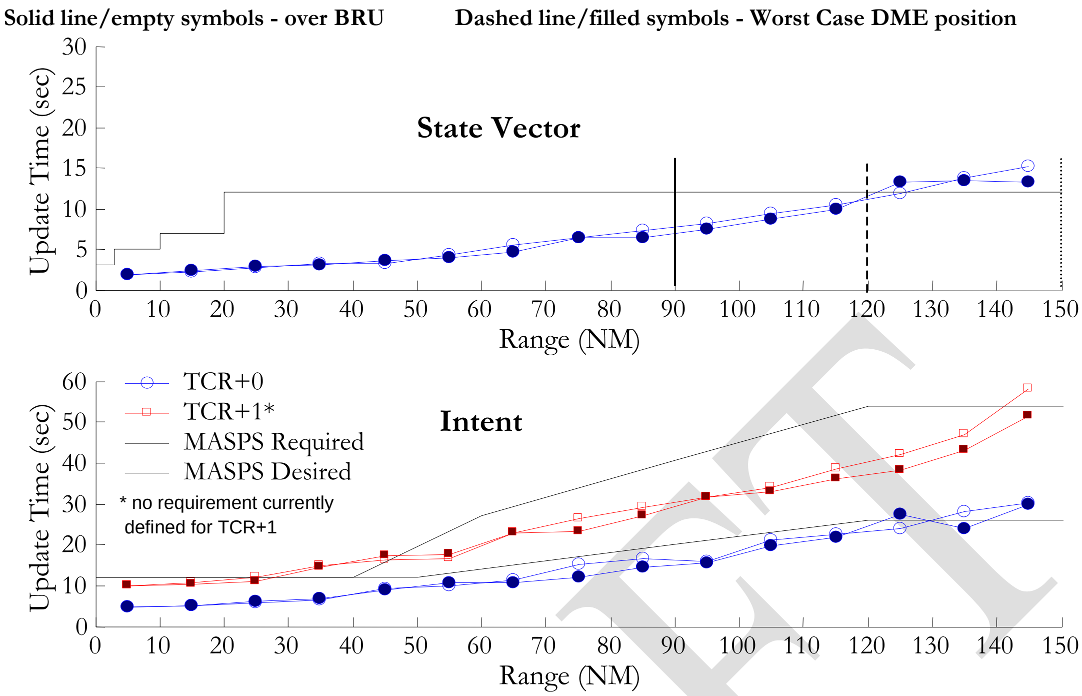


Figure K-87: A3 Receiver in CE2015 at FL 150 Receiving A3 Transmissions

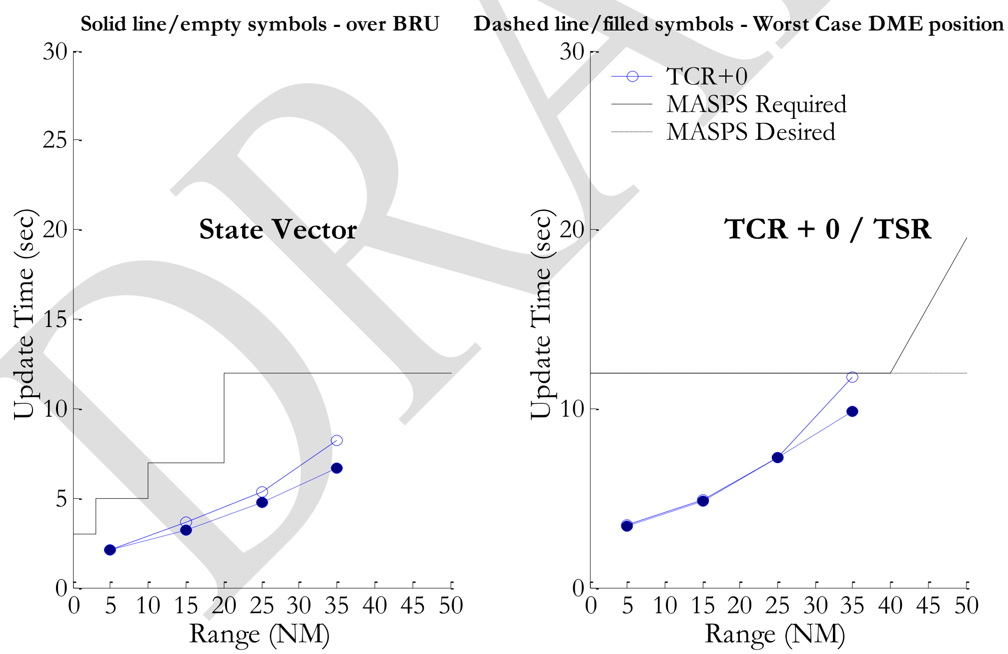
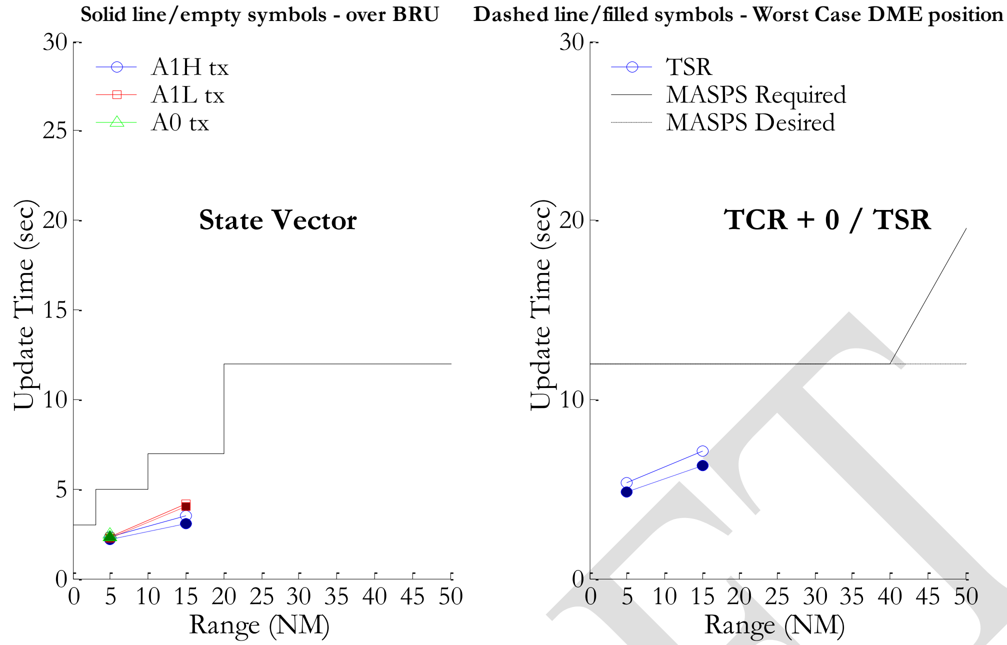
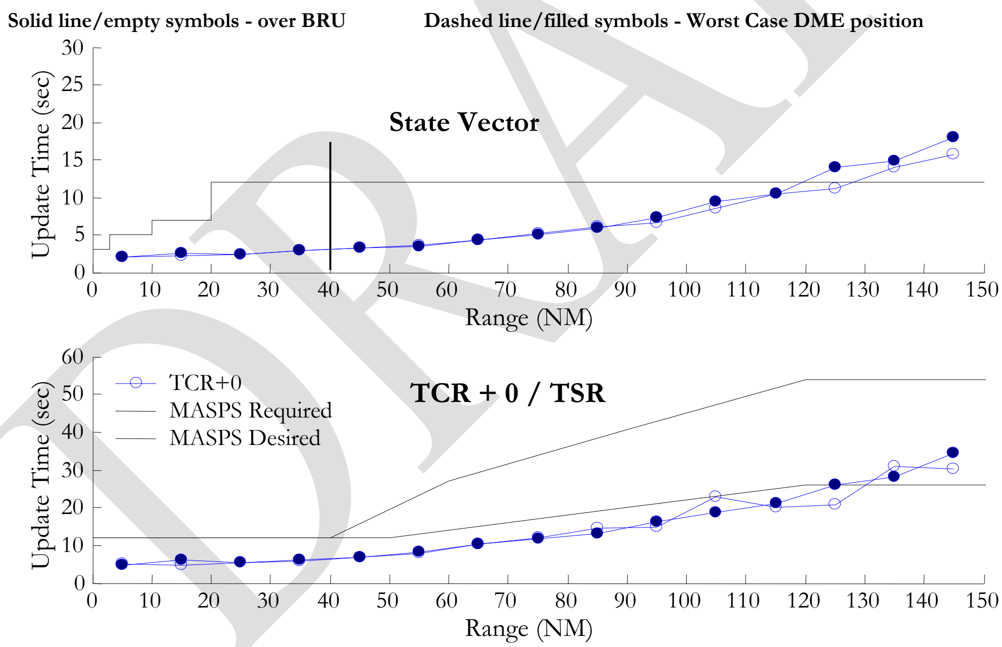


Figure K-88: A3 Receiver in CE2015 at FL 150 Receiving A2 Transmissions



<u>Figure K-89:</u> A3 Receiver in CE2015 at FL 150 Receiving A1 and A0 Transmissions



<u>Figure K-90:</u> A2 Receiver in CE2015 at High Altitude Receiving A3 Transmissions

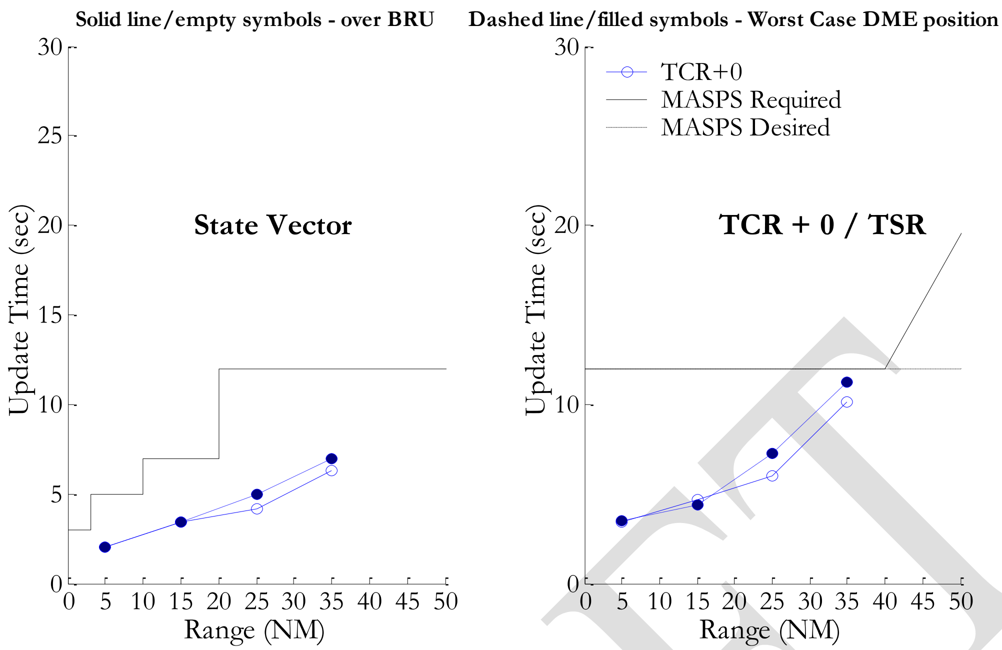


Figure K-91: **A2 Receiver in CE2015 at High Altitude Receiving A2 Transmissions**

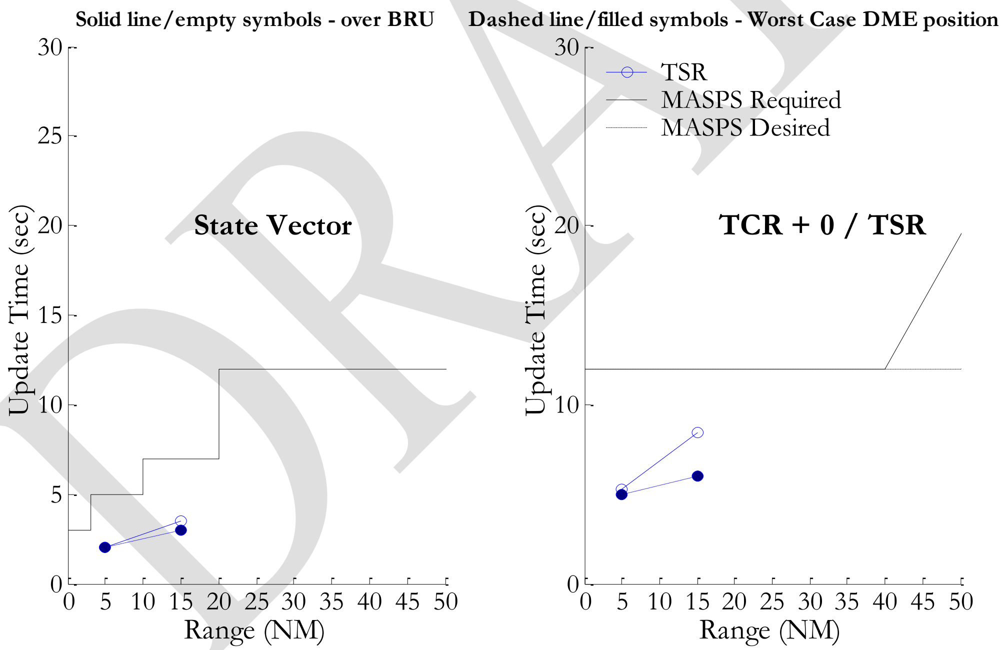
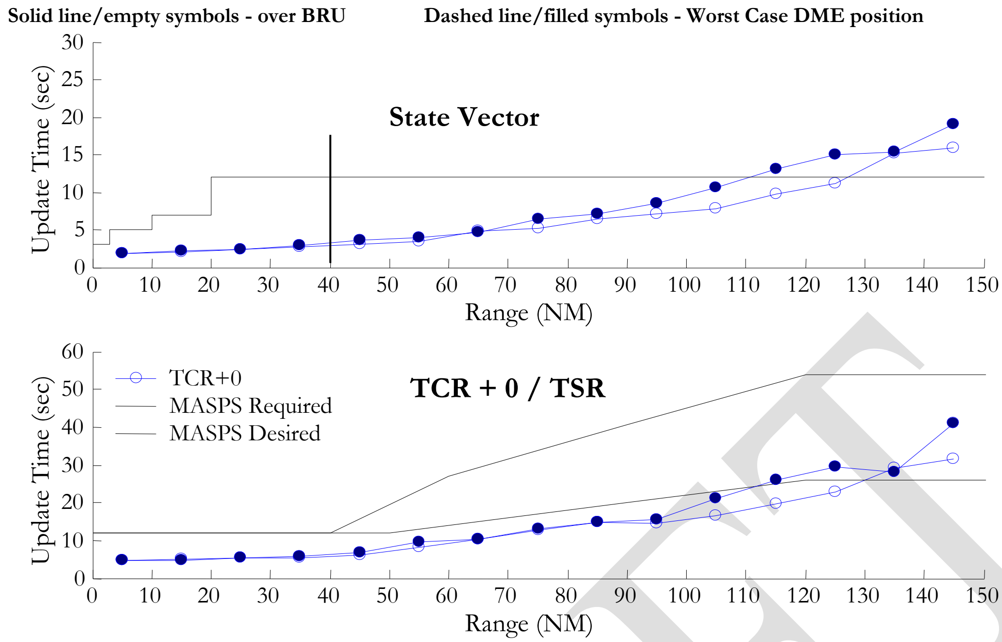
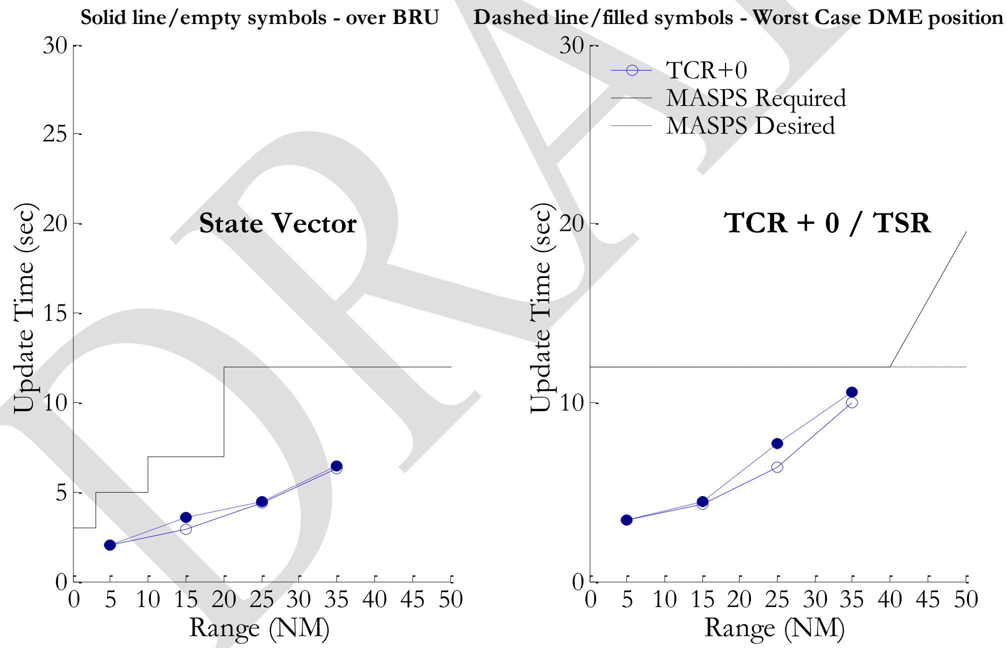


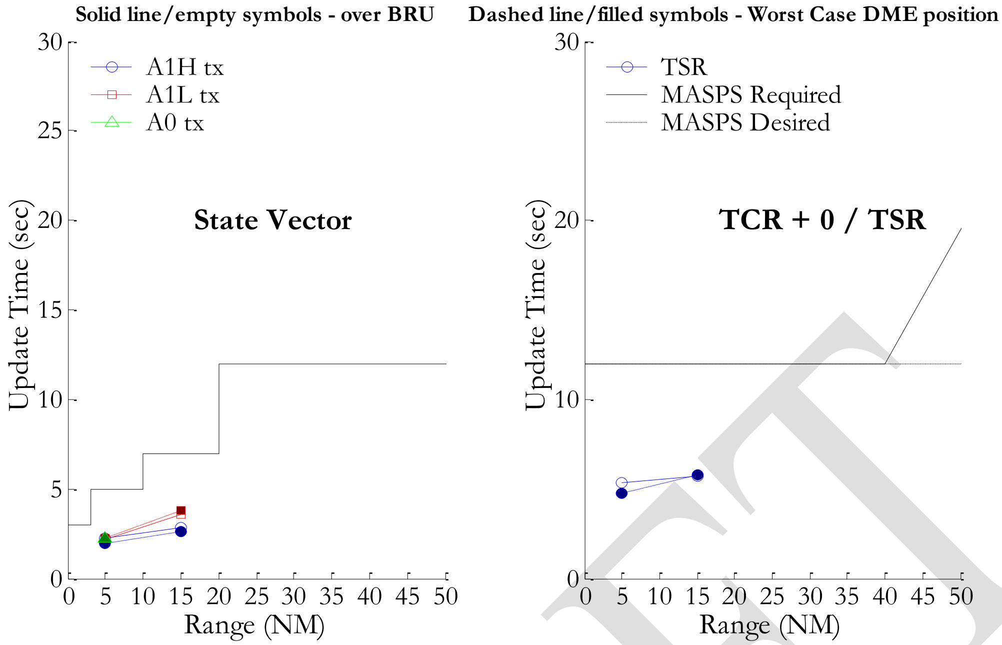
Figure K-92: **A2 Receiver in CE2015 at High Altitude Receiving A1 and A0 Transmissions**



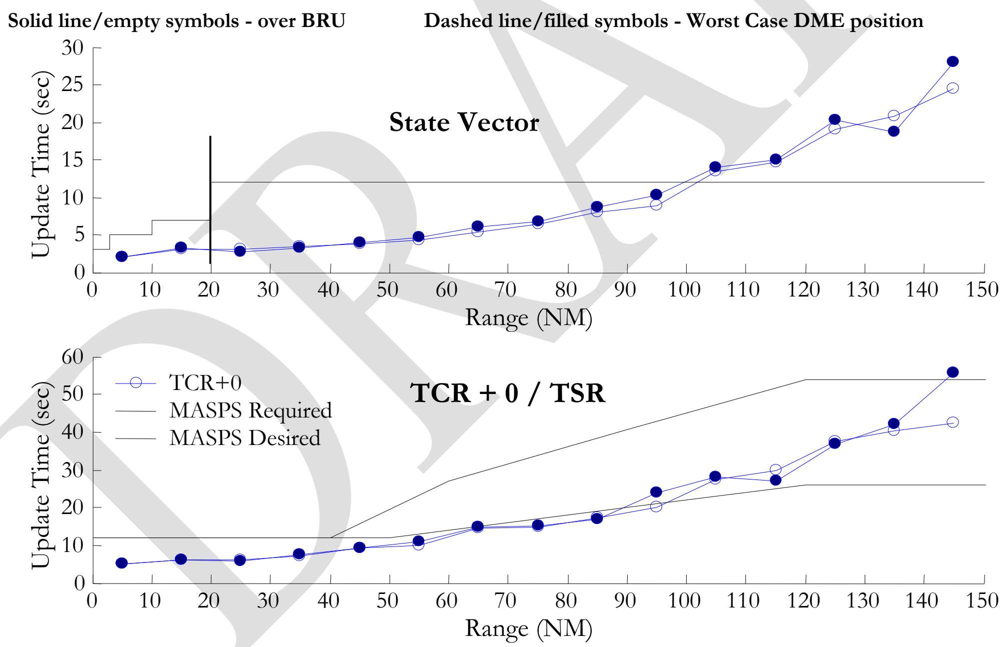
<u>Figure K-93:</u> A2 Receiver in CE2015 at FL 150 Receiving A3 Transmissions



<u>Figure K-94:</u> A2 Receiver in CE2015 at FL 150 Receiving A2 Transmissions



<u>Figure K-95:</u> A2 Receiver in CE2015 at FL 150 Receiving A1 and A0 Transmissions



<u>Figure K-96:</u> A1H Receiver in CE2015 at High Altitude Receiving A3 Transmissions

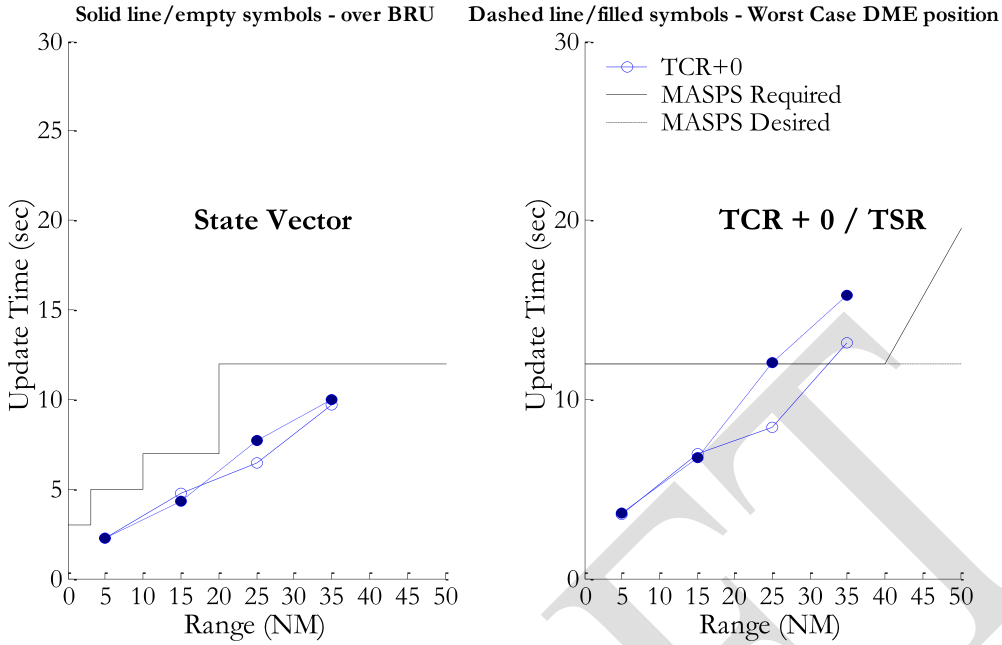


Figure K-97: A1H Receiver in CE2015 at High Altitude Receiving A2 Transmissions

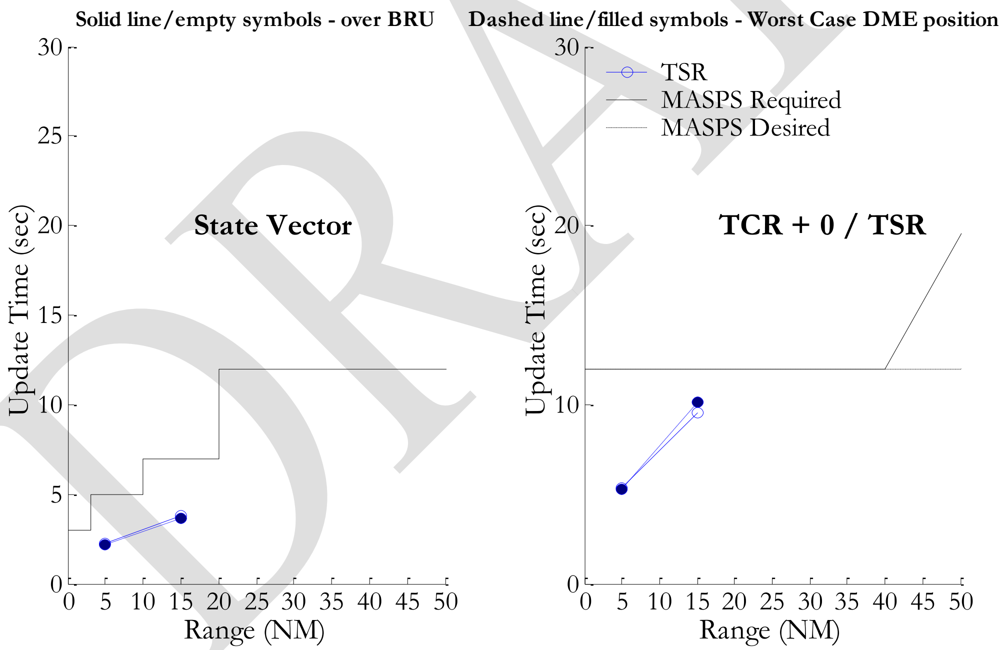


Figure K-98: A1H Receiver in CE2015 at High Altitude Receiving A1H Transmissions

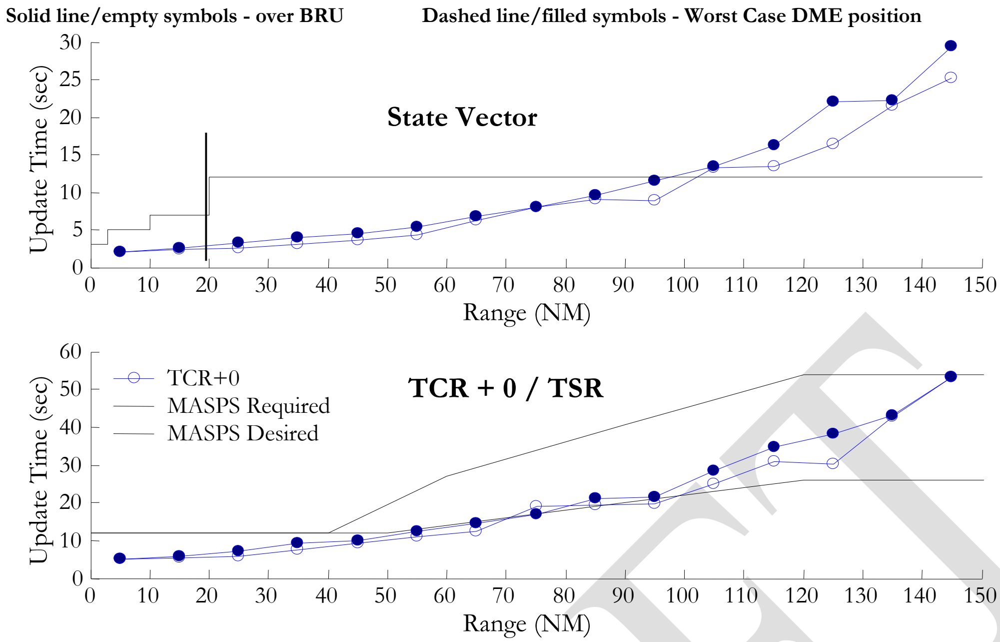


Figure K-99: A1 Receiver in CE2015 at FL 150 Receiving A3 Transmissions

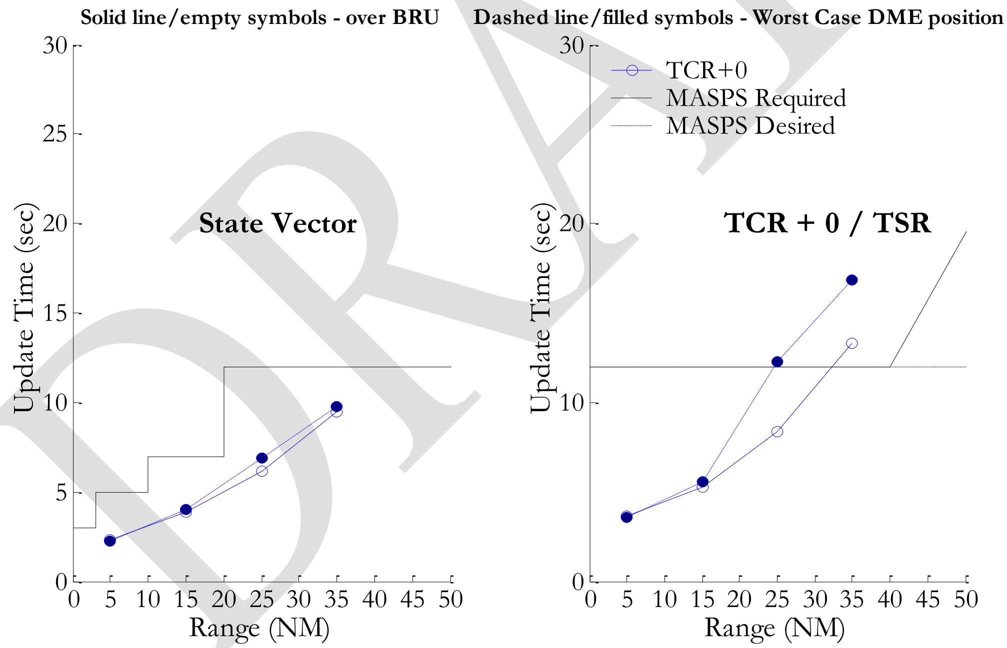


Figure K-100: A1 Receiver in CE2015 at FL 150 Receiving A2 Transmissions

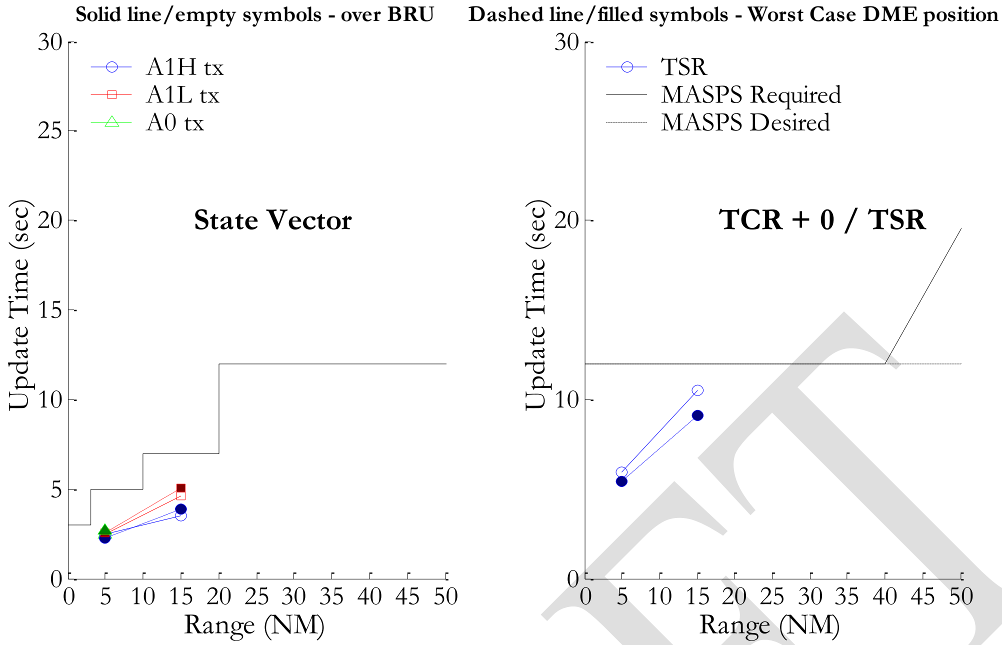


Figure K-101: A1 Receiver in CE2015 at FL 150 Receiving A1 and A0 Transmissions

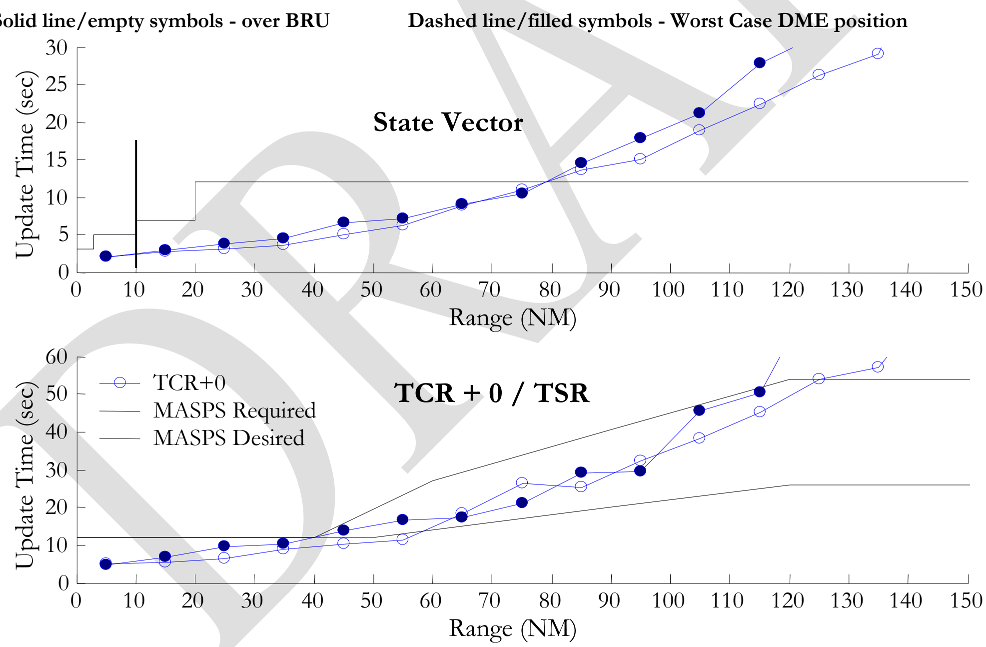
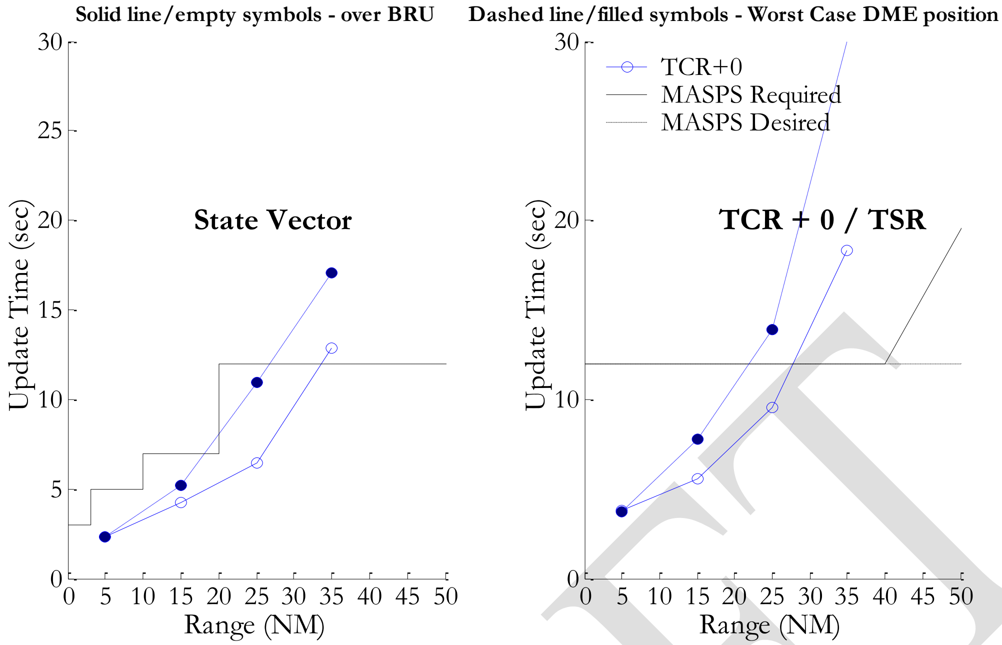
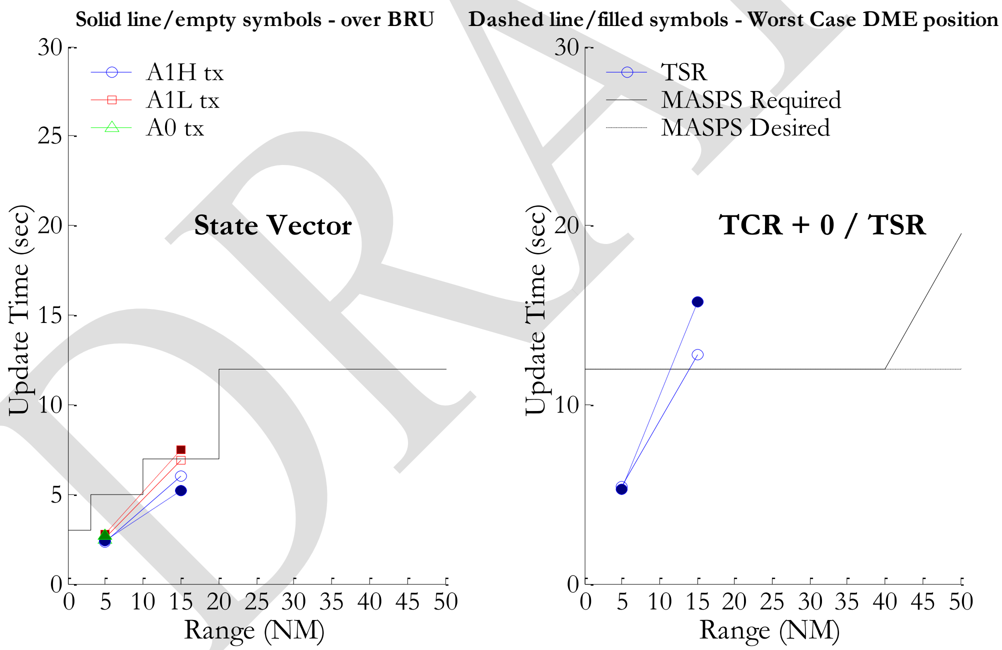


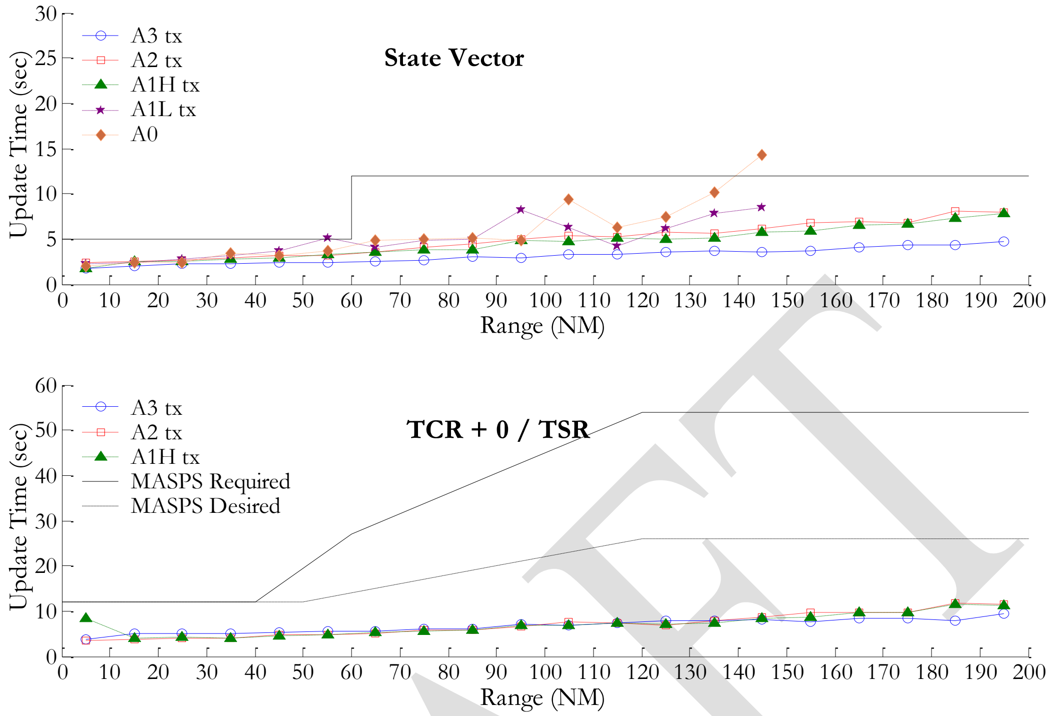
Figure K-102: A0 Receiver in CE2015 at FL 150 Receiving A3 Transmissions



<u>Figure K-103:</u> A0 Receiver in CE2015 at FL 150 Receiving A2 Transmissions



<u>Figure K-104:</u> A0 Receiver in CE2015 at FL 150 Receiving A1 and A0 Transmissions



<u>Figure K-105:</u> Ground Receiver in CE2015 with 3-Sector Antenna in Brussels Receiving all Equipage Transmissions

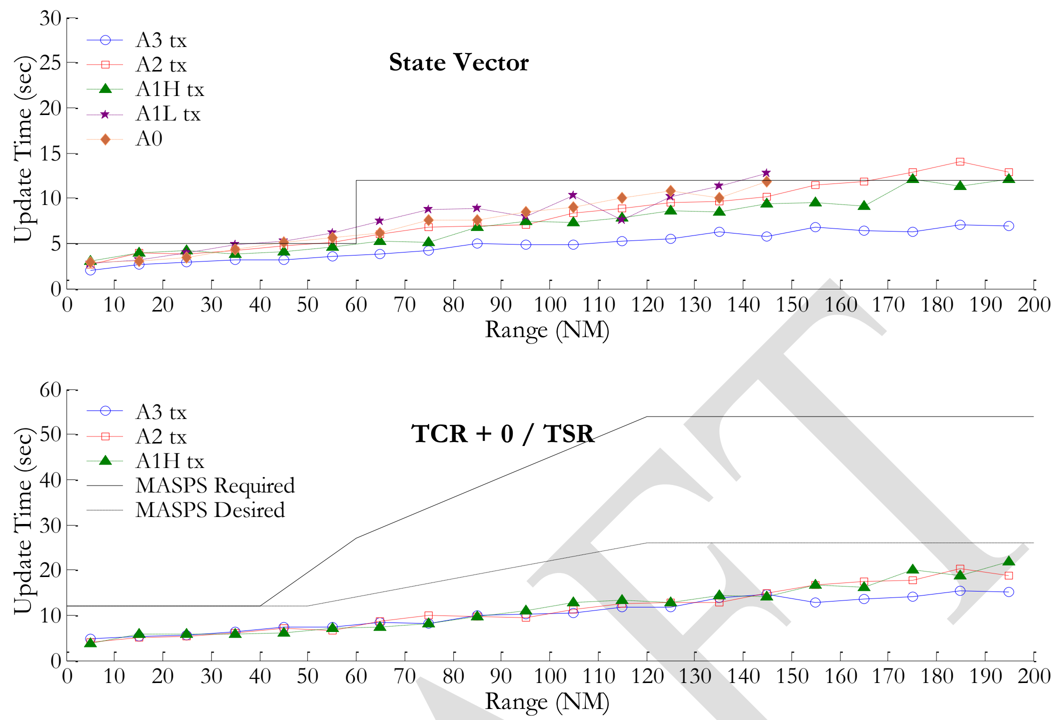


Figure K-106: Ground Receiver in CE2015 with 3-Sector Antenna in Brussels, co-located with a 979 MHz TACAN delivering –50 dBm power to antenna, Receiving All Equipage Transmissions

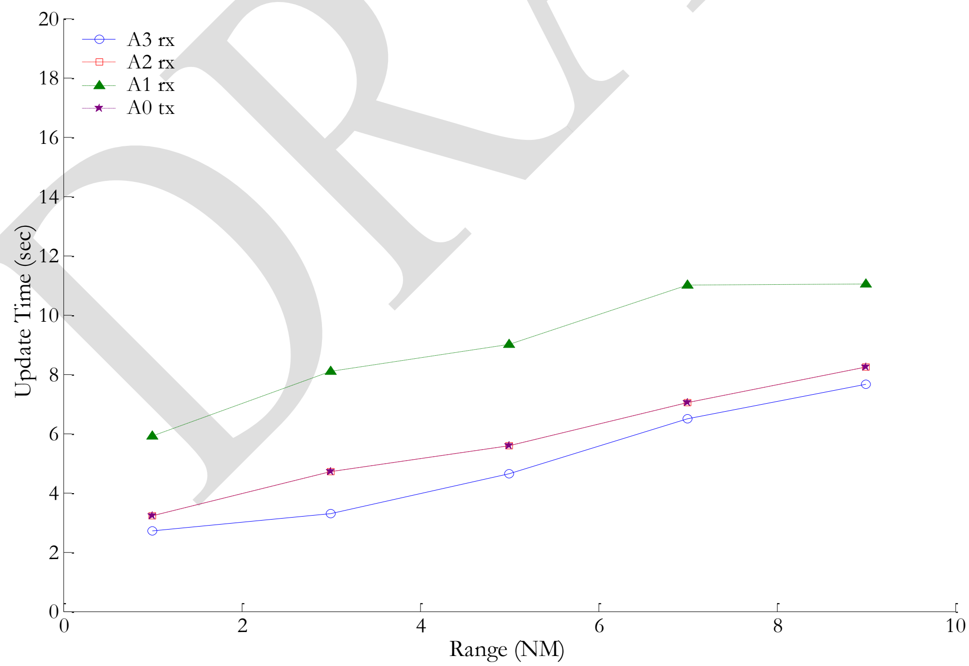


Figure K-107: Receptions of Ground Vehicle Transmissions by All Equipage Classes on Approach (at constant 2000 foot altitude) in CE2015 with 10 kW 979 MHz TACAN at Airport

Recall that the CE2015 scenario includes 2091 aircraft and 500 ground vehicles transmitting on UAT. The DME/TACAN interference environment is characterized by up to four adjacent-channel emitters, all at the maximum allowable powers. In addition, a baseline Link 16 scenario is also included as co-channel interference.

The UAT air-air performance in Core Europe shown in Figure K-84 through Figure K-104 is summarized in Table K-2. This summary indicates that the UAT System is projected to be fully compliant with the ADS-B MASPS (RTCA/DO-242A) air-to-air report update requirements at both the required and desired ranges.

Table K-2: Ranges of ADS-B MASPS Compliance for UAT Transmit-Receive Combinations in CE 2015 Scenario

	RECEIVER			
TRANSMITTER	**A3**	**A2**	**A1**	**A0**
A3	120-125	40+	20+	10+
A2	40+	40+	20+	10+
A1H	20+	20+	20+	10+
A1L	20+	20+	20+	10+
A0	10+	10+	10+	10+

The results for Core Europe 2015 shown in Figure K-84 through Figure K-107 may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs for both state vector and intent update rates at all ranges specified by the MASPS.
- The Eurocontrol extension to 150 NM for A3 equipage is not met at the 95% level, but the 95% state vector update time at 150 NM is 15-16 seconds, depending on receiver altitude and location. The 95% level is achieved to a range of around 120-125 NM, depending on receiver altitude and location.
- All known air-ground update rate requirements are substantially met for all classes of aircraft out to at least 150 NM, in the absence of a co-located TACAN emitter, by using a three-sector antenna. A test case was run, which included a 10 kW co-located 979 MHz TACAN. It was determined that the TACAN signal at the receive antenna had to be received at a level that did not exceed –50 dB, in order for all equipage classes to meet air-ground requirements. This corresponds to an isolation of 40 dB from the receive antenna, in addition to that provided by a 50 foot separation distance between the TACAN transmitter and ground receiver plus isolation provided by the receive antenna null. This could be achieved by increasing the separation distance, for example.
- System performance results are presented for updates of ground vehicles to an aircraft on approach. We know of no specific ADS-B MASPS requirements for this situation.

K.4.3 Low Density Scenario

In addition to the two high-density scenarios described above, a scenario was also run to represent low-density traffic levels. This scenario, for simplicity, was developed by scaling the current LA Basin distributions downward by a factor of five, amounting to 360 total aircraft. These aircraft are uniformly distributed in the horizontal plane within a circle of 400 nautical miles. In the vertical direction, they are distributed uniformly between 25,000 feet and 37,000 feet. The velocities are all set to 450 knots and are randomly distributed in azimuth. All of the aircraft are assumed to be A3 equipped. In order to evaluate the performance of a ground receiver in this environment, one was located at the center of the scenario, along with a co-located TACAN transmitter at 979 MHz.

Results of the MAUS runs for the low-density scenario are shown in Figure K-108 and Figure K-109, and conclusions are presented below. The ADS-B MASPS requirements for state vector and TSR updates, and preliminary requirements for TCR+0 updates are shown as black lines on the plots. Although results for TCR+1 transmissions are shown, there are currently no requirements that have been set for TCR+1 reception. The ADS-B MASPS specify that the maximum ranges for air-air update rates required for A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. Performance in compliance with MASPS requirements is indicated by results that are below the black line.

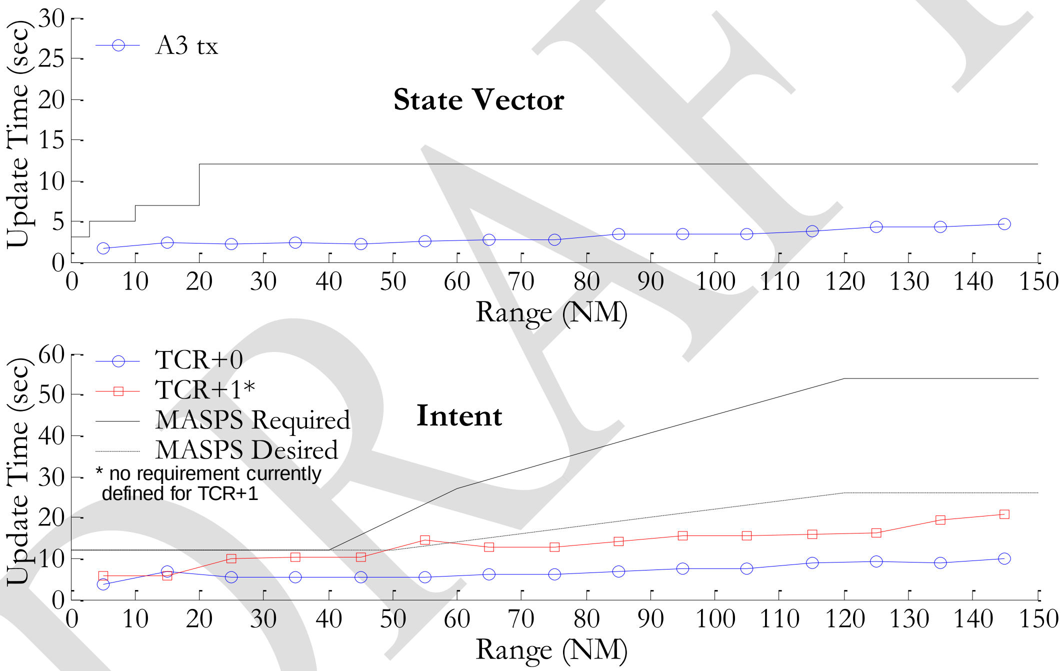


Figure K-108: A3 Receiver in Low Density Scenario Receiving A3 Transmissions

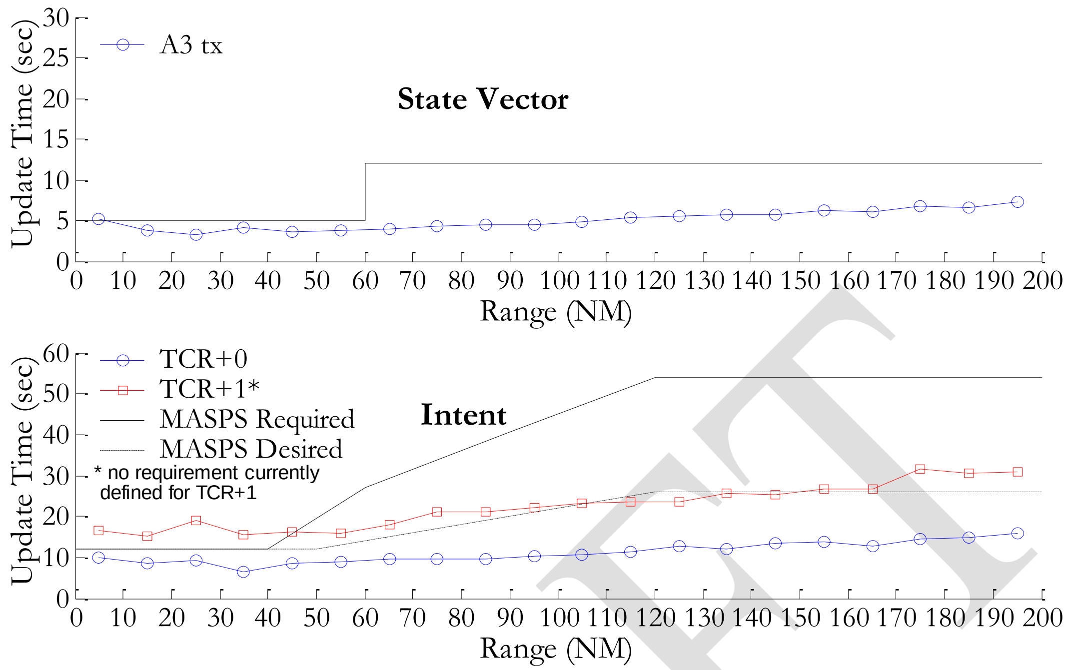


Figure K-109: Receptions of A3 Transmissions by a Standard Ground Receiver in a Low Density Scenario co-located with a TACAN at 979 MHz with –30 dBm Power at the UAT Antenna

The results for the low-density scenario may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for all aircraft for both state vector and intent update rates at all ranges specified by the ADS-B MASPS.
- The Eurocontrol extension to 150 NM for A3 equipage is met at the 95% level, as required.
- All known air-ground update rate requirements are met out to at least 150 NM, in the absence of the co-located TACAN emitter, with the use of a single antenna on the ground. A test case was run, which included a 10 kW co-located 979 MHz TACAN. It was determined that the TACAN signal at the receive antenna had to be received at a level that did not exceed –30 dBm, in order to meet air-ground requirements. This corresponds to an isolation of 20 dB from the receive antenna, in addition to that provided by a 1000 foot separation distance. A three-sector ground antenna configuration should also enable satisfaction of the air-ground requirements to 150 NM.

K.4.4 Acquisition Performance

Performance of the UAT ADS-B system in the area of aircraft information acquisition was evaluated. In a head-on situation in the LA2020 scenario, the 99th percentile range for acquisition by the victim receiver of all information transmitted on ADS-B by the desired aircraft was determined for each aircraft equipage type. This was done for a large sample of cases, and the 99th percentile case was chosen. In other words, 99% of aircraft are expected to achieve a 99% probability of acquiring all information about an aircraft flying on a head-on path by the range selected.

The information necessary to acquire varies by aircraft equipage, so the evaluation was done for various transmitter-receiver combinations of equipage. For each equipage type, the message transmit sequence used was that defined in Section 2.2.6.1.3. Table K-3 shows the assumptions made in this analysis for information required to achieve acquisition for each type of transmit equipage.

Table K-3: Acquisition Requirements

Transmit Equipage	Required Information for Acquisition
A3	SV, MS, TSR, TCR0, TCR1
A2	SV, MS, TSR, TCR0
A1H	SV, MS, TSR
A1L	SV
A0	SV

The abbreviations used in the Table are:

- SV: State Vector
- MS: Mode Status
- TSR: Target State Report
- TCR0: Trajectory Change Report 0
- TCR1: Trajectory Change Report 1

The methodology used in this analysis was to run a set of probe aircraft in a head-on scenario and determine, for each, probe aircraft, the 99th percentile range at which all of the above information was received by the victim aircraft. The results are shown in Table K-4 for each transmit-receive combination.

Table K-4: 99th Percentile Range for Information Acquisition for Various Combinations of Transmit-Receive Pairs (NM)

		Transmitter				
		A3	**A2**	**A1H**	**A1L**	**A0**
Receiver	**A3**	137	53	53	49	18
	A2	145	54	53	52	17
	A1	122	50	48	37	11

The results shown in Table K-4 are for somewhat more restrictive acquisition criteria than are usually applied. From the results, it appears that UAT will be able to comply with all known ADS-B track acquisition requirements.

Simulations of aircraft and/or ground stations equipped with the UAT data link were made to determine the range of acquisition of the UAT track when the Mode Status payload alternates the inclusion of the Call Sign and the Flight Plan ID (see §2.2.4.5.4.15). The following assumptions were made for these simulations:

- Mode Status payloads (encoded in UAT Payload Type Codes #1 and #3, see §2.2.4.3) are assumed to alternate between including the Call Sign and the Flight Plan ID on each transmission of that Payload Type Code.

- Acquisition of a UAT transmitter for a ground receiver is defined as receiving at least one State Vector payload, one Mode Status payload containing the Call Sign, and one Mode Status payload containing the Flight Plan ID.

- Acquisition of a UAT transmitter on an airborne receiver is defined as receiving at least one State Vector payload and one Mode Status payload containing the Call Sign.

- Results are shown as the 99th percentile range. The acquisition range for each probe aircraft flying towards the receiver is calculated 500 times, and the 99th percentile range is determined for that transmitter. The 99th percentile of the distribution of this quantity for all transmitters is then used as the acquisition range of that transmitter equipage class.

Table K-5 shows the results for air-ground acquisition for the LA2020 and CE2015 scenarios. Table K-6 and Table K-7 shows the results for air-air acquisition for the LA2020 and CE2015 scenarios, respectively.

Table K-5: 99th Percentile Air-Ground Acquisition Ranges for Both Scenarios

Transmitter Equipage	Start Range for Probes (NM)	LA2020 Ground Receiver	CE2015 Ground Receiver
A3	200	193	192
A2	200	183	182
A1H	160	147	149
A1L	160	140	141
A0	150	121	121

Table K-6: 99th Percentile Air-Air Acquisition Ranges for LA2020 Scenario

Receiver Equipage	Transmitter Equipage (Initial Range)		
	A3 (150 NM)	**A2/A1H (100 NM)**	**A1L/A0 (75 NM)**
A3	121	55	27
A2	130	55	26
A1	115	49	25
A0	117	50	24

Table K-7: 99th Percentile Air-Air Acquisition Ranges for CE2015 Scenario

Receiver Equipage	Transmitter Equipage (Initial Range)		
	A3 (150 NM)	A2/A1H (100 NM)	A1L/A0 (75 NM)
A3	125	54	25
A2	122	53	25
A1	107	50	24
A0	101	49	24

Table K-8 compares the acquisition ranges of A1L/A0 transmitters between the alternating Mode Status payload and the non-alternating (standard definition with only the Call Sign) case.

Table K-8: 99th Percentile Air-Air Acquisition Ranges for CE2015 Scenario

Receiver Equipage	Alternating Mode Status Acquisition Range (NM) in LA2020 (from Table K-6)	Call Sign only Acquisition Range (NM) in LA2020	Alternating Mode Status Acquisition Range (NM) in CE2015 (from Table K-7)	Call Sign only Acquisition Range (NM) in CE2015
A3	27	30	25	29
A2	26	28	25	30
A1	25	25	24	25
A0	24	24	24	24

K.4.5 Surface Performance

An evaluation was performed of the performance of the UAT system on the surface, i.e., aircraft-to-aircraft state vector update rates were determined for transmit-receive pairs on the ground at LAX in the LA2020 scenario. The aircraft separation was varied between one and five nautical miles, and cases were run with and without severe horizontal surface multipath included. The multipath model used is described in Appendix M.6 of the ADS-B Technical Link Assessment Team (TLAT) Technical Link Assessment Report, March, 2001. It was thought that these two cases would provide conservative bounds on expected performance, since it was assumed that the severe multipath effects would always interfere destructively with the received signal.

Results of the MAUS runs for the surface performance as a series of plots of transmitter/receiver pairs in Figure K-110 through Figure K-125, and conclusions are presented below. The ADS-B MASPS requirement for 95% time of state vector updates on the surface is 1.5 seconds. This is shown by a solid black line on the plots below.

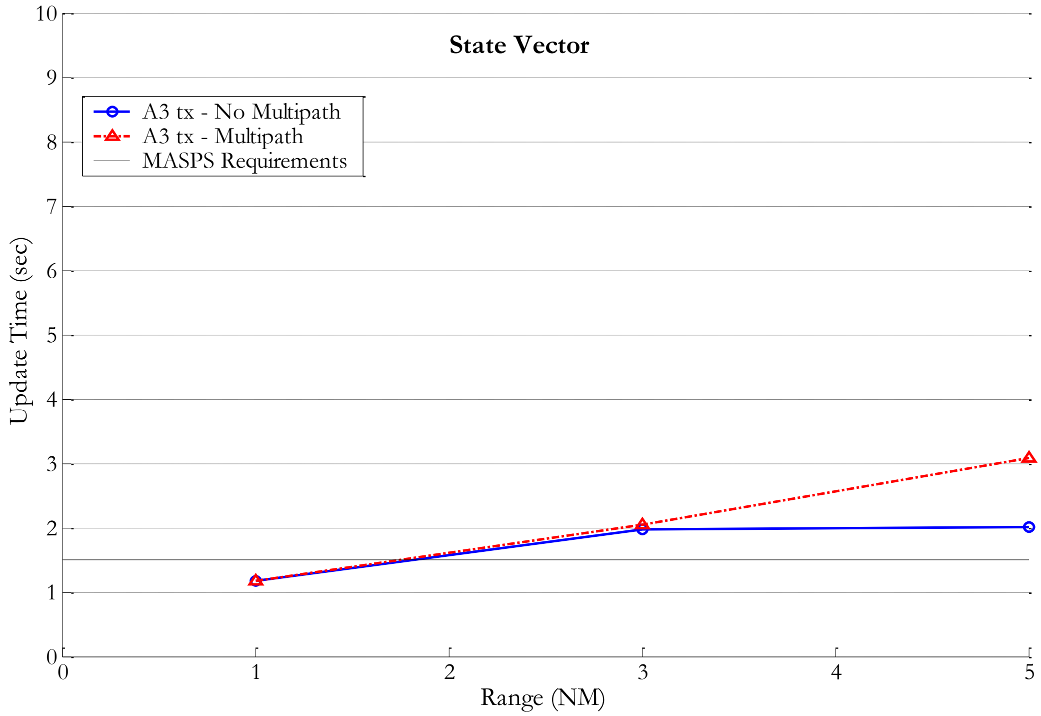


Figure K-110: A3 Receiver on the Surface in LA2020 Scenario Receiving A3 Transmissions

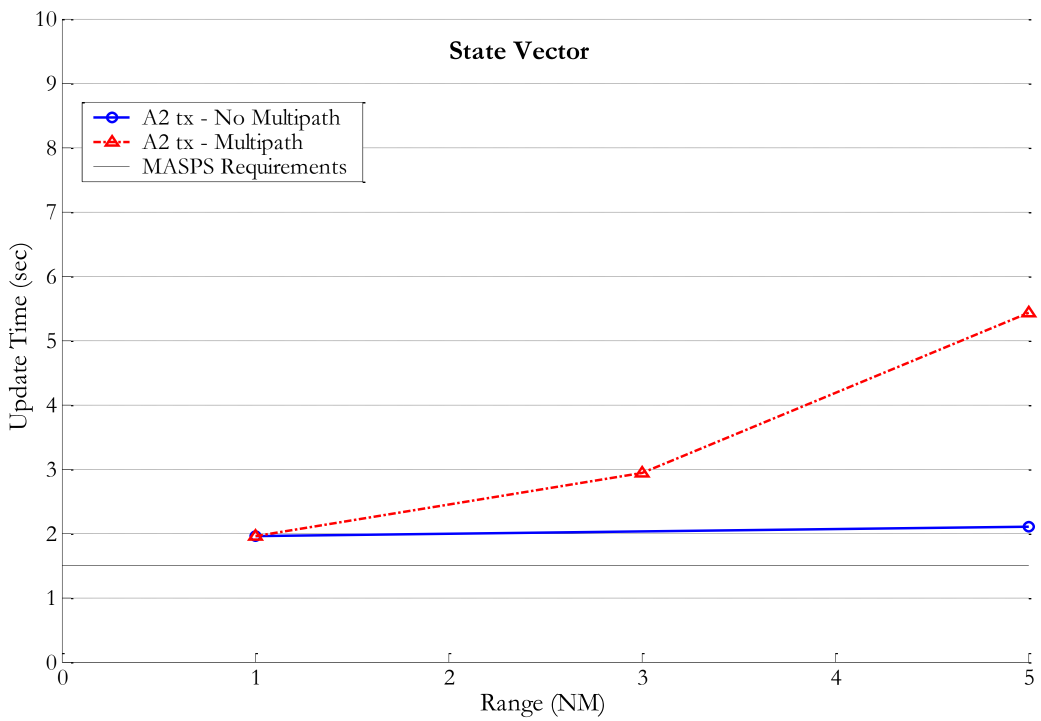


Figure K-111: A3 Receiver on the Surface in LA2020 Scenario Receiving A2 Transmissions

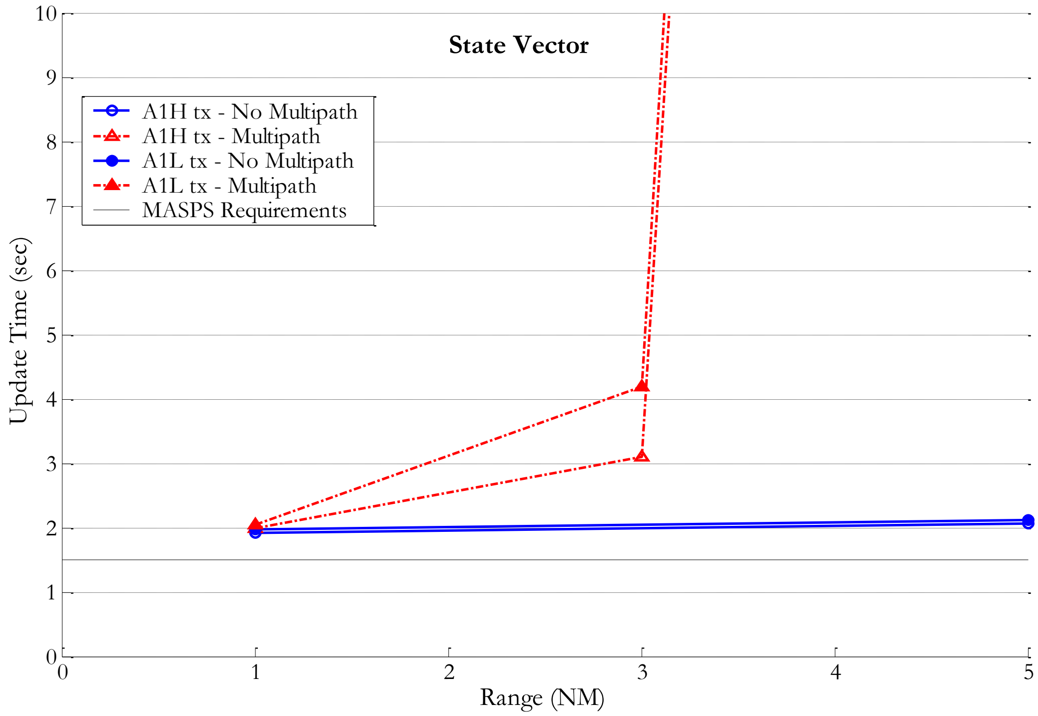


Figure K-112: A3 Receiver on the Surface in LA2020 Scenario Receiving A1 Transmissions

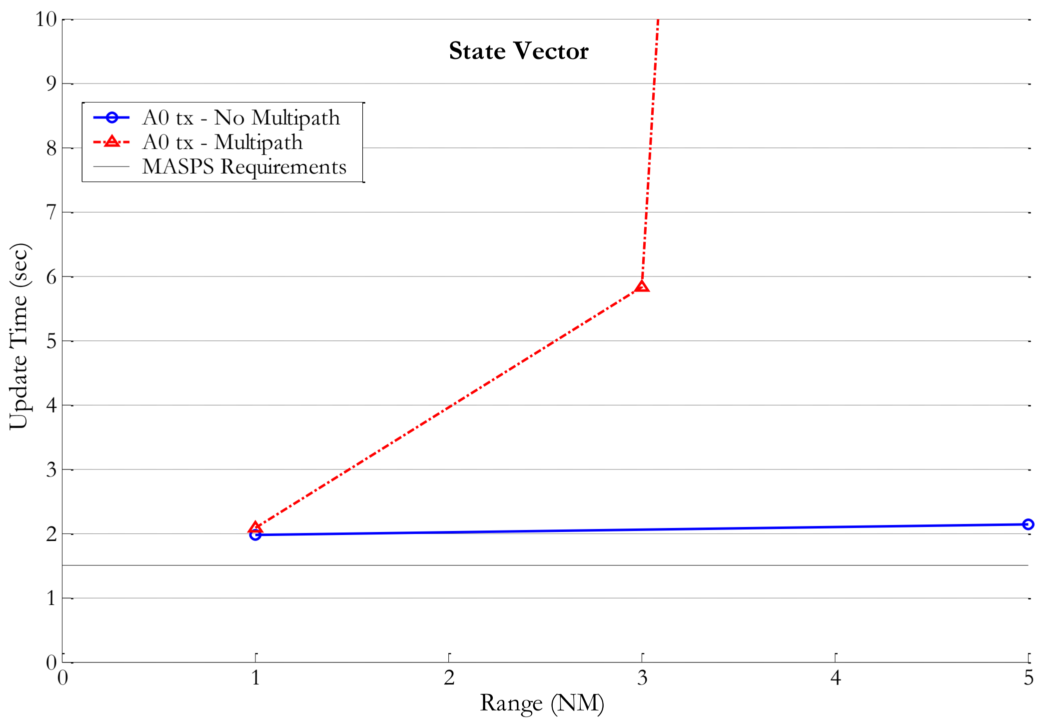


Figure K-113: A3 Receiver on the Surface in LA2020 Scenario Receiving A0 Transmissions

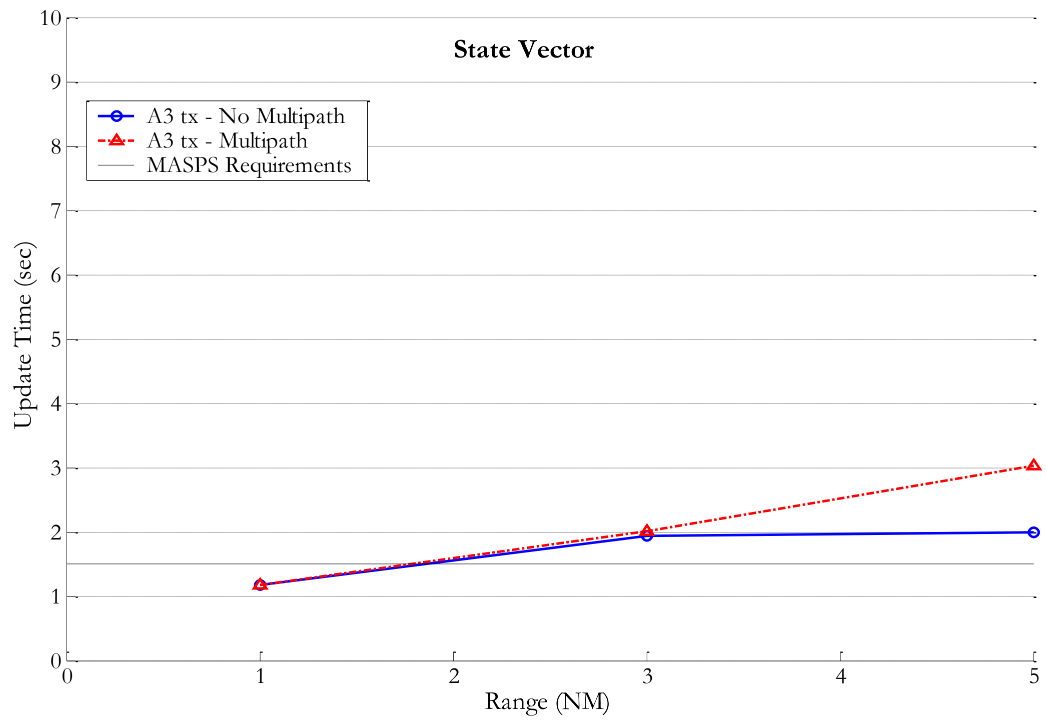


Figure K-114: **A2 Receiver on the Surface in LA2020 Scenario Receiving A3 Transmissions**

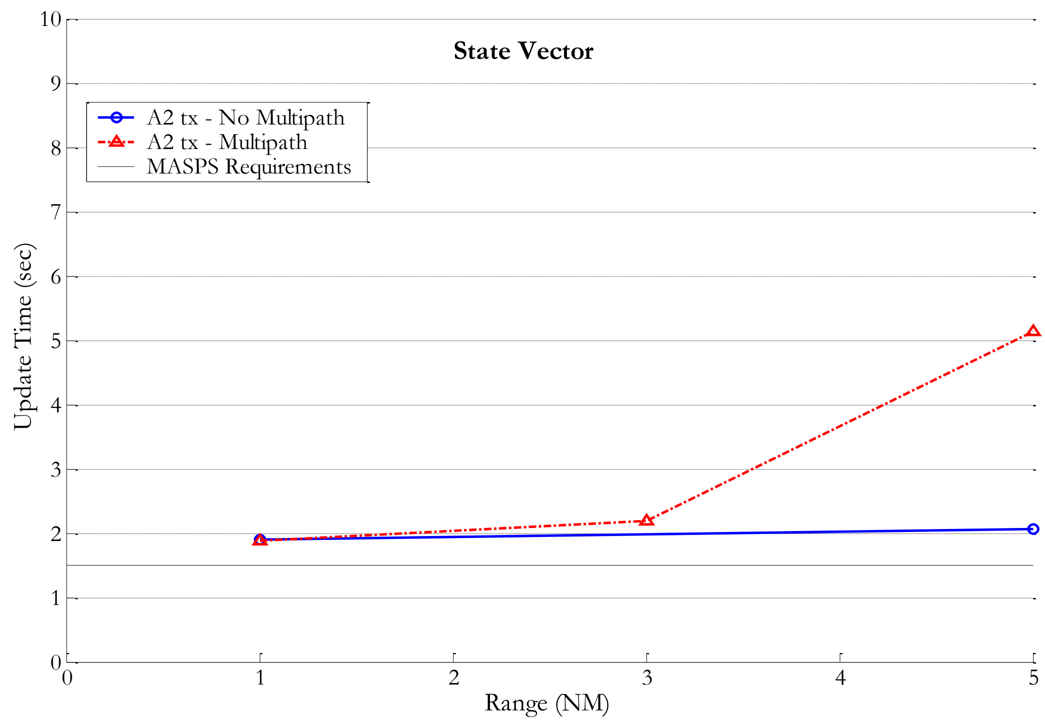


Figure K-115: **A2 Receiver on the Surface in LA2020 Scenario Receiving A2 Transmissions**

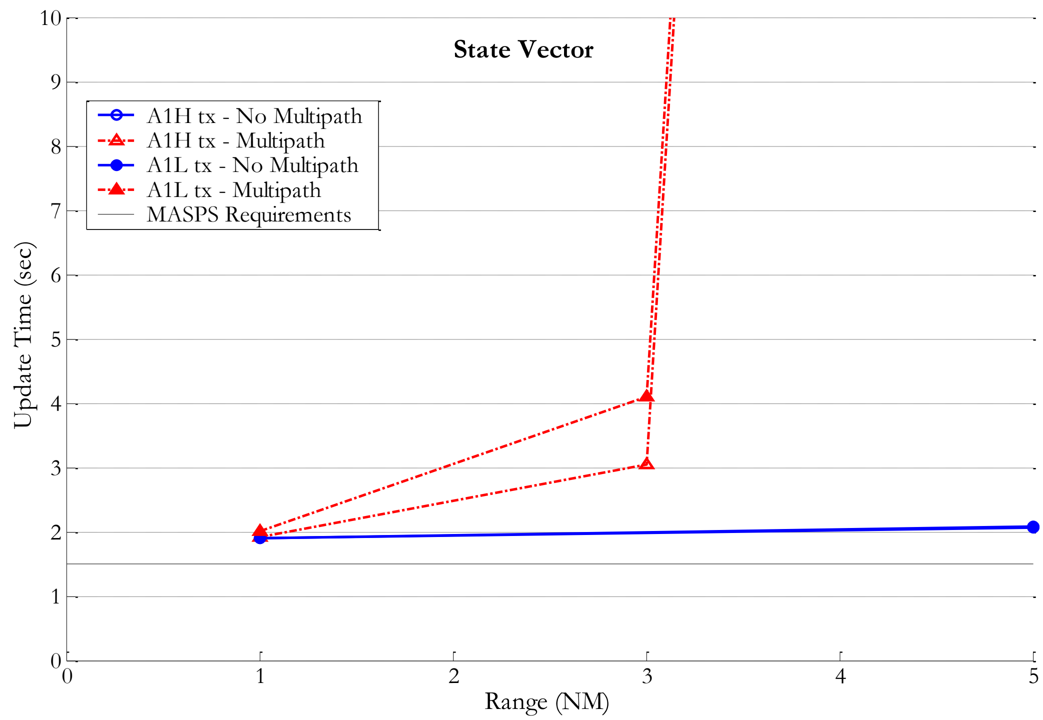


Figure K-116: **A2 Receiver on the Surface in LA2020 Scenario Receiving A1 Transmissions**

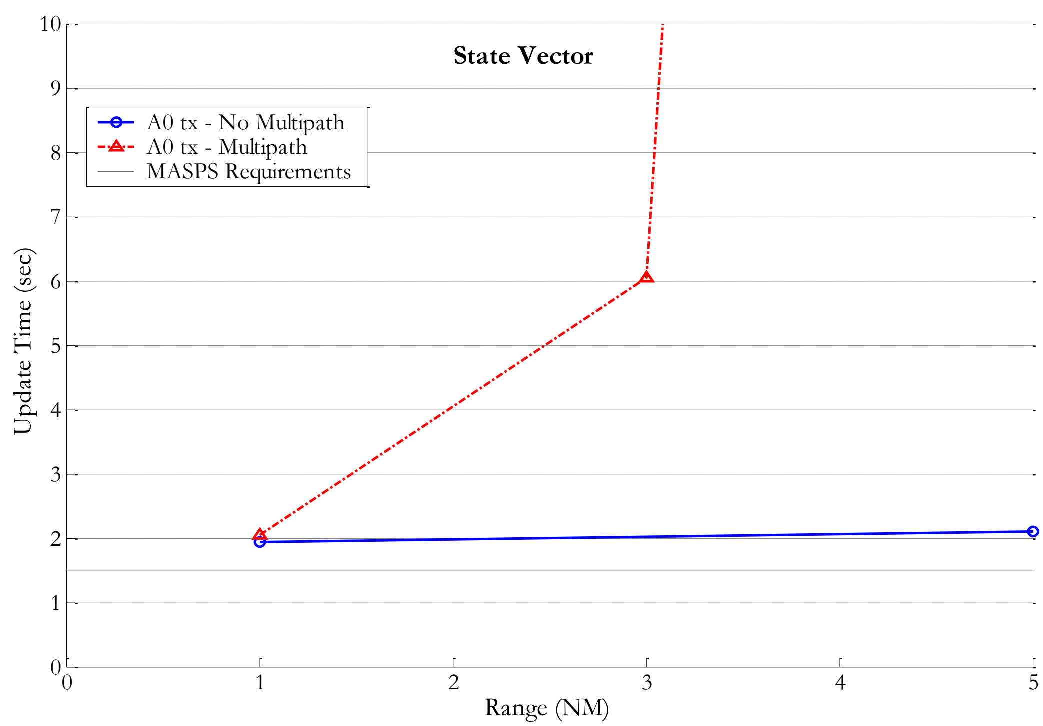


Figure K-117: **A2 Receiver on the Surface in LA2020 Scenario Receiving A0 Transmissions**

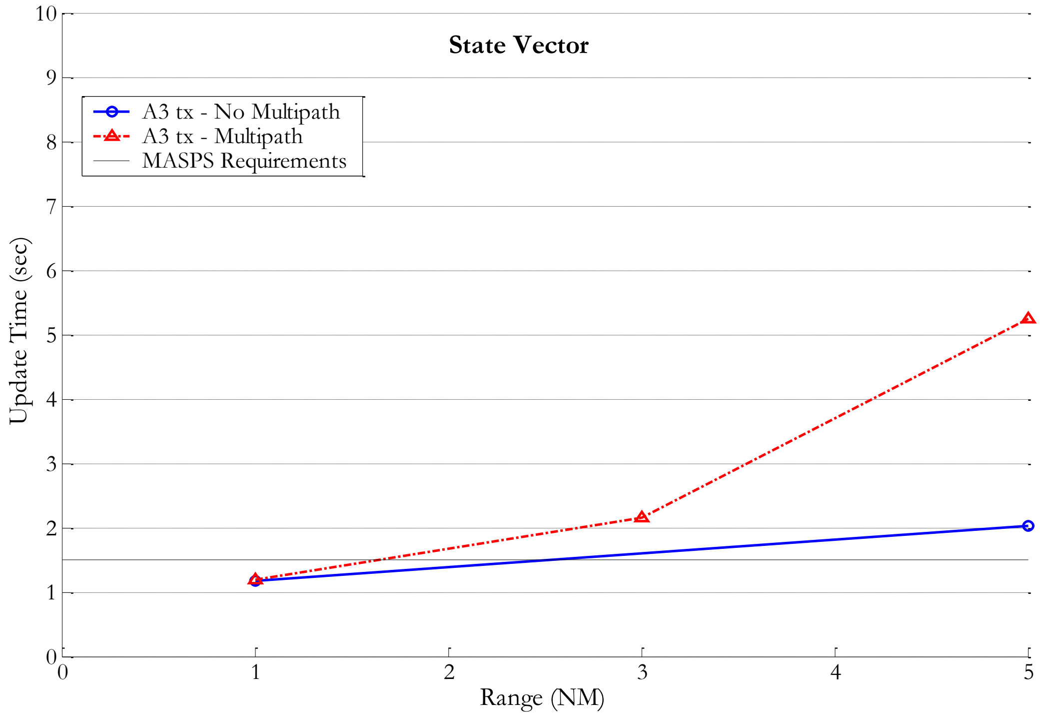


Figure K-118: A1 Receiver on the Surface in LA2020 Scenario Receiving A3 Transmissions

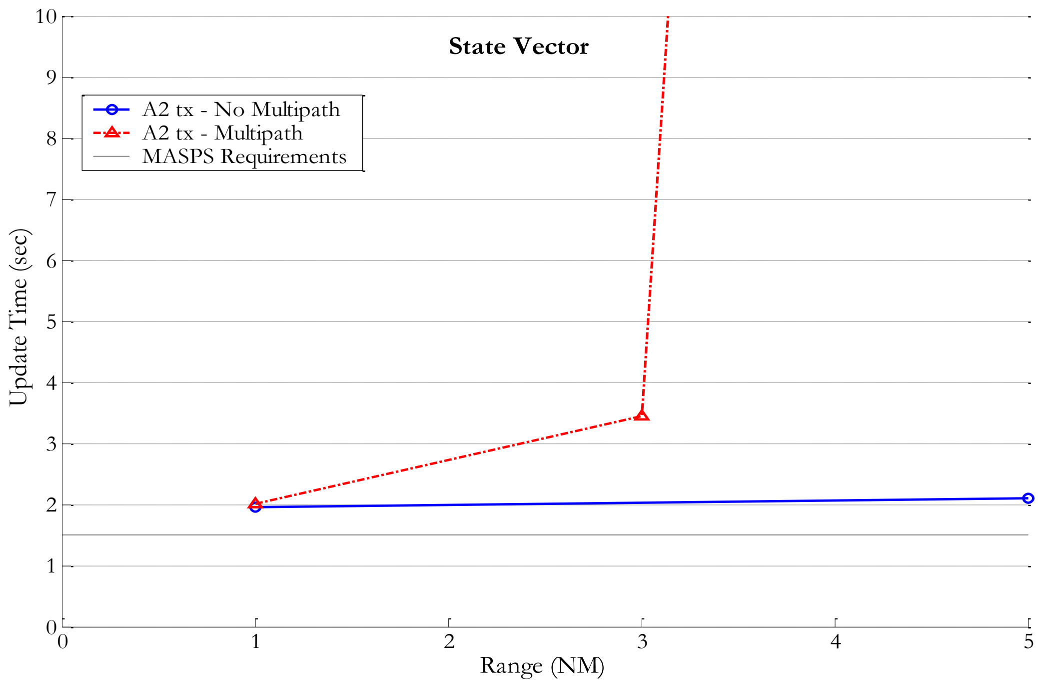


Figure K-119: A1 Receiver on the Surface in LA2020 Scenario Receiving A2 Transmissions

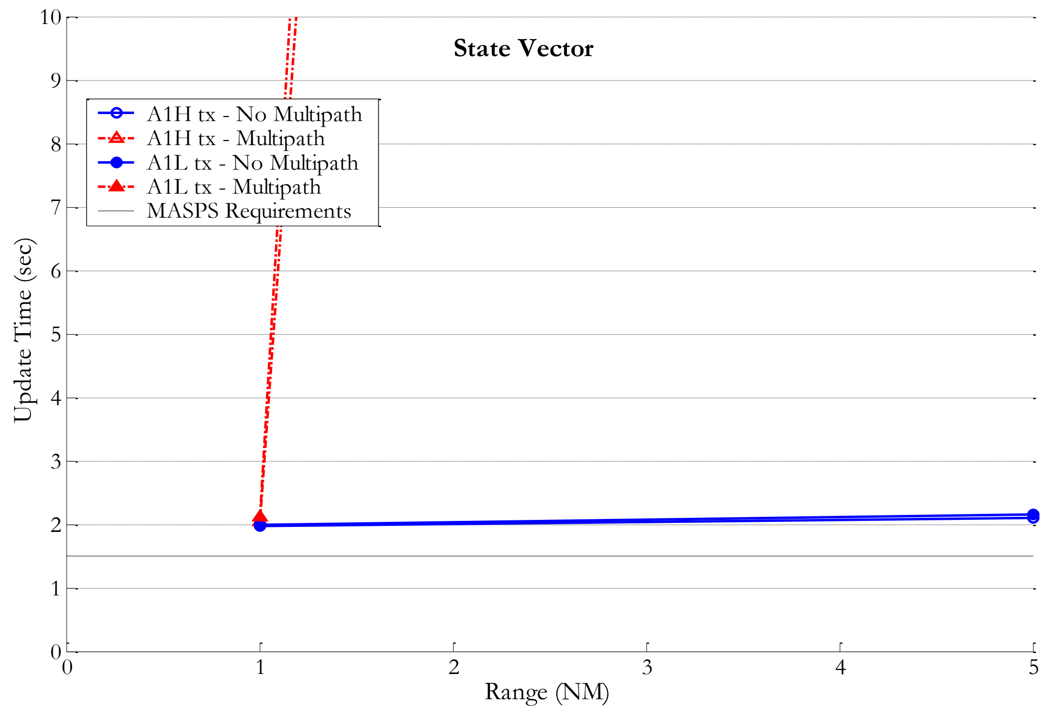


Figure K-120: A1 Receiver on the Surface in LA2020 Scenario Receiving A1 Transmissions

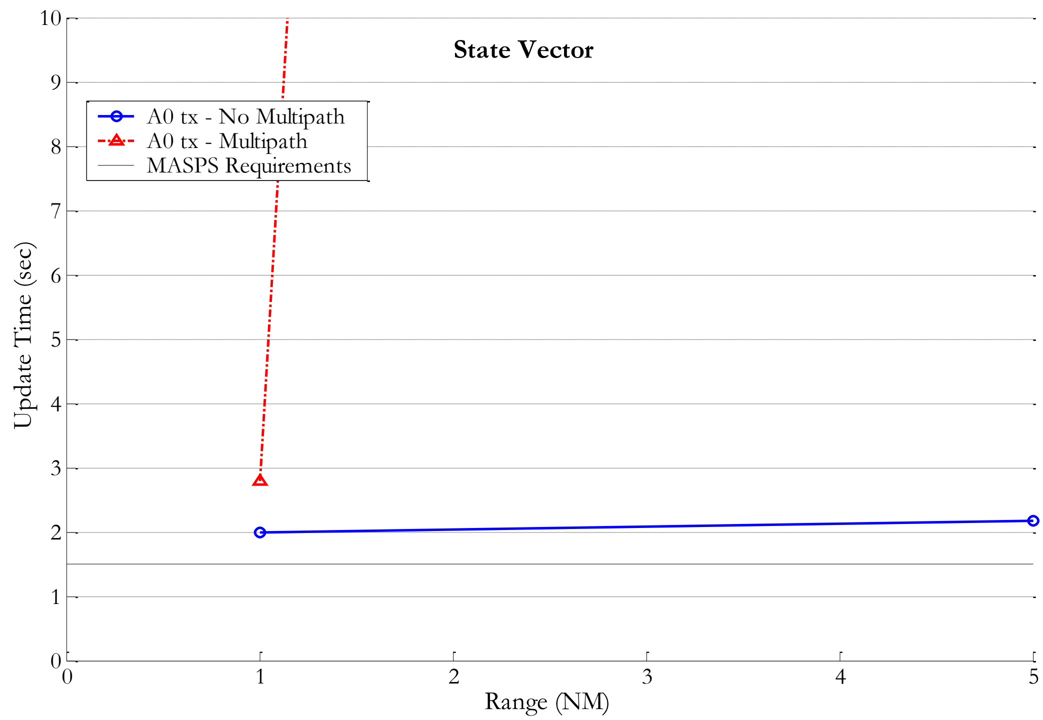


Figure K-121: A1 Receiver on the Surface in LA2020 Scenario Receiving A0 Transmissions

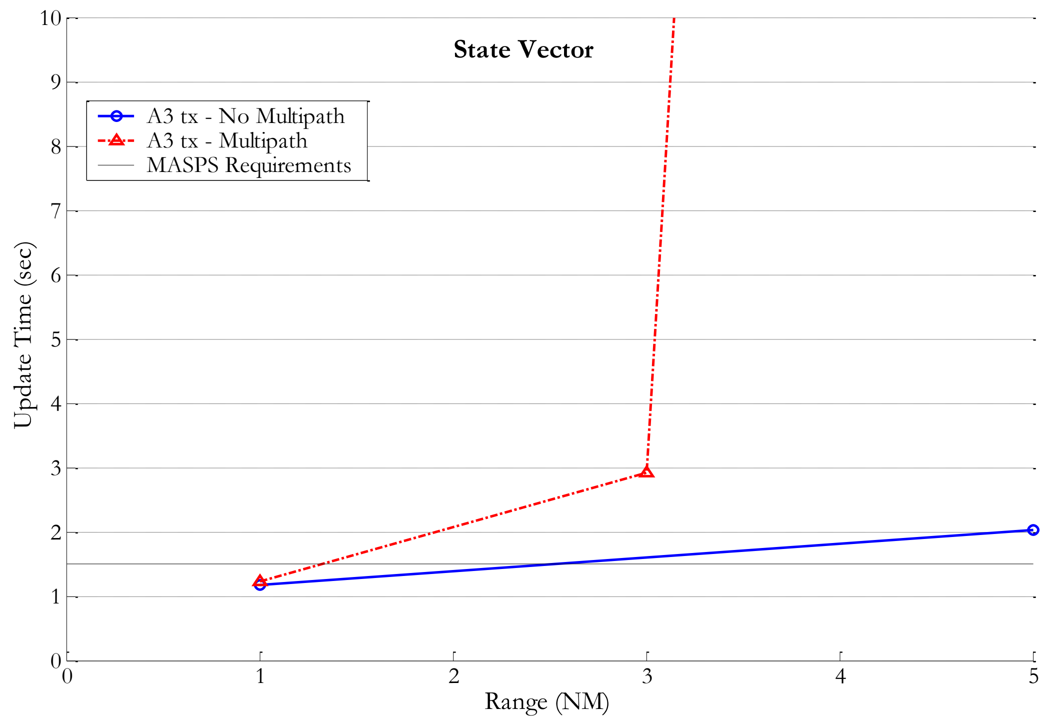


Figure K-122: **A0 Receiver on the Surface in LA2020 Scenario Receiving A3 Transmissions**

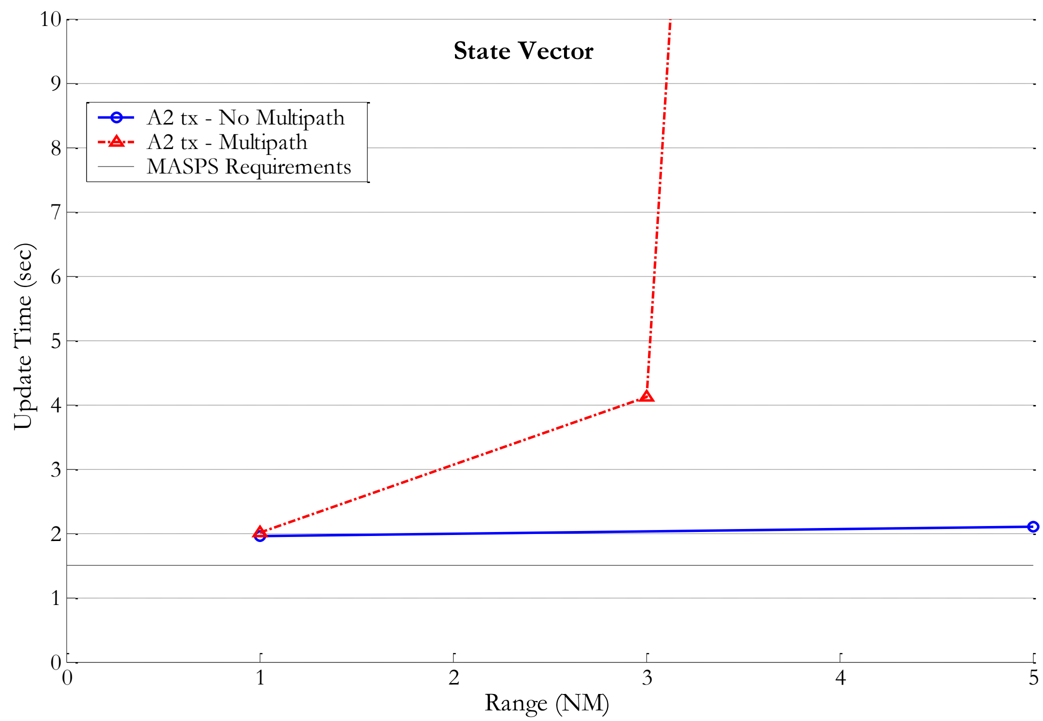


Figure K-123: **A0 Receiver on the Surface in LA2020 Scenario Receiving A2 Transmissions**

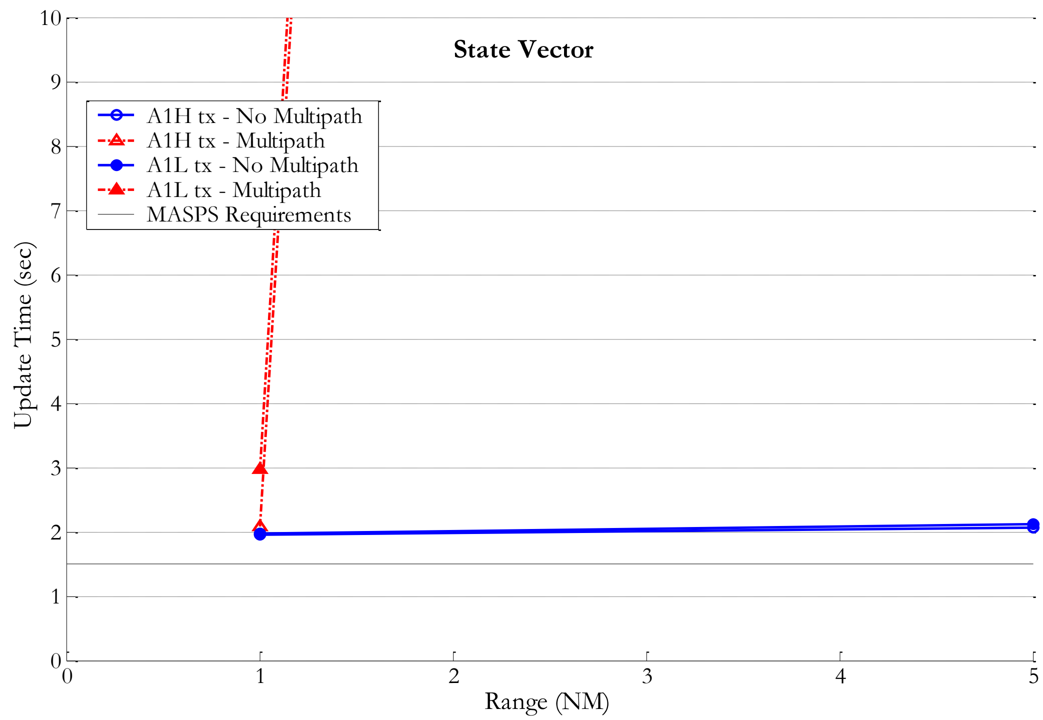


Figure K-124: A0 Receiver on the Surface in LA2020 Scenario Receiving A1 Transmissions

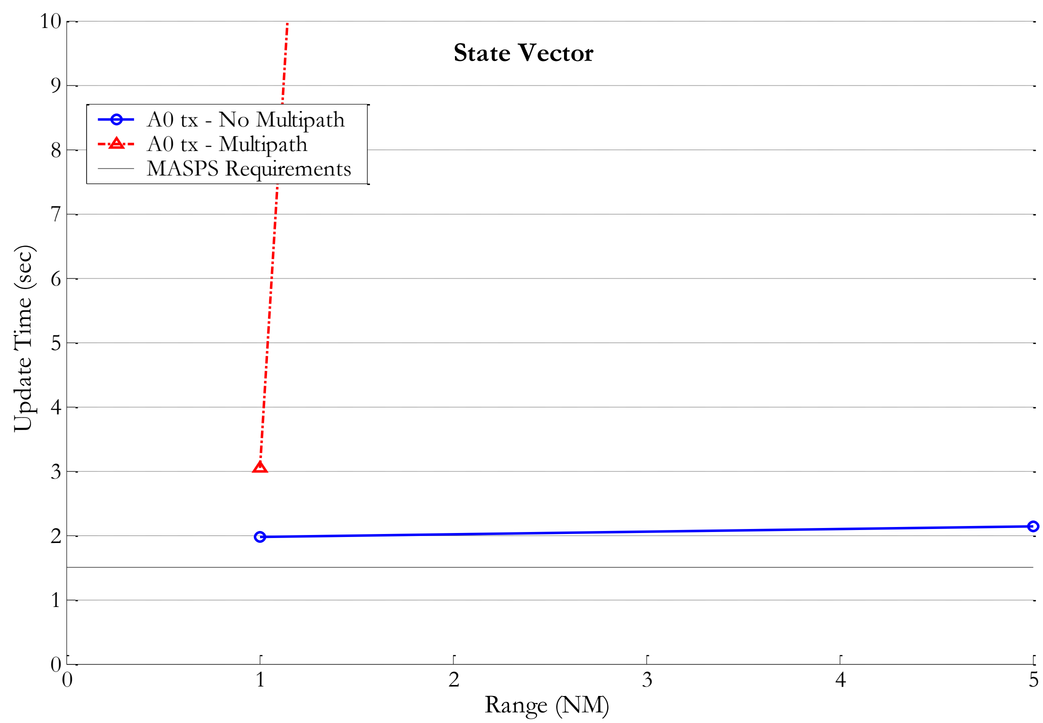


Figure K-125: A0 Receiver on the Surface in LA2020 Scenario Receiving A0 Transmissions

Recall that the LA2020 scenario, in addition to a total of 2694 aircraft (75 on the ground at LAX) transmitting UAT, includes 100 transmitting ground vehicles at LAX as well.

The results for the aircraft-to-aircraft surface-to-surface performance from Figure K-110 through Figure K-125 may be summarized as follows:

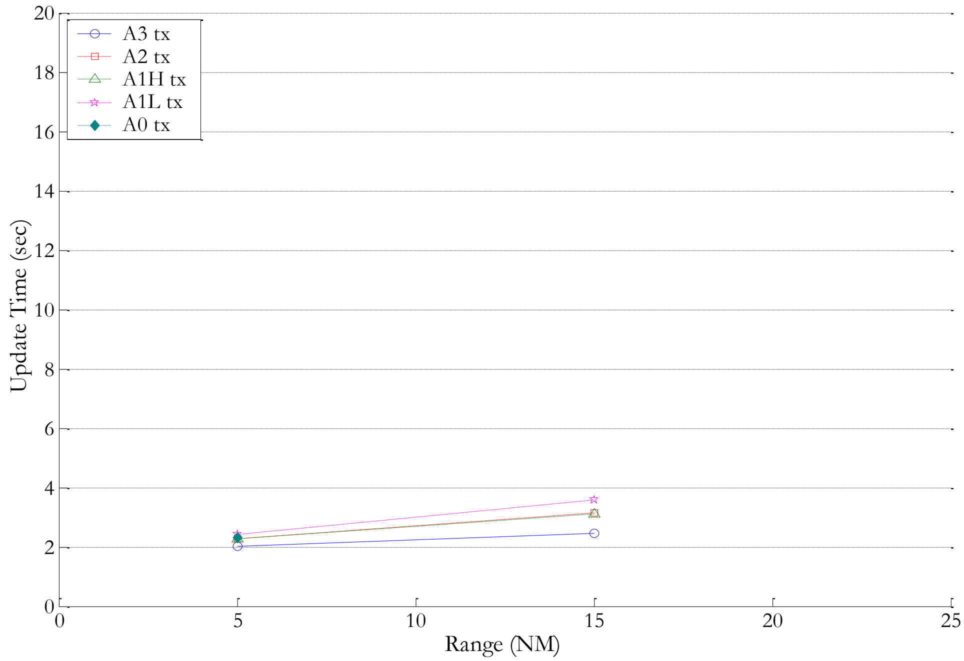
- For the bounding cases with no multipath and with worst-case elevation plane multipath, the 95th percentile surface update requirement for the ADS-B MASPS (1.5 seconds out to 5 NM) are met for A3 transmitters up to 1-2 NM away.
- The 95th percentile surface update requirement for the ADS-B MASPS (1.5 seconds out to 5 NM) are not met for all other cases on the surface.
- The 95th percentile update time on the surface for all aircraft classes to 5 NM for the bounding case of no multipath is approximately 2 seconds. A3 transmitters can be seen by A2 and A3 receivers out to 5 NM with, approximately, a 3 second 95th percentile update time. A2 transmitters can be seen by A2 and A3 receivers out to 5 NM with, approximately, a 5 second 95th percentile update time.
- The 95th percentile update time on the surface for all aircraft classes for the bounding case of worst-case multipath is approximately 3 seconds at a range of 1 NM. The limiting factor at ranges greater than 1 NM is the transmit power and antenna placement for A0 and A1L class equipment, combined with the effect of 175 interferers at close range.

K.4.6 An A0 on the Surface Receiving an Aircraft that is on Approach

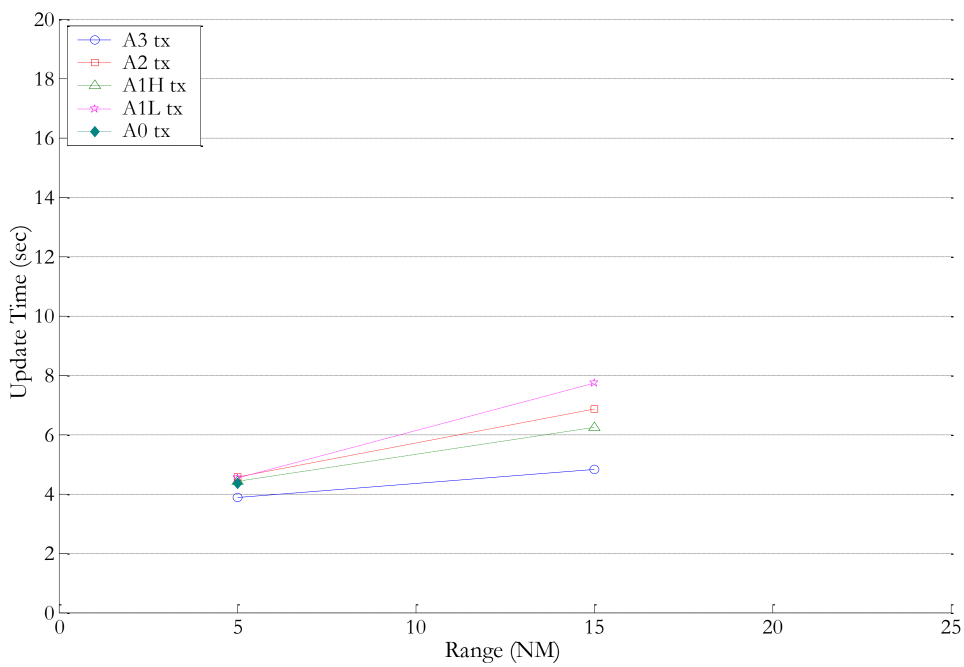
An evaluation was performed of the performance of the UAT system for an aircraft on the surface receiving state vector transmissions from aircraft on landing approach in both the LA2020 and Core Europe 2015 scenarios. The aircraft on approach were modeled at an altitude of 2000 feet. The receiving aircraft on the ground is equipped as an A0 receiver. It was thought this would provide a worst case performance for aircraft on the surface receiving airborne transmitters due to the A0 receiver potentially only having antenna on the bottom of the aircraft. No multipath was included.

The evaluation was performed using the same co-site interference environment as for the airborne scenarios. In practice, the actual interference environment would be more benign, because of much lower instances of interrogations from TCAS/ACAS and radar ground systems when operating on the surface, and potentially from a lack of DME equipment on some portion of the A0 and A1L fleet. In addition, the Core Europe scenario had a 10 kW 979 MHz TACAN located 1000 feet away from the UAT receiving antenna.

Results of the MAUS runs for an A0 aircraft on the ground receiving UAT transmissions from aircraft on approach are shown in Figure K-126 and Figure K-127 for the LA2020 and CE 2015 scenarios, and conclusions are presented below. We know of no specific ADS-B MASPS requirements for this situation.



<u>Figure K-126:</u> A0 Receivers on the Ground in LA2020 Receiving All Aircraft on Approach at an Altitude of 2000 feet



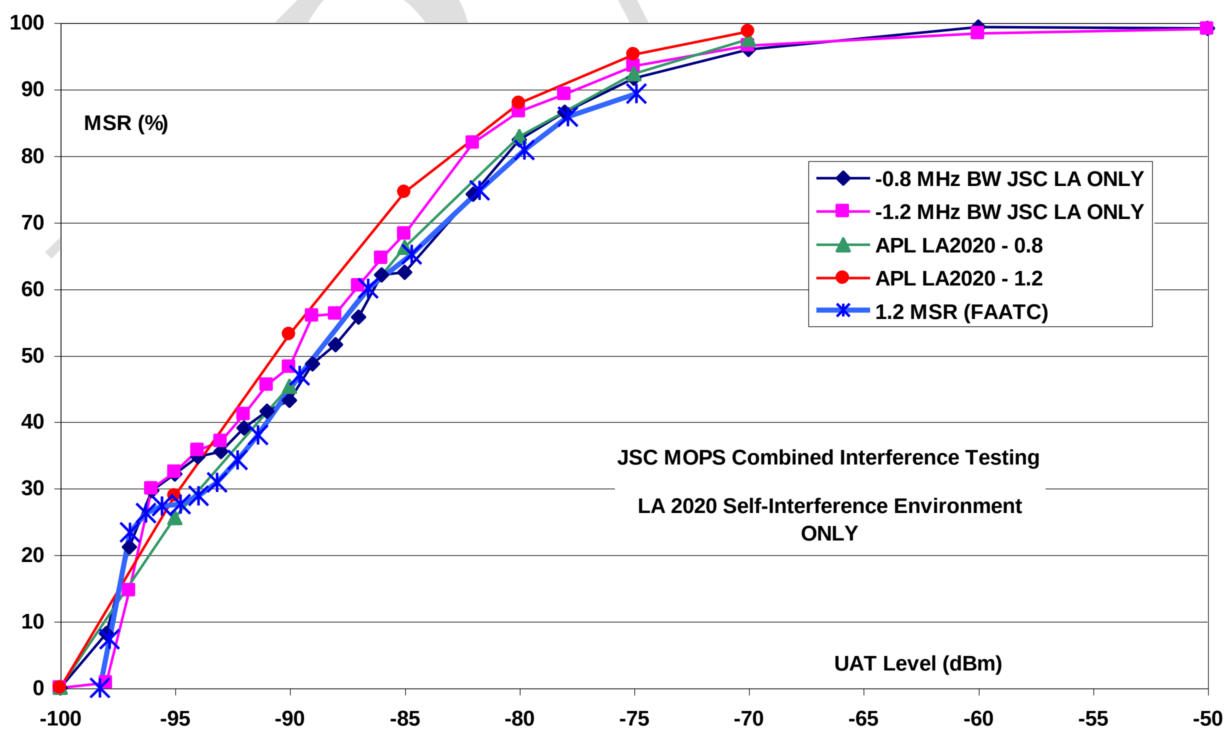
<u>Figure K-127:</u> A0 Receivers on the Ground in CE2015 Receiving All Aircraft on Approach at an Altitude of 2000 ft to Brussels co-located with a 10 kW 979 MHz TACAN

Recall that the LA2020 scenario, in addition to a total of 2694 aircraft (75 on the ground at LAX) transmitting UAT, also includes 100 transmitting ground vehicles at LAX as well. Furthermore, the CE2015 scenario has 2091 aircraft transmitting UAT, including 25 aircraft and 100 ground vehicles on the surface in Brussels.

The results for an aircraft on the surface receiving aircraft on approach are shown in Figure K-126 and Figure K-127. We know of no specific ADS-B MASPS requirements for this situation.

K.5 Model Validation

The validation effort for MAUS focused on reproducing a complete interference environment. The FAA's William J. Hughes Technical Center (FAATC) developed a UAT interference simulator, which was capable of reproducing both the LA2020 and CE2015 UAT self-interference environments. The additional capability of simultaneously inserting DME and Link 16 interference along with the UAT self interference was also implemented, resulting in emulation of high density, stressful environments containing a combination of all three types of interference. This simulator, along with "desired" UAT messages were combined and fed into MOPS compliant UAT receivers. The Message Success Rate (MSR) was then measured as a function of desired signal level for the various combinations of interference, and compared with predictions of the MAUS for identical circumstances and assumptions. In all cases, the predictions of the MAUS were in agreement with the measured results, within the experimental uncertainties. An example of this comparison is shown in Figure K-128 for the LA2020 UAT self interference environment. The results comparing measurements taken at the FAATC and the Joint Spectrum Center of the Defense Information Systems Agency (JSC) on MOPS compliant equipment with MAUS simulation results are shown in Figure K-128.



<u>Figure K-128:</u> Comparison of Bench Test Measurements of MOPS-Compliant UAT Reception in LA2020 Self-Interference with Predictions by MAUS

As is evident from Figure K-128, there is very little difference between the bench test data and the predictions of the MAUS. The two sets of data are quite consistent with each other within the limits of measurement. It is important to note that there were no free parameters that needed to be adjusted to achieve this agreement. This type of validation provides an increased measure of confidence in the simulation predictions.

Bench test measurements were also made of the Core Europe environment, which included UAT self-interference, DME/TACAN interference, and Link 16 interference. Results of these measurements are shown in Figure K-129 and Figure K-130. Figure K-129 shows the measurement results for the 0.8 MHz filter receiver, which is to be used for A3 class equipment. The addition of Link 16 interference to the DME/TACAN and UAT interference results in a reduction in MSR of up to around 10% for a given desired signal level, although the curves are much closer than that over much of the signal range. Simulation results have not been run for comparison in this scenario; however, there is a slight reduction in performance when Link 16 interference is added to the identical Core Europe scenario.

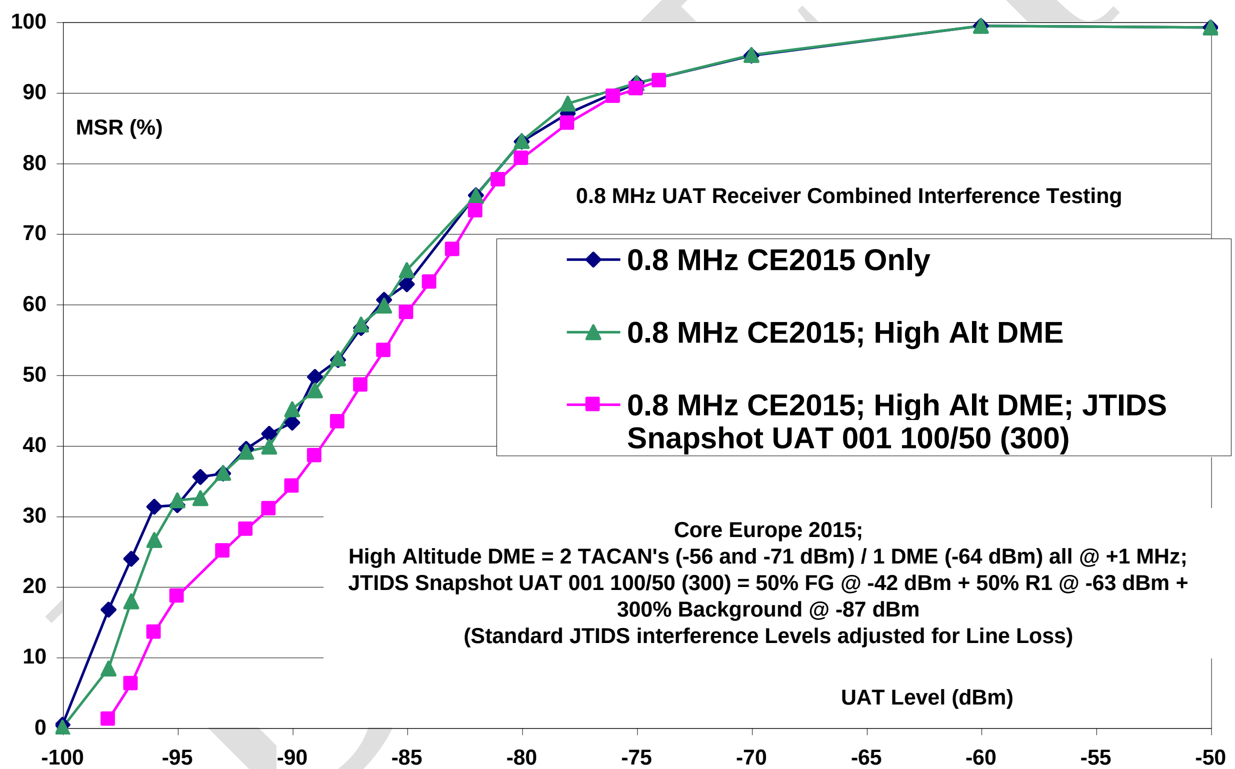


Figure K-129: Bench Test Measurements of UAT Performance in Core Europe UAT Self-Interference, Combined with DME/TACAN and Link 16 Interference

Figure K-130 shows the results for measurements taken with the 1.2 MHz receiver filter, which corresponds to the receiver used for all equipage classes other than A3. These results are similar in nature to those for the Core Europe scenario shown in Figure K-129, in that the addition of Link 16 interference results in a small reduction of the MSR at a given desired signal level.

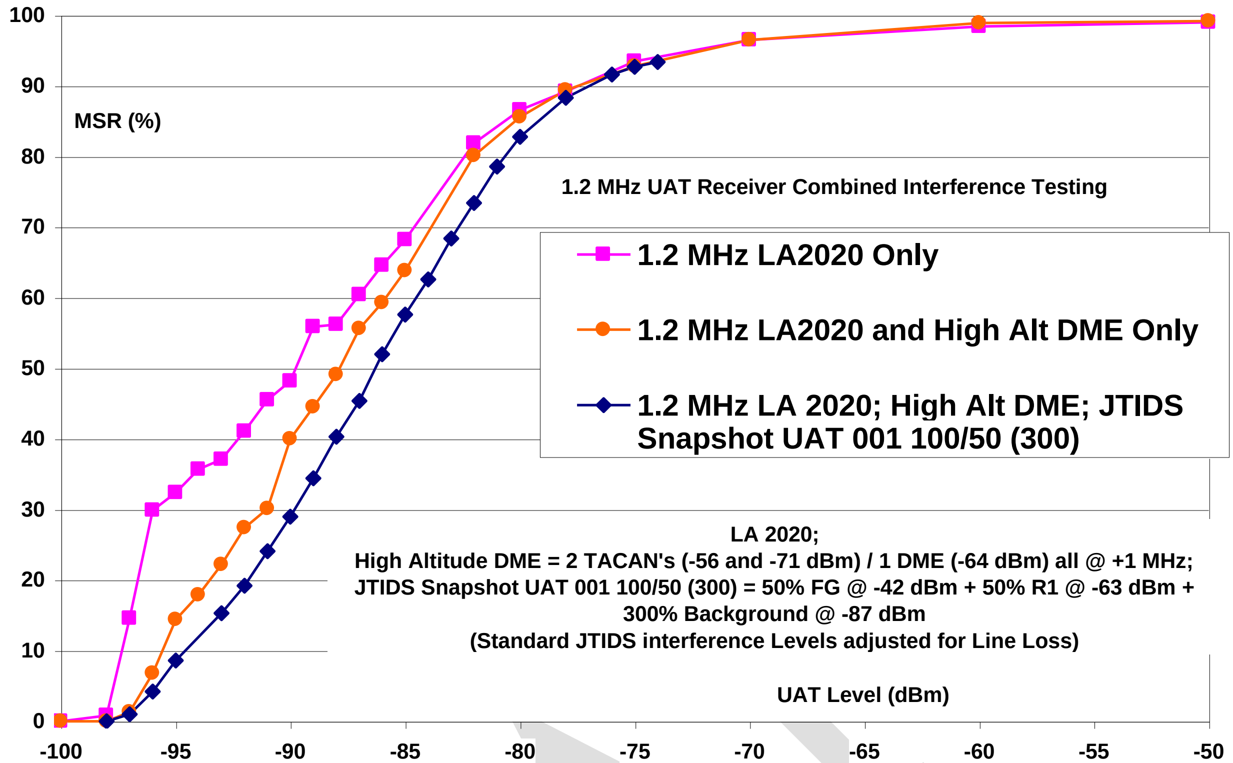


Figure K-130: **Bench Test Measurements of UAT Performance in the LA2020 UAT Self-Interference, Combined with DME/TACAN and Link 16 Interference**

K.6 UAT A1S Performance Analysis

A new category of aircraft type has been defined for this version of these MOPS, the A1 single antenna (A1S). The A1S is required to have a medium transmit power as defined in Table 2-2, but it will use a single bottom-mounted antenna. An evaluation of this category of equipage has been performed in a highly stressful environment. The three challenging situations that were specified for this analysis were:

1. A stationary A1S aircraft on the surface of LAX attempting to receive ADS-R being broadcast by the ground infrastructure. A DME/TACAN antenna pattern at low power was used for the ground transmitting antenna. Scenario 1 will focus on surface transmissions from the ground infrastructure, and it is assumed that there is no interference from other ground station transmissions.

2. An A1 aircraft on approach attempting to receive ADS-B transmissions from an A1S aircraft on the surface of a GA airport. An A1 aircraft was chosen, because the alternating receive antenna is expected to provide the worst case. Scenario 2 will include a heavy load of ADS-R and TIS-B transmissions from nearby ground stations.

3. A bottom-mounted A1S banking away from a ground receiver at various bank angles, with various multipath losses. For this scenario, the aircraft is assumed to be moving in a circle with constant speed and bank angle; thus it is always facing away from the ground receive antenna. Scenario 3 will include a heavy load of ground transmissions as receiver blanking of the ground station.

The air traffic scenario used for this analysis is the LA2020 scenario developed for the TLAT. This scenario is based on the LA Basin 1999 maximum estimate. It is assumed that air traffic in this area would increase by a few percent each year until 2020, when it would be 50 % higher than in 1999. The distribution of aircraft in the scenario is based on approximations of measured altitude and range density distributions. For the purposes of this study, it is assumed that UAT comprises all airborne A0 (replaced by A1S for this analysis) and around 65% of airborne A1 aircraft in the scenario, for a total of 1232 aircraft below FL180 and within 400 NM of LAX. In addition, 113 aircraft are located on the ground at LAX and other airports in the region. For the LAX ground scenario, it is assumed that there are 10 ground vehicles equipped with 1090 ES that are being transmitted over UAT via ADS-R. The approach scenario also assumes that there are 3 ground vehicles transmitting directly over UAT.

For A1S equipage, the model simulates transmission and reception on a bottom antenna. When on the surface, aircraft with top antennas transmit from those antennas without switching. The simulation assumes a single multipath ground reflection.

Scenario 1: For this scenario, the ground transmit power was varied between 1 watt and 1 kilowatt, and the ranges examined were 1, 3, and 5 NM between ground transmitter and A1S receiver on the ground. It is assumed that there is a single multi-path ground reflection. The values used in the multi-path calculation were provided by Stan Jones of Mitre Corporation [1]. The metric used is the standard 95% update interval. Results are shown in Table K-9.

Table K-9: 95% Update Interval for Scenario 1 as a Function of Range and Transmit Power

	Ground Transmitter Power				
		1 w	10 w	100 w	1000 w
Range	1 NM	2.0 s	1.2 s	X	X
	3 NM	X	3.0 s	2.0 s	X
	5 NM	X	X	6.9 s	2.1 s

In Table K-9, “X” is used to indicate that this case was not evaluated. These results should be compared to a required 95% update interval of two seconds for the ASSA and FAROA applications (as described in RTCA DO-289). Table K-9 indicates that, for a surface separation of no more than one NM, a 1 watt transmitter would meet the two second update interval, while it is likely that a 10 watt transmitter would be needed if the distance were two NM.

Scenario 2: For this scenario, **(Scenario 2a)**, there is an A1S on a GA airport surface transmitting ADS-B to an A1 dual-antenna aircraft five miles away on approach to the airport. There is also a high power (100 w) ground transmitter 5 NM from the A1 receiver, which interferes with the reception of transmissions by the A1S on the ground. There is a variable single multipath ground reflection used by the model, since the model itself predicts no multipath effect at 5 NM. The metric used is the standard 95% update interval. Results are shown Table K-10.

Table K-10: 95% Update Interval for Scenario 2a as a Function of Multipath Effect and Ground Transmissions

	Number of Ground Station Messages per Second		
Multipath Effect		**0**	**400**
	0 dB	**2.0 s**	**3.4 s**
	-10 dB	**2.1 s**	**4.0 s**
	-20 dB	**6.5 s**	**12.8 s**

The results in Table K-10 should be compared to a required 95% update interval of two seconds for the ASSA and FAROA applications.

This scenario, **(Scenario 2b),** was also run for the case of the aircraft on approach three NM away from the airport. The results are shown in Table K-11.

Table K-11: 95% Update Interval for Scenario 2b as a Function of Multipath Effect and Ground Transmissions

	Number of Ground Station Messages per Second		
Multipath Effect		**0**	**400**
	0 dB	**2.1 s**	**3.9 s**
	-10 dB	**2.1 s**	**3.9 s**
	-20 dB	**3.0 s**	**5.9 s**

The results in Table K-11 should be compared to a required 95% update interval of two seconds for the ASSA and FAROA applications.

Scenario 3: For this scenario, there is an A1S at FL 120 at variable range from a ground receiver. The A1S is banking at a variable angle away from the ground receive antenna. The ground uplink transmissions (0 or 100 uplinks/second) prevent simultaneous reception of the A1S ADS-B transmissions. The ranges examined were 10, 30, and 50 NM.

For all ranges, the A1S achieved a 95% update interval less than three seconds (3 seconds is required in the terminal domain) with no bank angle and no ground uplinks. Adding 100 ground uplinks resulted in an increase in the 95% update interval to around 5 seconds at 10 NM and around 6 seconds at 50 NM. Increasing the bank angle resulted in a gradual increase in update interval up to a critical angle, where the curve experiences a sharp rise (see figure below). The critical angle varies with the range from the receive antenna: a greater range corresponds to a smaller critical angle.

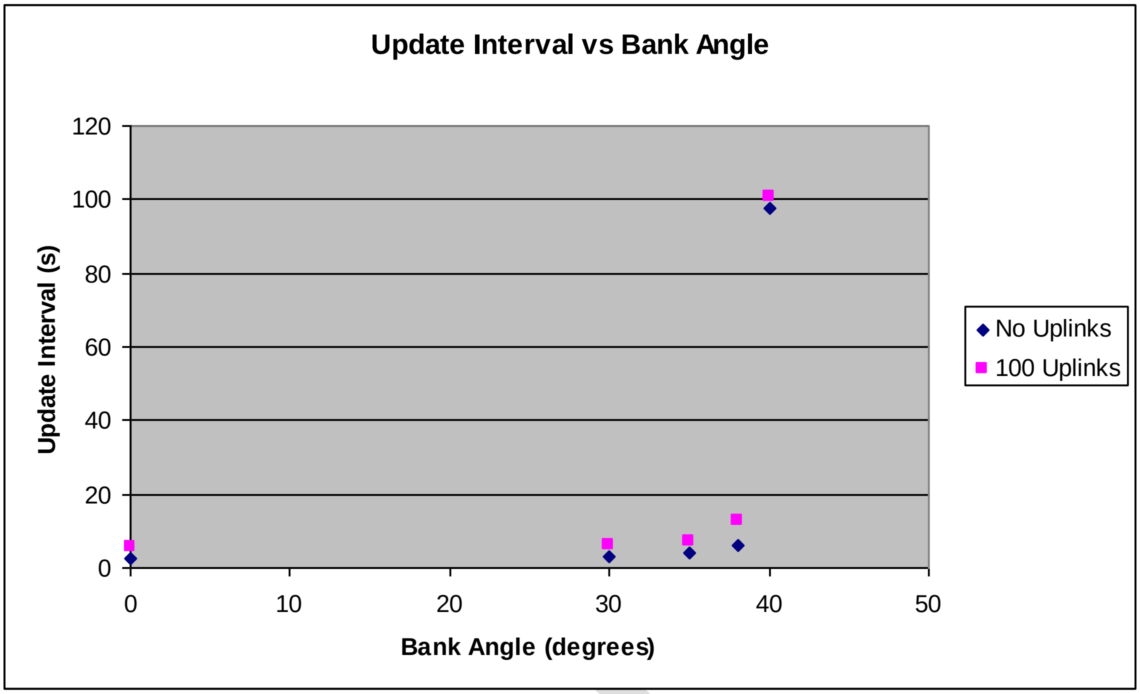


Figure K-131: Typical Result for Scenario 3 for Update Interval as a Function of Bank Angle

Note that the critical angle for the case in Figure K-131 is around 40 degrees. Also, the effect of the addition of 100 uplink transmissions is shown.

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Appendix L

Supporting the Trajectory Change Reports

Within the Established UAT Message Payload

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L. Proposed Support of the Trajectory Change Report

Two of the UAT ADS-B Message Payload Type Codes ("4" and "5") contain the Trajectory Change (TC) Element capable of conveying 96 bits of message payload. In this UAT MOPS, all 96 bits of the TC element are Reserved and are set to ALL ZEROs pending their definition in a future UAT MOPS version. Although the TC element is undefined in this UAT MOPS, the performance assessment provided in Appendix K takes into account that the 96 bits supports TC+0 for A2 equipment; and TC+0 and TC+1 for A3 equipment. To justify this assumption, Table L-1 below shows how all the information required for the Trajectory Change Report could be supported within the established UAT ADS-B Message payload.

Table L-1: Proposed Trajectory Change Report Elements

	DO-242A TC Report Elements		How Supported by UAT Message Payload
ID	Participant Address	[24 bits]	Conveyed in HEADER Element (2.2.4.5.1.3)
	Address Qualifier	[4 bits]	Conveyed in HEADER Element (2.2.4.5.1.2)
TOA	Time of Applicability	[1 s resolution]	Not explicitly transmitted; added by receiver (2.2.8.3.5)
TC Report #	TC Report Sequence Number	[2 bits]	Can be determined from the Payload Type Code (see Table 2-10)
TC Report Version	TC Report Cycle Number	[2 bits]	2 bits conveyed in the TC Element
	(Reserved for TC Management Indicator)	[3 bit]	3 bits conveyed in the TC Element
TTG	Time To Go	[4 s resolution]	9 bits conveyed in the TC Element (34 minutes @ 4s resolution)
Horizontal TC Report Information	Horizontal Data Available and Horizontal TC Type	[4 bits]	4 bits conveyed in the TC Element
	TC Latitude	[700 m or better]	15 bits conveyed in the TC Element (angular weighted binary)
	TC Longitude	[700 m or better]	16 bits conveyed in the TC Element (angular weighted binary)
	Turn Radius	[700 m or better]	7 bits conveyed in the TC Element (~40 NM @ 700m resolution)
	Track to TCP	[1 degree]	9 bits conveyed in the TC Element (0.7 deg resolution)
	Track from TCP	[1 degree]	9 bits conveyed in the TC Element (0.7 deg resolution)
	(Reserved for Horizontal Conformance)	[1 bit]	1 bit conveyed in the TC Element
	Horizontal Command/Planned Flag	[1 bit]	1 bit conveyed in the TC Element
Vertical TC Report Information	Vertical Data Available and Vertical TC Type	[4 bits]	4 bits conveyed in the TC Element
	TC Altitude	[100 ft resolution]	10 bits conveyed in the TC Element
	TC Altitude Type	[1bit]	1 bit conveyed in the TC Element
	(Reserved for Altitude Constraint Type)	[2 bits]	2 bits conveyed in the TC Element
	(Res. for Able/Unable Altitude Constraint)	[1 bit]	1 bit conveyed in the TC Element
	(Reserved For Vertical Conformance)	[1 bit]	1 bit conveyed in the TC Element
	Vertical Command/Planned Flag	[1 bit]	1 bit conveyed in the TC Element
Spare bits in TC Element of UAT Message Payload→			0 bits
Total bits utilized in TC Element of UAT Message Payload →			**96 bits**

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Appendix M

UAT Error Detection and Correction Performance

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M. UAT Error Detection and Correction Performance

This Appendix provides information on the performance of the Reed Solomon (RS) codes used by the various message types of UAT. The Short ADS-B Message is a RS (30, 18) code word; the Long ADS-B Message is a RS (48,34) code word; and the ground up link message is six RS (92, 72) code words. These codes provide very strong error correction. Also, the error detection provided by these codes is sufficient to provide a maximum undetected error rate that is less than 10^{-8} for each of the message types, so additional CRC coding is not needed. Note that this excellent undetected error performance is due, in part, to the use of hard decision decoding. Schemes involving erasures might have considerably larger (i.e., degraded) undetected error rates.

The total word error rate for a RS (n, k) code is given by the formula:

$$P_E = \sum_{j=t+1}^{n} \frac{n!}{j!(n-j)!}\, p_S{}^{j}(1-p_S)^{n-j},$$

where t=(n-k)/2 and p_S is the symbol error rate (SER). P_E includes both undetected and detected word error probabilities. Because there are 8 bits per symbol, the connection between the SER and the channel bit error rate (BER) is given by:

$$p_S = 1-(1-p)^8.$$

where p is the channel BER.

The asymptotic value for the undetected word error rate (achieved when the channel bit error rate is 0.5) for a RS (n, k) code can be calculated using the formula:

$$P_U = \frac{256^k - 1}{256^n}\sum_{j=0}^{t}\frac{n!}{j!(n-j)!}\,255^j$$

where t=(n-k)/2. The results are given in Table M-1.

Table M-1: Maximum Undetected RS Word Error Rates

Code	Maximum Undetected Word Error Rate
RS(30,18)	2.06e-9
RS(48,34)	9.95e-10
RS(92,72)	5.74e-12

The undetected error performance of a RS code as a function of channel bit error rate can also be calculated, but the mathematical complexity is much greater [1]. The results are shown in Figure M-1 through Figure M-3. These graphs show total word error rate together with undetected word error rate. The detected word error rate, P_D, is just the difference between the two curves. If the correct word error rate is defined as P_C, then all the probabilities are related by:

$$1 = P_E + P_C = P_U + P_D + P_C.$$

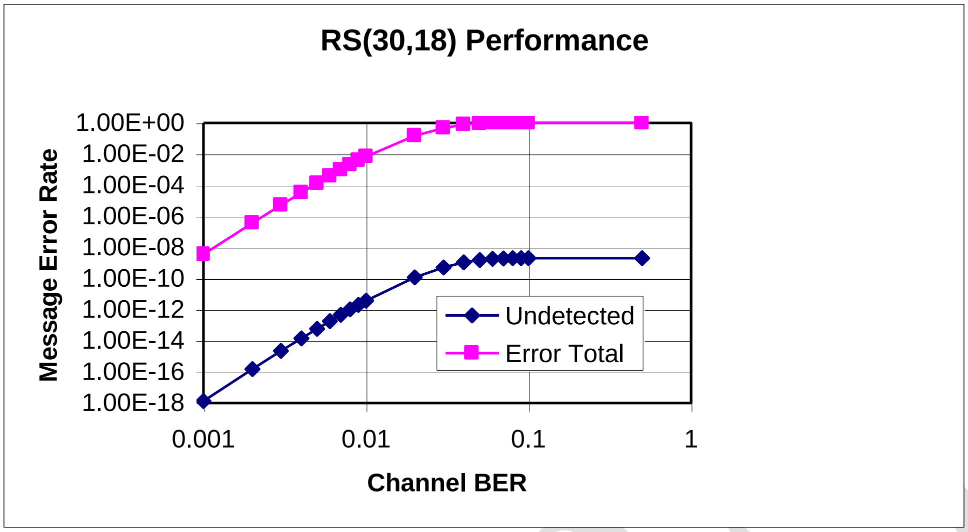


Figure M-1: **Short ADS-B Message Performance**

(“Undetected” = P_U ; “Error Total” = P_E .)

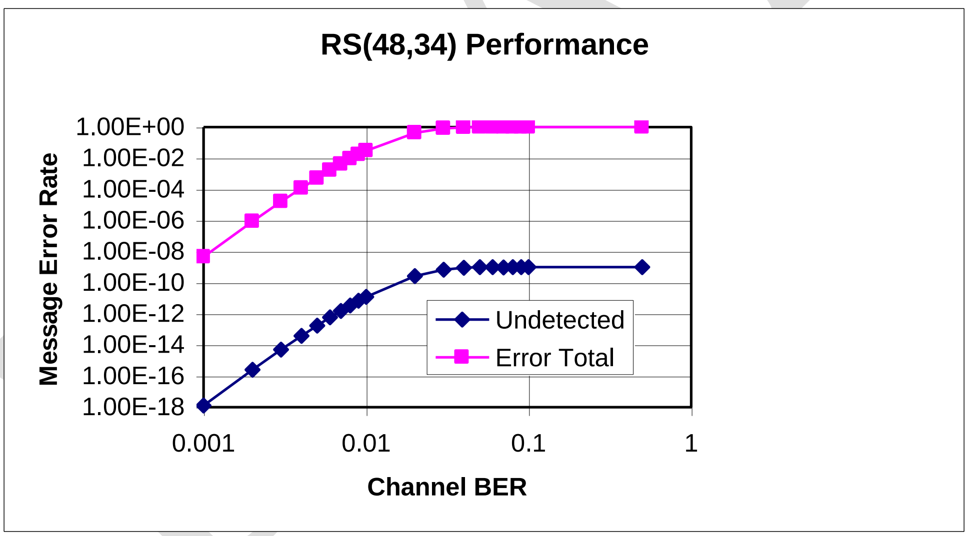


Figure M-2: **Long ADS-B Message Performance**

(“Undetected” = P_U ; “Error Total” = P_E .)

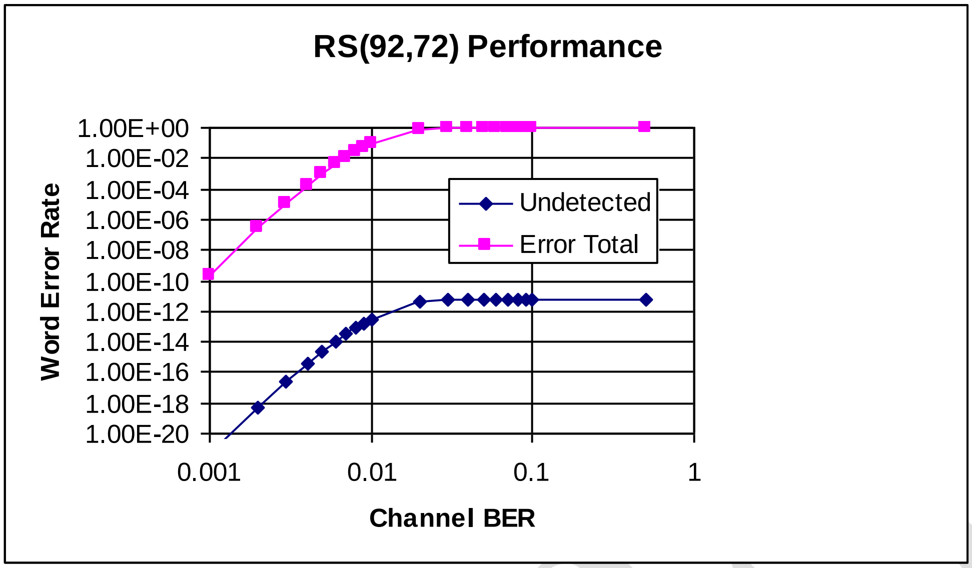


Figure M-3: Ground Up Link Message Performance

(“Undetected” = P_U ; “Error Total” = P_E .)

Note that for the ADS-B Messages, the word error rate is equal to the message error rate because there is one word per message. This is not true for the Ground Uplink Message. Figure M-3 shows the performance of a single RS (92, 72) word. The performance of an entire message, consisting of six words, is given by:

$$P_{Uburst} = (1 - P_E + P_U)^6 - (1 - P_E)^6 = (P_C + P_U)^6 - P_C{}^6$$

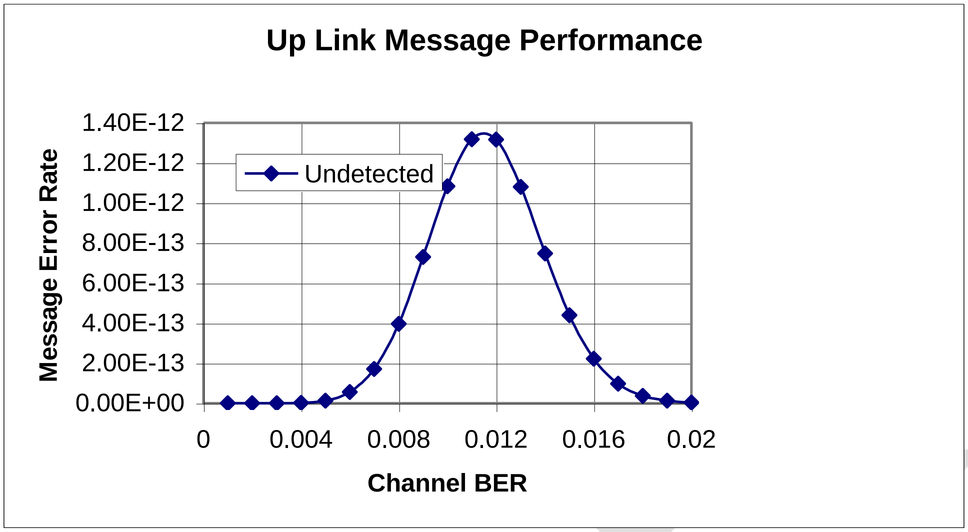
and

$$P_{Eburst} = 1 - (1 - P_E)^6 = 1 - P_C{}^6$$

Again, P_E is the total word error rate, and P_U is the undetected word error rate. A graph of the undetected message error rate versus the channel BER is shown in Figure M-4, which indicates that the maximum undetected error rate is about 1.3e-12, which occurs when the channel BER is about 0.012. To see why there is a maximum, consider the following approximation:

$$P_{UBurst} \approx 6P_U (1 - P_E)^5 .$$

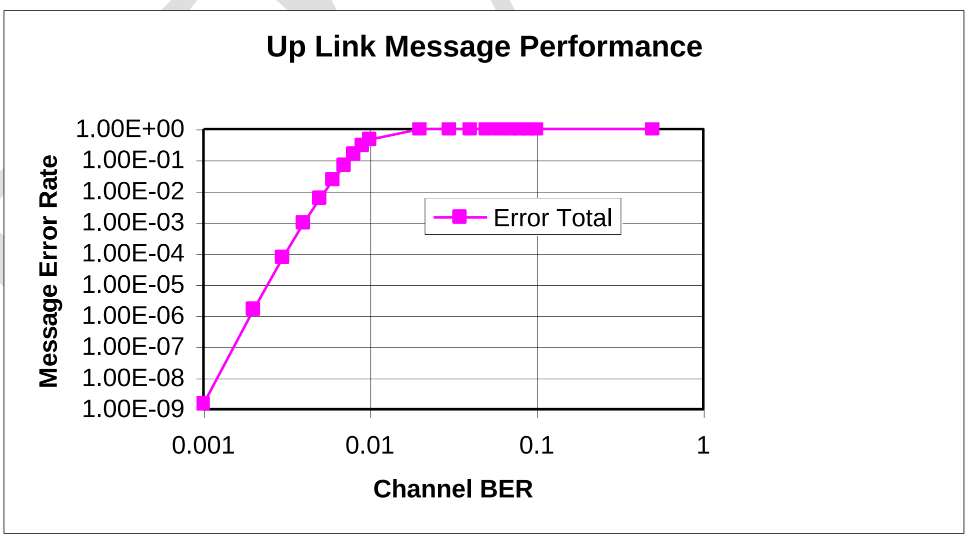
The P_U term is small at low BER and the $(1 - P_E)^5$ term is small at high BER (because P_E is nearly 1 in that case).



<u>Figure M-4:</u> Ground Up Link Message Undetected Message Error Rate

(“Undetected” = P_{UBurst} .)

For completeness, a graph of the total up link message error rate versus channel BER is also provided in Figure M-5.



<u>Figure M-5:</u> Ground Up Link Message Total Message Error Rate

(“Error Total” = P_{EBurst} .)

Up to this point the discussion has dealt with the performance of the RS codes in the presence of noise that generates random bit errors. However, in addition to protecting against errors created by stationary and non-stationary interference (see Appendix K), the RS codes are also used as the sole means to differentiate between Long and Short ADS-B messages. It is of interest to investigate the performance of this identification process.

In order to analyze this issue, it is useful to have a clear picture of the ADS-B reception process as defined in this document. The logical flow of the process is as shown in Figure M-6.

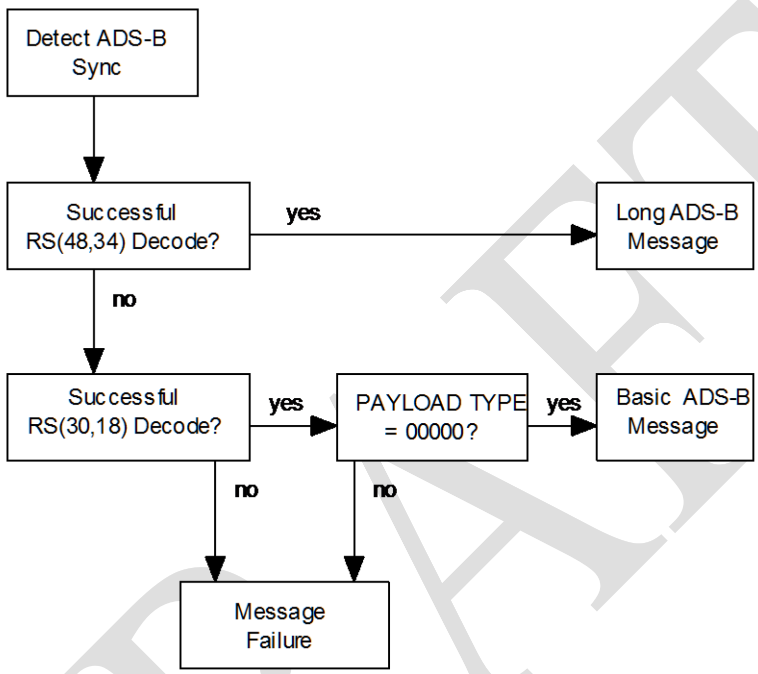


Figure M-6: Logical Flow of ADS-B Reception

After each successful detection of an ADS-B synchronization pattern, the receiver will first check if the RS (48,34) decoding process is successful. If so, the receiver will determine that a Long ADS-B message was actually sent. However, if this decoding process fails, the receiver will check if the RS(30,18) decoding process is successful. If it is, the message is a candidate Short ADS-B message. As a final safeguard, the receiver will check if the 5 bits of the PAYLOAD TYPE field are all zeros. If this test is successful, the receiver will determine that a Short ADS-B message was actually sent. If the PAYLOAD TYPE test fails or if the RS (30,18) decoding process fails, the entire message is discarded. (Note that this is a *logical* flow only. It is possible, for example, for the two RS decodes to be done in any time order.)

For this investigation there are two possible failure modes of interest. First, an actual Short ADS-B message could be perceived as a Long ADS-B message. Second, a Long ADS-B message could be perceived as a Short ADS-B message. These two will be discussed separately.

When a Short Message is received, it is first subjected to the RS (48,34) decoding process. The input to the decoder will be the 30 bytes of the Short Message (assumed to have no bit errors) plus 18 bytes of random data. Because the random part of the input to the decoder includes the entire parity check sequence, the probability of a successful decode is the same as the maximum undetected error rate reported in Table M-1, i.e., 9.95x10^{-10}. Thus, there is about one chance in one billion that a particular Short Message will appear to be a Long Message.

Note that in the case above a RS (30,18) decoding attempt would have been successful if carried out, since there are assumed to be no bit errors. However, the decoding rules give precedence to a successful Long ADS-B decision.

When a Long ADS-B message is received, it also is subjected initially to the RS (48,34) decoding process. If there are no bit errors, then the decoding will succeed, and the message will correctly be determined to be a Long ADS-B message. However, the process will not succeed if there are more than 7 incorrect bytes. In that case the decoder may (with probability no greater than 9.95x10^{-10}) produce an undetected error, i.e., it will produce a Long ADS-B message different from the one that was sent. It is far more likely that the decoder will fail to produce any result, and the RS (30,18) decoding process will be attempted next.

From the point of view of the RS (30,18) decoder, the first 30 bytes of the Long ADS-B message are equivalent to a random sequence of 240 bits, except that the first five bits (the location of the PAYLOAD TYPE field) are not 00000. Thus, the decoding process must change the first byte to include 00000 in order to succeed. The probability of this occurring is given by the following equation:

$$p = \frac{8}{256^{12}} \cdot \sum_{k=0}^{5} \binom{29}{k} 255^{k} = 1.29x10^{-11}.$$

Checking for the correct PAYLOAD TYPE lowers the false decode probability from 2.06x10^{-9} to 1.29x10^{-11}.

During the development of UAT there was some concern that there might be an abnormally high probability of misinterpreting a Long ADS-B message as a Short ADS-B message if there were a preponderance of zeros in the payload. This might happen if many of the fields were “stuffed” with zeros due to the unavailability of data. Since “all-zeros” is a valid RS code word and the RS (30,18) code can correct up to 6 erroneous bytes, the first 30 bytes of a Long ADS-B message will “successfully” decode to the all-zero Short ADS-B message whenever 6 or less of the 30 bytes are nonzero. Because the RS (48,34) decoding process has precedence, this scenario requires that the Long decoding process must fail and the Short decoding process must succeed. Normally, a BER high enough to cause the RS (48,34) decoding process to fail would turn enough of the zero bytes into nonzero bytes so that the RS (30,18) decoding process would also fail. However, it is possible that interference (e.g., another ADS-B message) could overlap only the tail end of a Long ADS-B message, leaving the first 30 bytes essentially intact. It is difficult to assess the likelihood that such a situation will arise since it depends on the number of potential interference sources and their relative signal strengths.

Whatever their probability might be, if the conditions described in the previous paragraph should prevail, the decoding process will incorrectly result in an all-zero Short ADS-B message. This decoded message will pass the PAYLOAD TYPE test; however, this should *not* generate an operational problem because such a message will necessarily contain the all-zero ICAO address, which is invalid. Thus, in order to cope with this (very unlikely) situation, any application that uses a decoded ADS-B message could check the validity of the ICAO address before processing the remainder of the information.

As a final note it should be pointed out that the receiver could, as an option, check the PAYLOAD TYPE field of candidate Long ADS-B messages as well as of candidate Short ADS-B Messages. Checking that the PAYLOAD TYPE field is *not* 00000 will lower very slightly (by a factor of 31/32) the probability of undetected error in the presence of random bit errors. It will also lower the probability of interpreting a

Short ADS-B Message as a Long ADS-B message by a factor of about 7; this probability is given by the following formula:

$$p = \frac{248}{256^{14}} \cdot \sum_{k=0}^{6} \binom{47}{k} 255^{k} = 1.41x10^{-10}.$$

This check is not a requirement since the improvement it provides is rather modest.

The information contained in this Appendix is summarized in Table M-2. The numbers presented are upper limits on the likelihood of potential ADS-B messages being misinterpreted. The first two rows assume that the input bit stream is corrupted by strong interference, and the entries are upper bounds on the probabilities of interpreting a Long (Short) ADS-B message as an incorrect Long (Short) ADS-B message. The other rows provide upper limits on the probabilities of incorrectly interchanging Long and Short. The shaded cells represent the results obtained by using the optional check of the PAYLOAD TYPE field for Long ADS-B message candidates. Table M-2 does not address the likelihood of a successful synchronization being followed by a very high BER for all or part of the remaining message; the probability of encountering the interference conditions necessary for misinterpreting message length is certainly much less than 1.

Table M-2: Upper Bounds on Undetected Message Error Probabilities

Transmission	Perceived Reception	Raw Probability of Undetected Error	Probability with PAYLOAD TYPE Check
Long	Long	9.95e-10	9.64e-10
Short	Short	2.06e-9	6.45e-11
Short	Long	9.95e-10	1.41e-10
Long	Short	2.06e-9	1.29e-11

Reference [1]: Kasami,T., and S. Lin, 1984, “On the Probability of Undetected Error for Maximum Distance Separable Codes,” IEEE Trans. Comm., COM-32,998-1006.

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Appendix N

Setup Files for Test Procedures

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N. Setup Files for Test Procedures

Some Test Procedures in this document require set up of Vector Signal Analyzers, Signal Generators and/or the insertion of UAT Messages with exact strings of data input engineered to verify that a particular UAT System is compliant with the requirement stated in the respective requirements section of this document. In an effort to ensure that the input of data, or the set up of a particular piece of test hardware is consistent across multiple vendors of UAT Equipment, we are providing the following set of files on the ADS-B/UAT MOPS web site for UAT Equipment vendors to download and use in their testing efforts.

The ADS-B/UAT MOPS web site is located at: **http://adsb.tc.faa.gov/WG5.htm**

Table N-1: Files Associated with Test Procedures

Filename	Test Procedure Subparagraph	File Description
UAT-DMD.STA	2.4.2.1	A state file used to configure the Agilent HP89441A Vector Signal Analyzer into the "Digital Demodulation" mode.
UAT-DMD.STA	2.4.2.3	A state file used to configure the Agilent HP89441A Vector Signal Analyzer into the "Digital Demodulation" mode.
UAT-DMD.STA	2.4.2.4	A state file used to configure the Agilent HP89441A Vector Signal Analyzer into the "Digital Demodulation" mode.
XT_ENC_BASIC.TXT	2.4.3.1.3.1	A file that contains Short ADS-B UAT Messages and its associated FEC Parity sequence as tabulated in Table 2-73. The data is written in HEX format.
XT_ENC_LONG.TXT	2.4.3.1.3.1	A file that contains Long ADS-B UAT Messages and its associated FEC Parity sequence as tabulated in Table 2-74. The data is written in HEX format.
UAT-VECT.STA	2.4.8.2.3	A state file used to configure the Agilent HP89441A Vector Signal Analyzer into the "Vector" mode.
UAT-VECT.STA	2.4.8.2.4	A state file used to configure the Agilent HP89441A Vector Signal Analyzer into the "Vector" mode.
RX_DEC_BURST.DOC	2.4.8.3.1.1	Tables that contain erroneous ADS-B UAT Messages (all 384 bits long), status, decoded Message Type, RS decoded ADS-B UAT Message Payload sequence as tabulated in Table 2-104. The data is written in HEX format.
RX_DEC_BRAND.DOC	2.4.8.3.1.1	Tables that contain erroneous ADS-B UAT Messages (all 384 bits long), status, decoded Message Type, RS decoded ADS-B UAT Message Payload sequence as tabulated in Table 2-105. The data is written in HEX format.
RX_DEC_GROUND.DOC	2.4.8.3.1.2	Tables that contain de-interleaved six consecutive erroneous RS blocks (736 bits long) for each of nine Ground Uplink Messages, status, decoded RS block and Ground Uplink Message status, as tabulated in Table 2-106 through Table 2-114. The data is written in HEX format.

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Appendix O

DME Operation in the Presence of UAT Signals

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O. DME Operation in the Presence of UAT Signals

This Appendix provides a summary of testing and analyses that verifies UAT compatibility with Distance Measuring Equipment (DME) and that DME equipment will operate without degradation in the presence of UAT signals.

Over the course of the development of the UAT MOPS, numerous studies and analyses were performed on UAT compatibility and the DME environment. All of the Working Papers detailing the results of that analysis can be found on the ADS-B/UAT MOPS web site, which is located at:

http://adsb.tc.faa.gov/WG5.htm

The goal of the DME testing, conducted as a part of the UAT MOPS development, was to verify that UAT signals do not interfere with the proper operation of DMEs, which operate in the band in which UAT will operate. The focus of the bench testing herein was to conduct tests on DME units that were representative of the vast majority of the DMEs used in the different categories of aviation equipage. However, due to the large number of different manufacturers and types of DMEs, it was unrealistic to test all of the possible DMEs in the system. Four DME units were selected based on availability, and representing the different categories of avionics instrumentation. The specific models used in the testing were:

1. Bendix King KD-7000
2. Narco DME-890
3. Rockwell-Collins DME-900
4. Honeywell 706-A

The latter two were selected to represent units currently in use in the European Union.

The first phase of testing was to determine the impact of overlapping UAT signals onto the DME pulse pairs. The test configuration consisted of a victim DME interrogator connected to a DME ground station simulator and a UAT message source generating Long ADS-B UAT Messages. The DME ground station simulator received interrogations from the DME unit under test and transmitted replies as well as unsolicited pulse pairs to closely match the operation of an actual ground simulator. Since the selected frequency for UAT does not reside in the interrogation frequency band, the testing was configured with a clear interrogation channel. This assumption is consistent with standard DME interrogator test procedures and any interference on the interrogator channel would be manifested in the system as a reduction in transponder reply efficiency. The UAT frequency was tested co-channel with the DME reply frequency and testing was also conducted with DMEs located on adjacent DME channels. On the reply channel, every reply was completely overlapped with the same level of UAT interference. This is much more severe than any real world interference environment, but is appropriate for the purposes of the bench testing where performance under extreme conditions provides the data required to model real world scenario performance. A data point consists of measuring both the interfering signal level that prohibits the DME to acquire a track (Acquire Stable Operating Point (ASOP)) and the level that causes the

DME to lose a track that it has already acquired (Break Stable Operating Point (BSOP.)) In general, it was found that these two levels were separated by approximately 1 dB.

One especially informative measurement was taken where ASOP and BSOP were determined as a function of the reply efficiency of the ground station. The simulator utilized in the test configuration had the capability to randomly reply to 0-100% of the interrogations it received. The measurements showed that the DME interrogator could acquire and track in the presence of the same level of UAT interference as long as at least 30% of its interrogations elicit replies. Each DME model tested could tolerate relatively high amplitude UAT interference, although each unit tolerated a slightly different level of interference. This seems to indicate that as long as a DME is able to receive more than 30% of the replies from its interrogations with interference less than the ASOP/BSOP point particular to that DME unit, it will operate. It is important to note that although this was a consistent characteristic of the four DME units tested, this may not be true of all DME units operating in the system. However, given the significant margin with respect to the 70% reply efficiency monitor limit, there is enough of a margin to have the confidence to apply these results to operational DMEs in the system.

The results of the bench test conducted are depicted in the following figures. Figure O-1 summarizes the data results of co-channel and adjacent channel DME operation of the Bendix King KD-7000 DME. The DME levels utilized were –68 dBm and –83 dBm and reply efficiency was set at 100%.

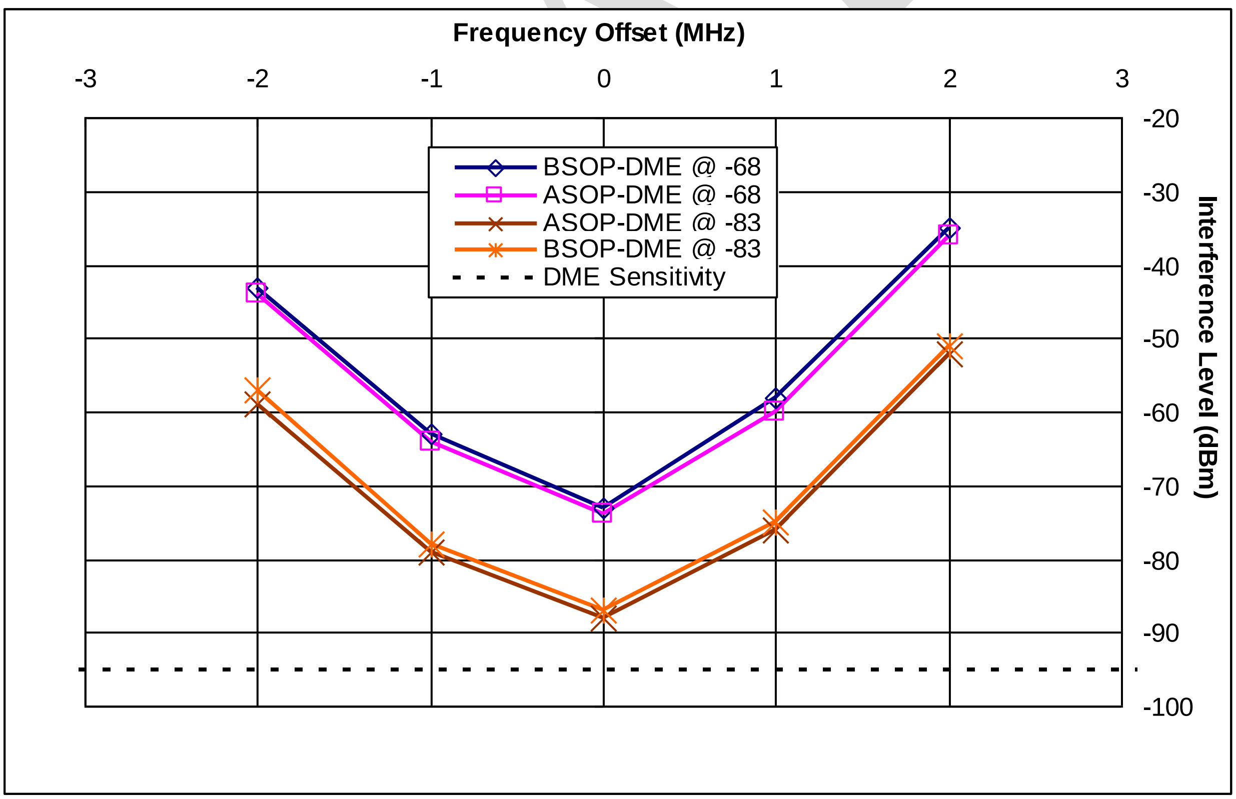


Figure O-1: Bendix King KD-7000 Frequency Offset Test

Figure O-2 depicts the performance of the Bendix King KD-7000 DME as a function of reply efficiency. DME levels of –68 dBm and –83 dBm were utilized and these signals were co-channel. This plot shows the consistent behavior of the DME as a function of reply efficiency above 30%.

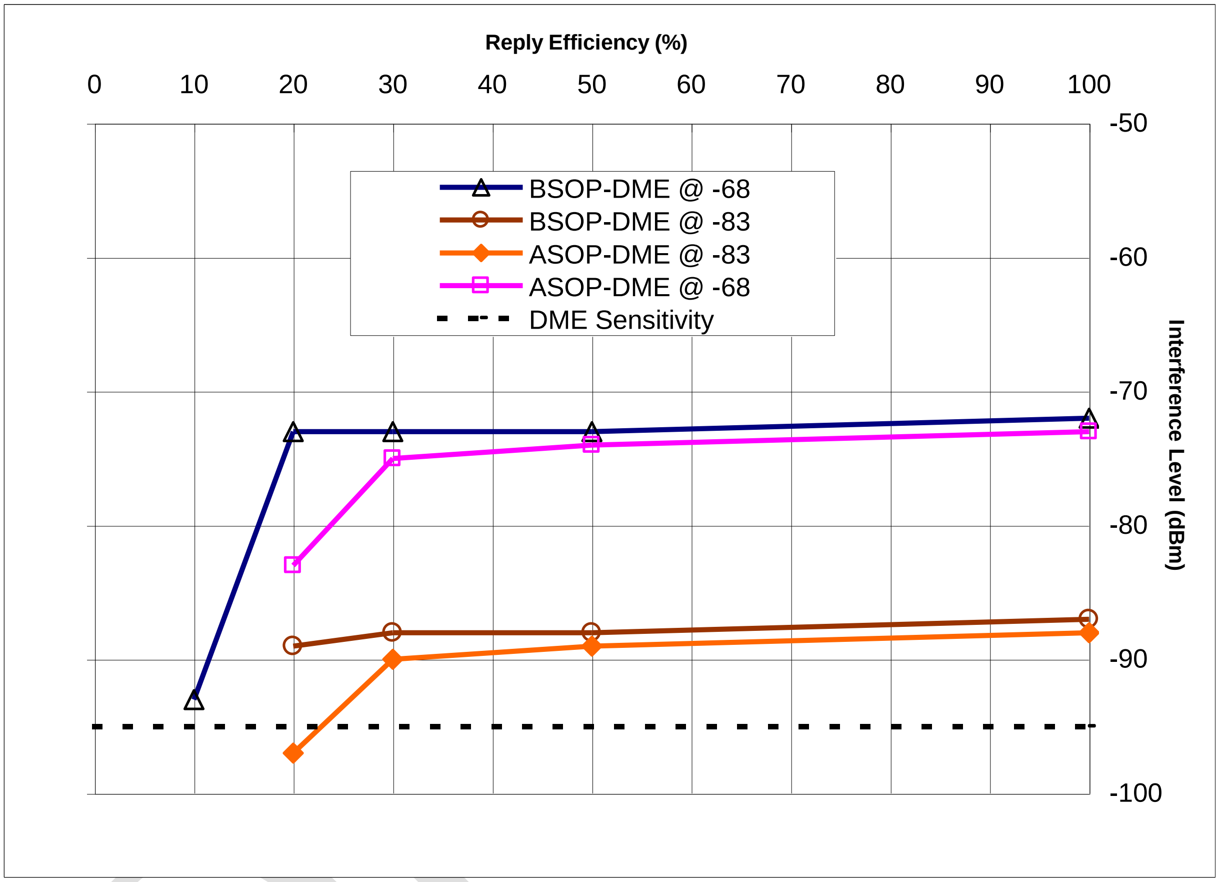


Figure O-2: Bendix King KD-7000 Reply Efficiency Test

Figure O-3 depicts the performance of the Bendix King when subjected to CW with a DME level of –83 dBm. The results are very similar to the UAT signal interference results as a function of frequency offset.

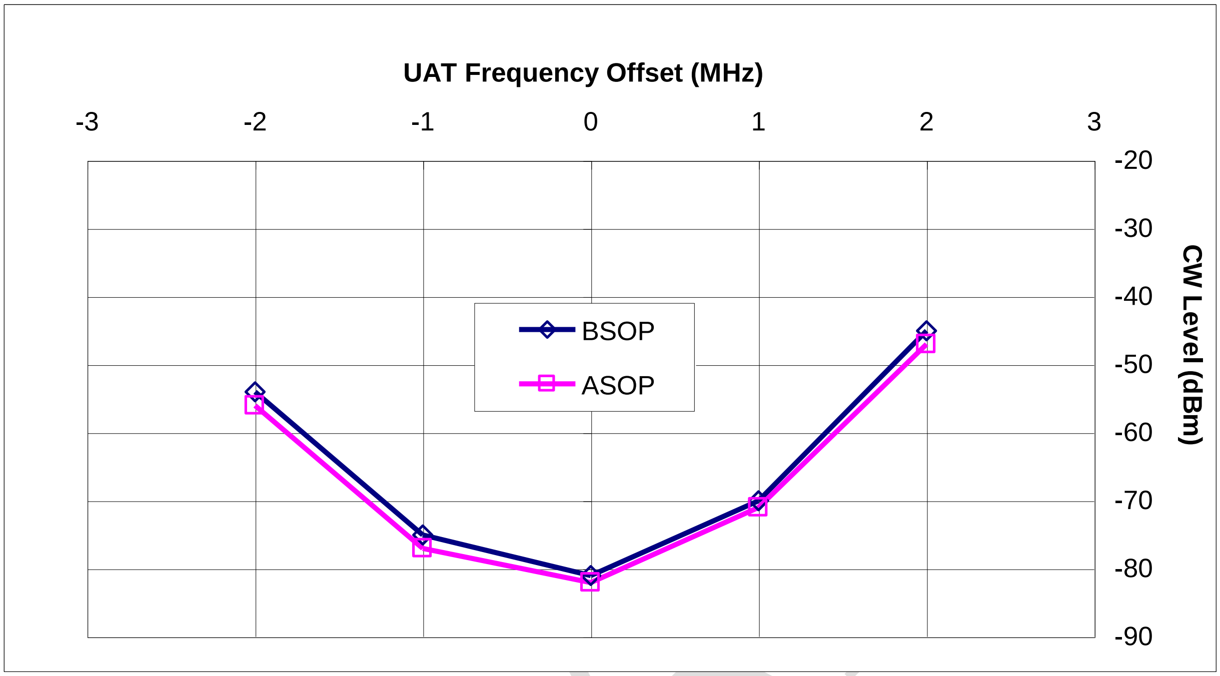


Figure O-3: Bendix King KD-7000 CW testing: DME level –83 dBm

Figure O-4 summarizes the data results of co-channel and adjacent channel DME operation of the Narco DME-890. The DME levels utilized were –60 dBm and –75 dBm. These amplitude levels were chosen to allow comparison with the other DME units at comparable levels above sensitivity. The Narco DME-890 had the least sensitive receiver of the four units which was measured at –81 dBm.

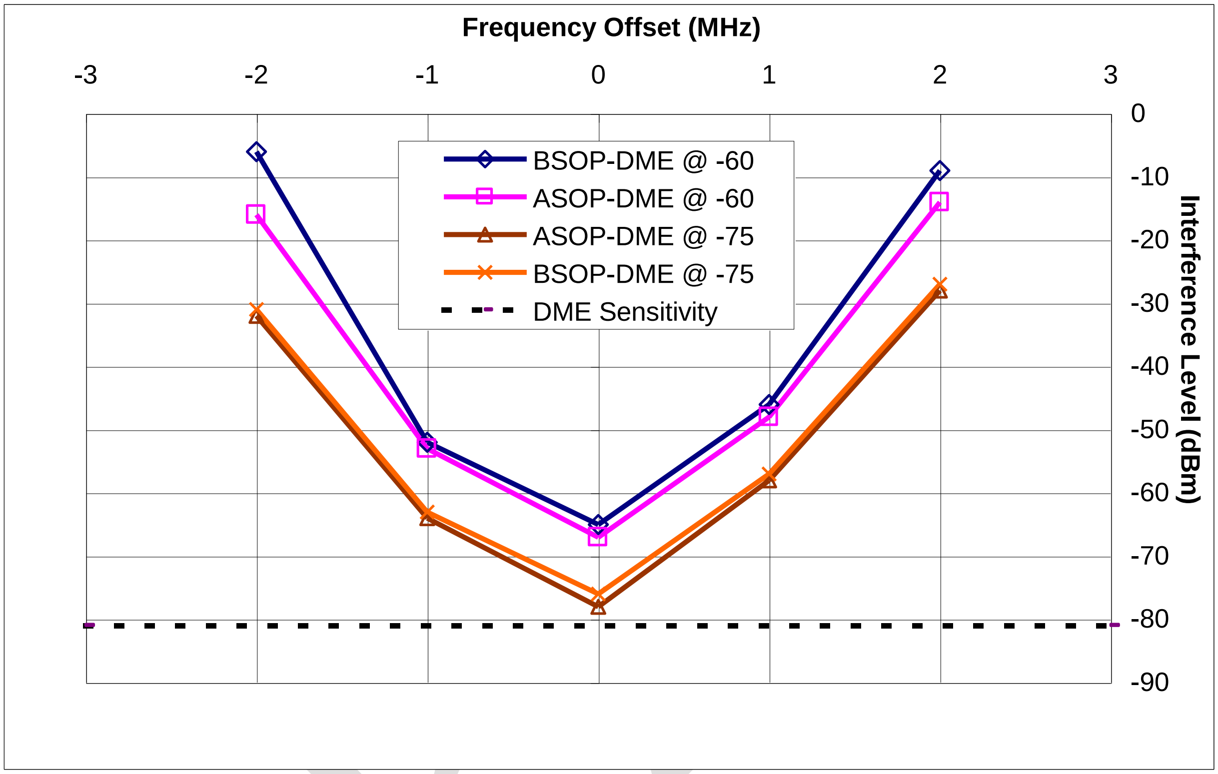
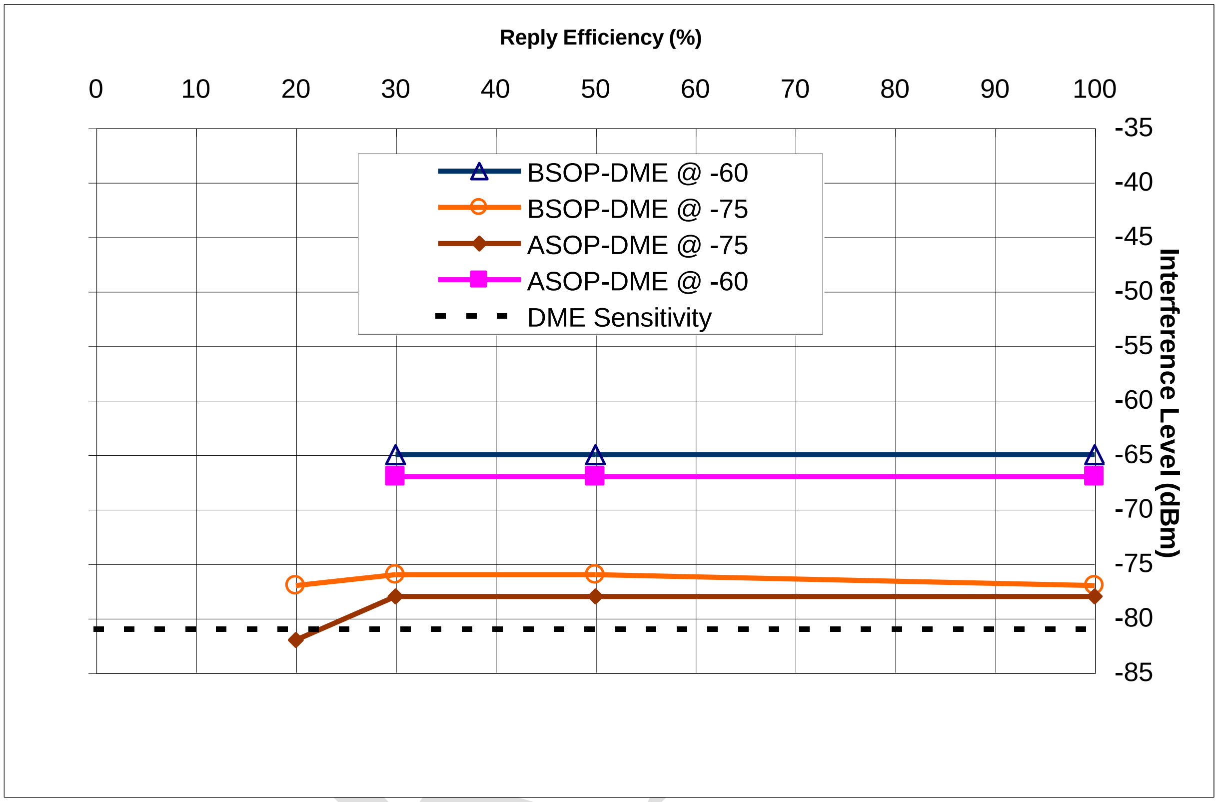
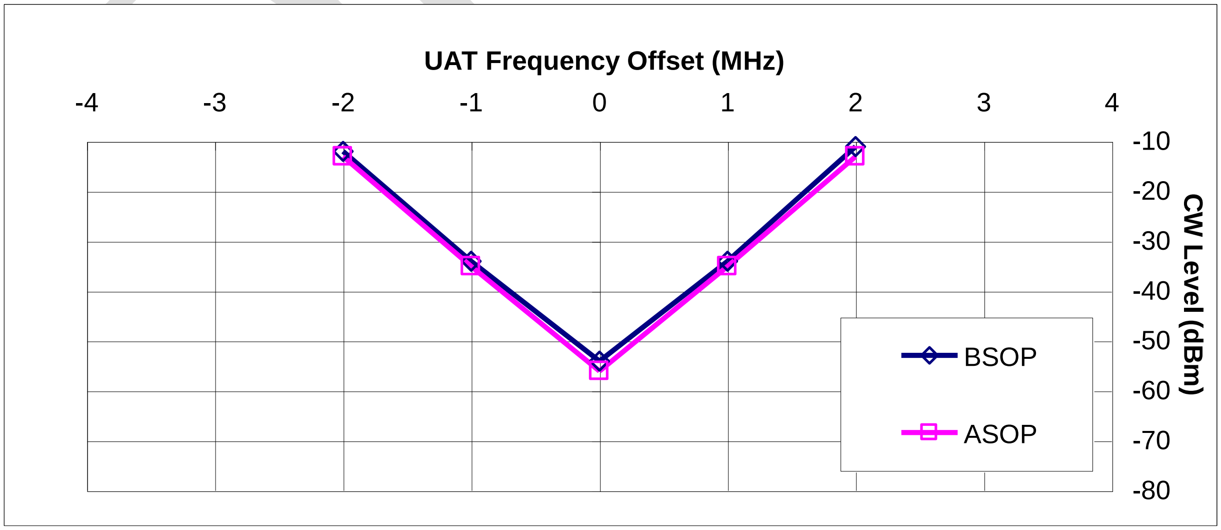


Figure O-4: Narco DME-890 Frequency Offset Test

Figure O-5 depicts the performance of the Narco DME-890 as a function of reply efficiency. DME levels of –60 dBm and –75 dBm were utilized and these signals were co-channel. As also seen in the behavior of Bendix King KD-7000, the performance is consistent as a function of reply efficiency above 30%. Figure O-6 depicts the performance of the Narco DME-890 when subjected to CW with a DME level of –75 dBm.

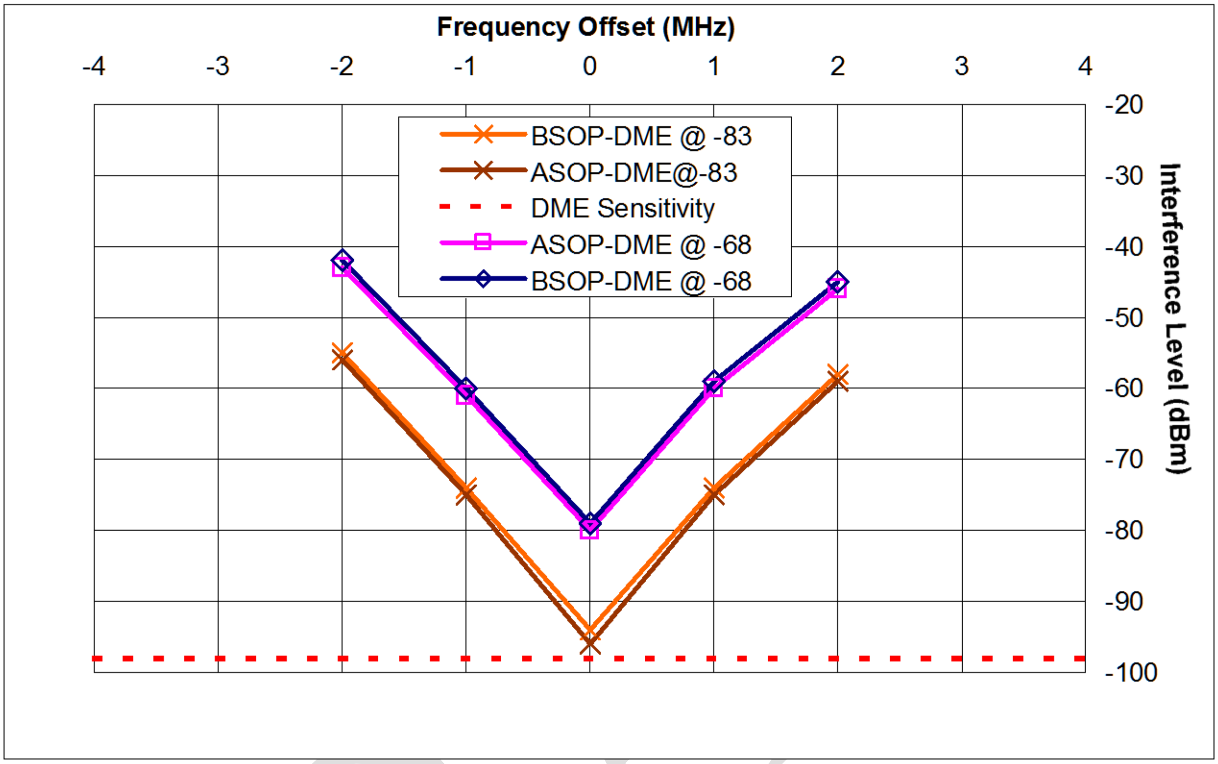


<u>Figure O-5:</u> Narco DME-890 Reply Efficiency Test



<u>Figure O-6:</u> Narco DME-890 CW testing: DME level -75 dBm

Figure O-7 summarizes the data results of co-channel and adjacent channel DME operation of the Honeywell KDM-706A DME. The DME levels utilized were –68 dBm and –83 dBm and reply efficiency was set at 100%.



<u>Figure O-7:</u> Honeywell KDM-706A Frequency Offset Test

Figure O-8 depicts the performance of the Honeywell KDM-706A DME as a function of reply efficiency. DME levels of –68 dBm and –83 dBm were utilized and these signals were co-channel.

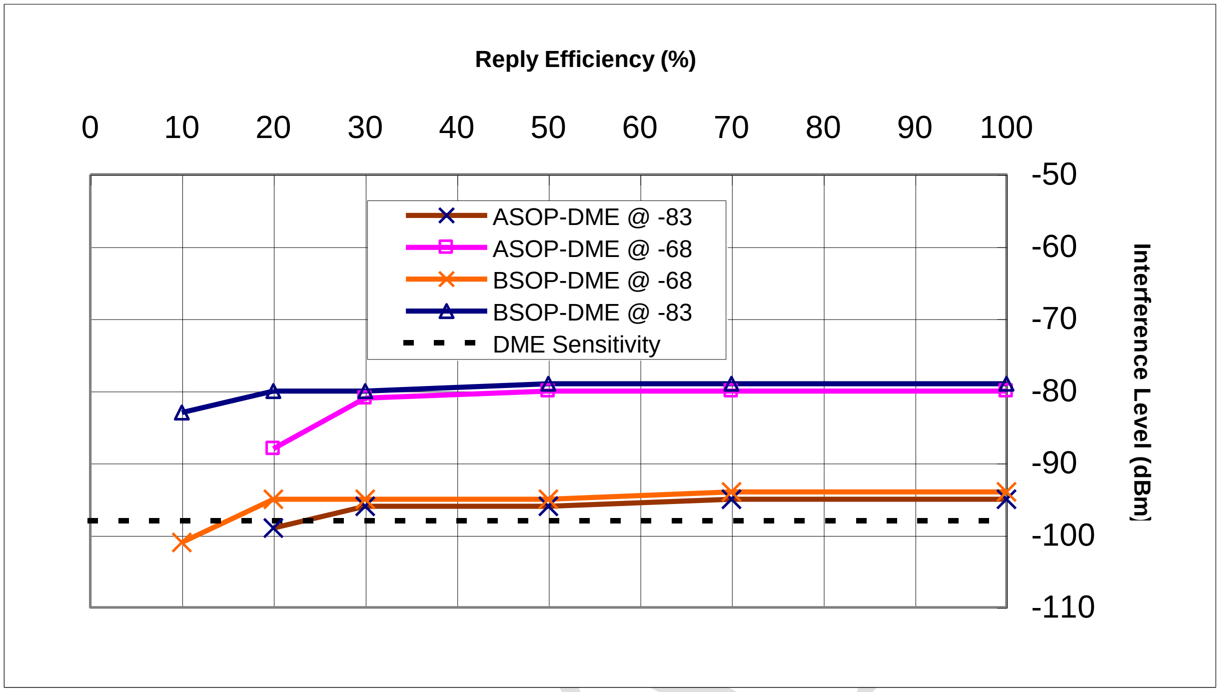
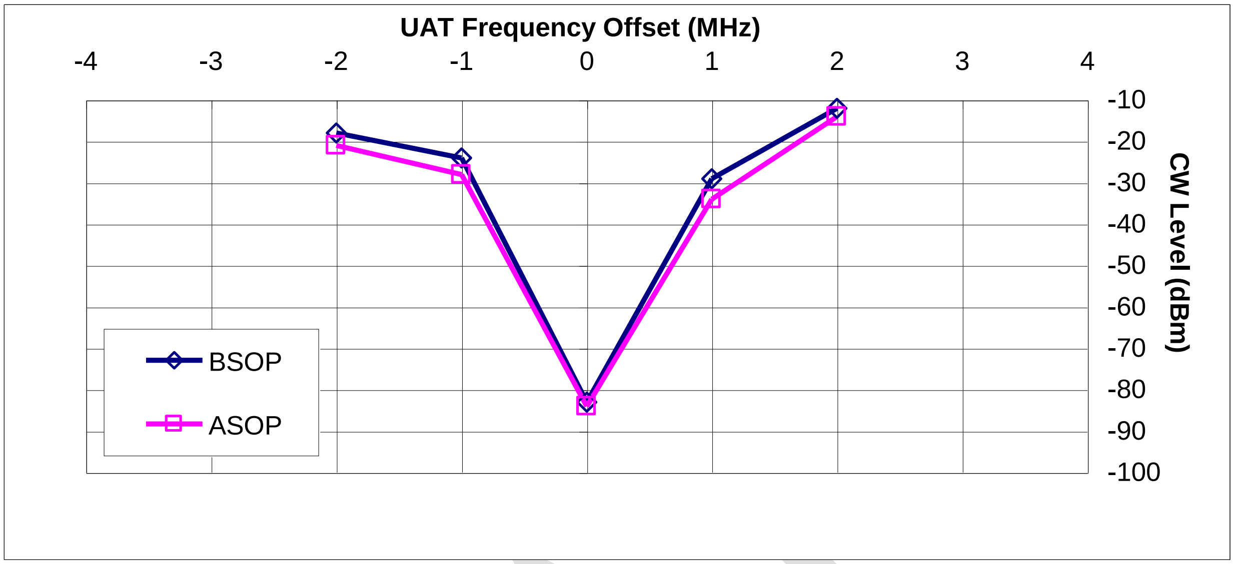


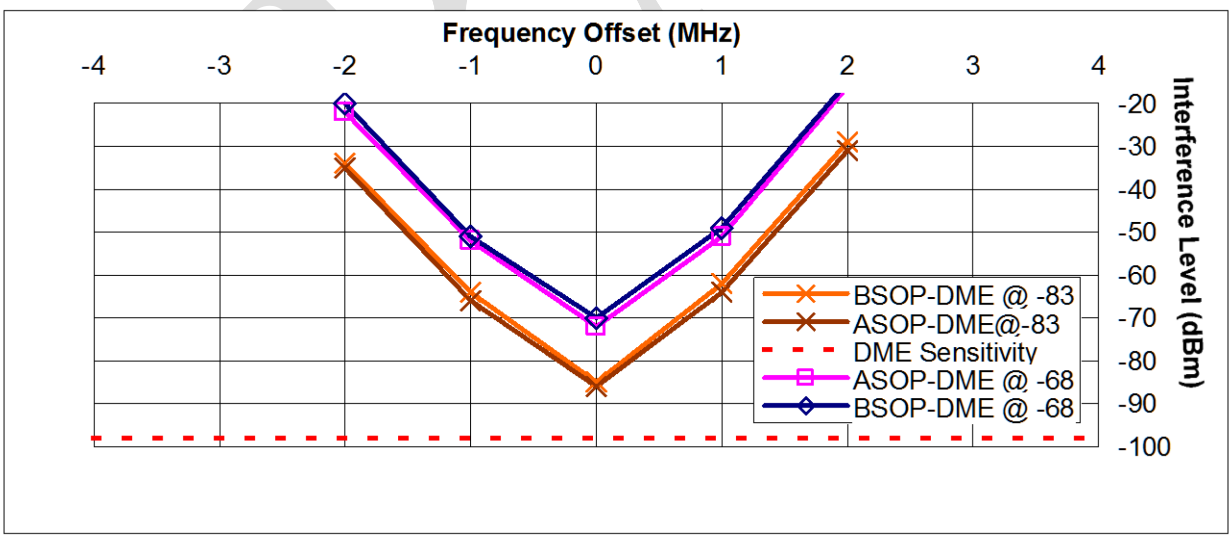
Figure O-8: Honeywell KDM-706A Reply Efficiency Test

Figure O-9 depicts the performance of the Honeywell KDM-706A DME when subjected to CW with a DME level of –83 dBm. As with the previous DME units, the results are very similar to the UAT signal interference results as a function of frequency offset.

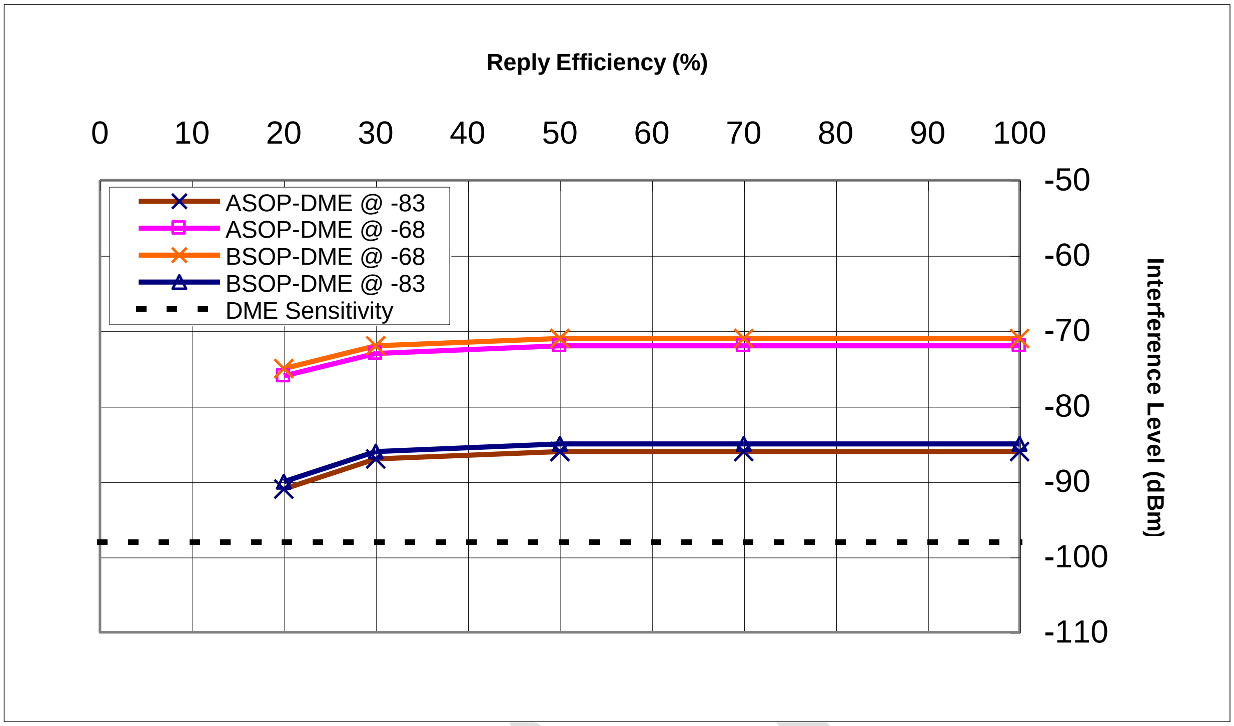


<u>Figure O-9:</u> Honeywell KDM-706A CW testing: DME level –83 dBm

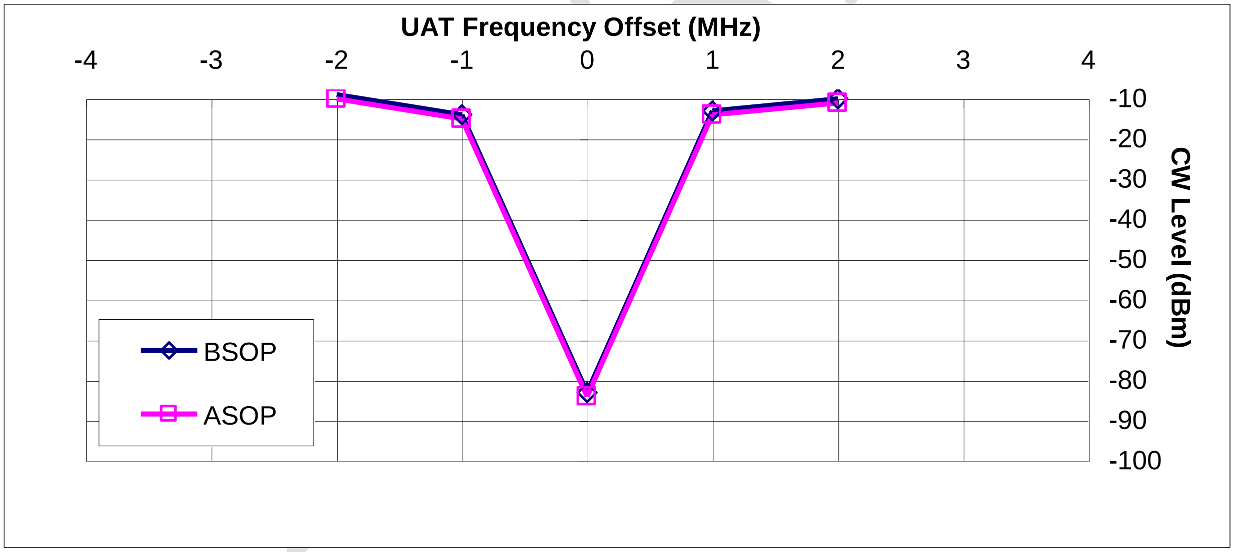
Figure O-10 through Figure O-12 summarizes the data results of the Rockwell-Collins DME-900.



<u>Figure O-10:</u> Rockwell-Collins DME-900 Frequency Offset Test



<u>Figure O-11:</u> Rockwell-Collins DME-900 Reply Efficiency Test



<u>Figure O-12:</u> Rockwell-Collins DME-900 CW testing: DME level –83 dBm

The comparisons of all four DME units tested are depicted in the following figures. Figure O-13 summarizes the data results of co-channel and adjacent channel DME operation of the four DMEs. Figure O-14 depicts the performance of the four DMEs as a function of reply efficiency. Figure O-15 depicts the performance of all four DMEs when subjected to CW. As can be seen by the co-channel results in Figure O-13 and Figure O-15, the KDM-706A had the worst signal to interference rejection.

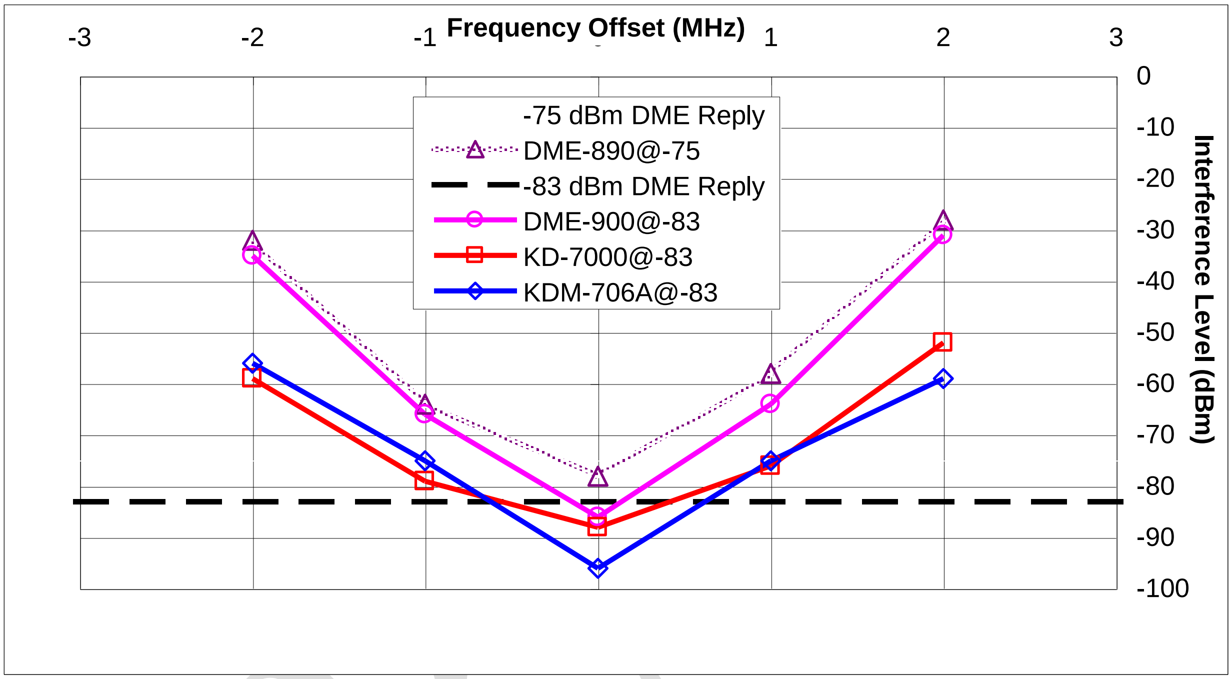


Figure O-13: Comparison of all DME Frequency Offset Tests

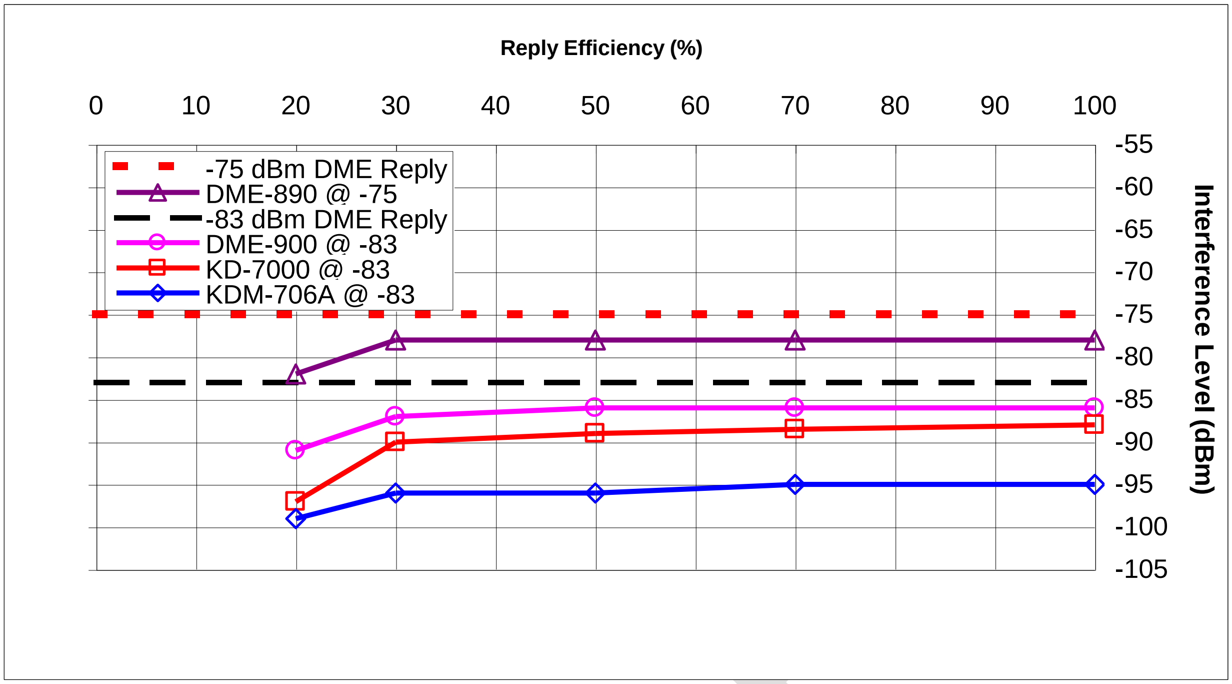


Figure O-14: **Comparison of all DME Reply Efficiency Tests**

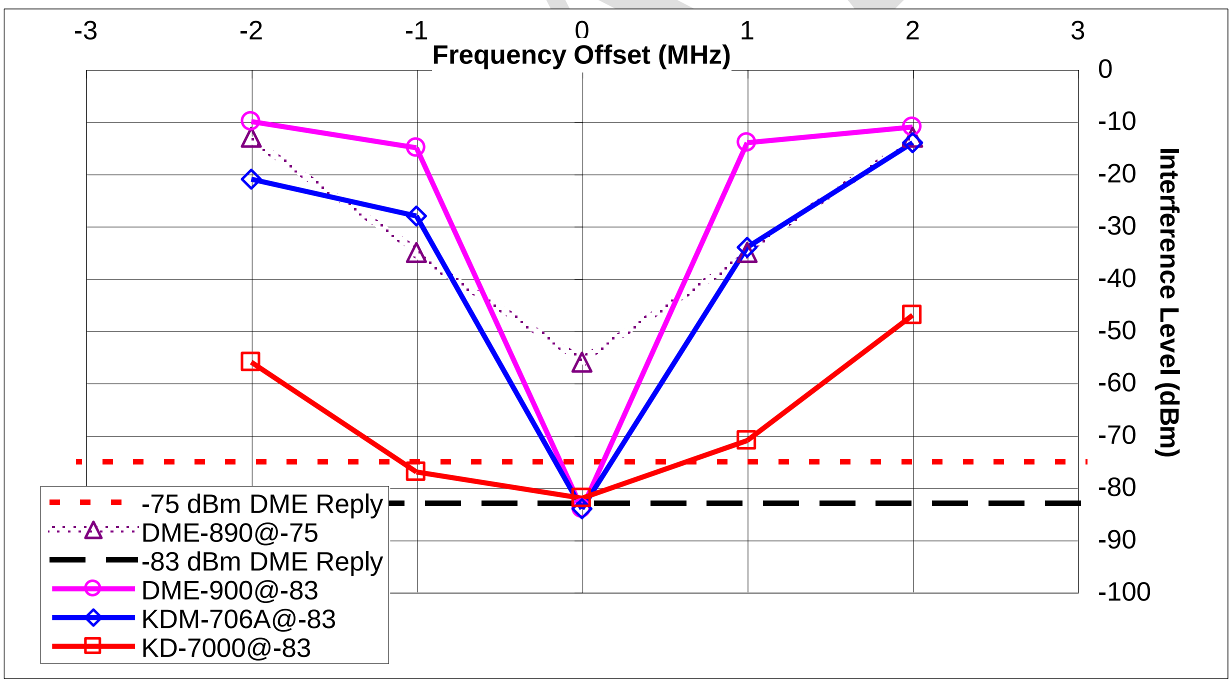


Figure O-15: **Comparison of all DME CW Interference Tests**

Using the combined data from the aforementioned bench testing and simulated high-density UAT traffic scenarios, the basis for making some basic conclusions on UAT and DME compatibility can be made. It can be determined, for example, at what desired signal level, which can then be converted into a range, that a particular DME can be expected to stop working in a specified UAT environment. It can also provide a measure of how much of a margin is left for DME performance after UAT interference and other DME interference sources are considered. As shown by the bench results where all DME pulse pairs are directly overlapped by UAT Messages, the DMEs exhibit exceptional immunity to even co-channel UAT interference. The UAT/DME environments that must be considered span different time frames. In the near term, over approximately a ten year time interval, DMEs operating at 978 MHz are expected to be moved. However, over this time span, there will be DMEs operating at 978 MHz co-channel with UAT in a number of European locations. In the longer term after these DMEs are moved, the closest DME will be 1 MHz away from the UAT 978 MHz frequency. Upon examining the bench test results, the consistent behavior of the DMEs at a given UAT interference level down to reply efficiency of 30%, can be utilized to make conclusions of UAT effect on DME in the projected environments. If one analyzes the Core Europe 2015 scenario to determine the probability of overlapping a DME pulse pair at or above the UAT interference level that would cause loss of operation, it can be determined that the DME will operate without any measurable degradation in that environment. For example, taking the co-channel Honeywell KD-7000 DME unit results with a desired signal level of –83 dBm, UAT signals at or above –96 dBm could potentially impair DME operation if the reply efficiency reduced to 30% or below. Taking the Core Europe 2015 scenario and looking at the number of UAT messages at a level of –96 dBm or above, on average, less than 900 messages per second would be received if a DME receiver is positioned over Brussels at 40,000 feet. This is the same aircraft location used in the high density Core Europe 2015 analysis in Appendix K. The probability of overlap is significantly less than the minimum probability that would cause probability of reception to be reduced to the level that would impact DME operation. Since the co-channel case would not occur at the aircraft densities produced by the Core Europe 2015 scenario, the operation of DMEs on 978 MHz can be safely achieved. Since the co-channel DME case is validated for Core Europe 2015, the DME channels 1 MHz or more from the UAT occupied frequency will not be impacted given there is on average 10 dB additional protection shown by the bench test results when the DME is 1 MHz away from UAT signals.

The UAT environment described in Appendix K, the Core Europe 2015 scenario, represents the future environment under which DMEs and UAT were examined to verify that proper operation would be maintained. A bench measurement with a DME unit subjecting the victim DME to the Core Europe 2015 UAT environment was performed to validate that DMEs would properly operate in the future UAT environment. Utilizing a UAT Message Generator, which produced UAT signal environments for model validation efforts described in Appendix K, the Core Europe 2015 UAT Messages that would be experienced by a victim airborne DME receiver were input to the DME receiver. Performance as a function of DME signal amplitude was examined. Rate, timing and amplitudes of UAT Messages for this scenario represent a more realistic worst-case scenario than the conditions under which the bench tests were conducted. The testing was conducted on the Narco DME-890 and the results were measured to determine the DME level to achieve ASOP. This was compared to the measured sensitivity of the DME unit without interference. The results indicated that when the DME unit is subjected to the future UAT environment, it was able to achieve ASOP within 1 dB of its normal sensitivity without UAT interference.

Further examination of the effect of UAT on DME was performed to examine the combined effect of UAT and JTIDS on DME. Since the bench results and analysis indicates significant margin before UAT would impact DME operation, it was not expected that UAT combined with JTIDS would result in an impact on DME operation. An analysis was performed to determine quantitatively how much interference JTIDS could produce relative to the UAT signal interference produced by the Core Europe 2015 environment. Figure O-16 depicts the incremental change in interference that would be experienced by a DME receiver by the combined effect of UAT and JTIDS when compared to UAT interference alone in the ADS-B segment of the UAT Frame. The CDF is a measure of the percentage time that interference is experienced by the victim DME receiver at or below the corresponding interference signal level. This analysis was performed with the DME and UAT co-channel in the Core Europe 2015 scenario and the JTIDS Baseline B scenario described in Appendix G. As observed by the results, the combination of JTIDS and UAT is not significantly different than UAT interference alone.

In summary, a significant amount of testing on 4 models of DME equipment representative of the existing equipment population was performed to validate proper operation of DMEs when subjected to UAT signals. This testing has shown the DME interrogators to be very tolerant to the UAT signal even when operated co-channel with UAT. Based on tests conducted to date, no compatibility issues are expected with DME operation even when operated co-channel with UAT even with very high levels of future UAT/ADS-B equipage in high density European airspace.

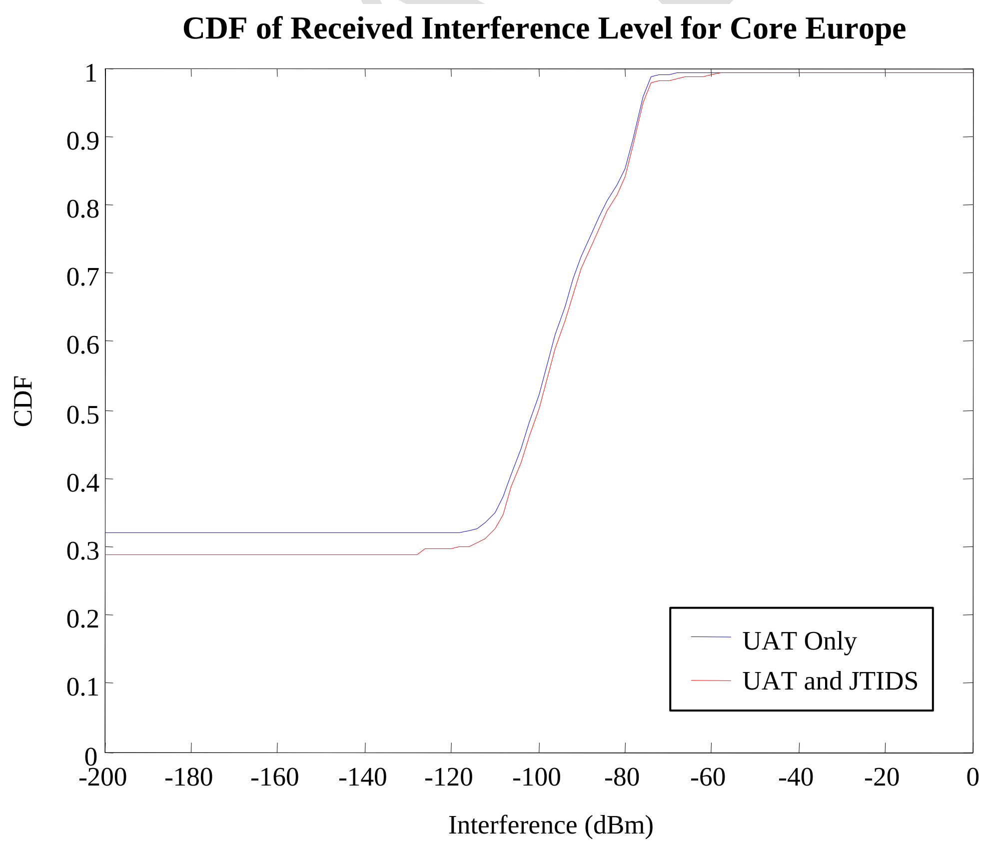


Figure O-16: JTIDS and UAT Combined Interference Analysis

Appendix P
UAT Message Overlap Statistics

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P. UAT Message Overlap Statistics

P.1 Introduction

This Appendix addresses issues pertaining to the statistics of overlapping ADS-B signals in a multi-user environment. These issues are of interest because they have an impact on receiver design requirements and, hence, on MOPS test procedures. The basic question is to determine how many overlapping ADS-B signals a UAT receiver must be able to process. This question is best answered in the context of a hypothetical receiver architecture. The receiver design considered here is shown in Figure P-1.

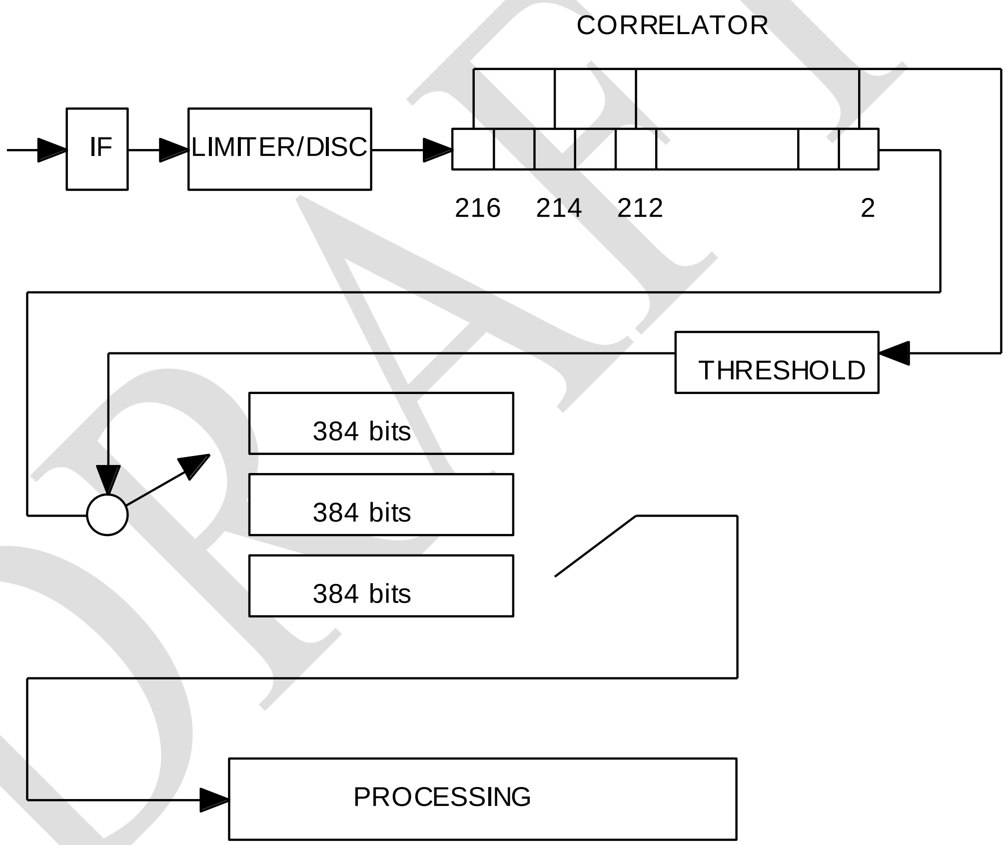

Figure P-1: Possible UAT Receiver Architecture

In this design the incoming signal is demodulated into a string of ones and zeroes that is compared to a known synchronization sequence in a correlator. A sequence that passes a certain threshold will cause the ensuing bit samples to be placed in one of a number of 384-bit registers. The size of the registers is determined by the size of a long ADS-B message. Such messages are sent as RS(48, 34) code words, so the required length of a register is just 48 x 8 = 384 bits. It is assumed that when one of these registers is filled its contents are immediately passed along to the input queue of a RS decoder and the register is available for another incoming message. Of course, it is possible that the incoming message is a basic ADS-B message whose length is only 240 bits (since it is a RS(30, 18) code word). The system design is based on the ability of the RS decoder to sort out (with very high probability) which of the two possible types was actually sent. It is also possible that the RS decoder will determine that the message cannot be decoded because there are too many errors or because the whole message was the result of a false alarm.

The issue to be resolved in this appendix can be paraphrased as, "How many registers are necessary?" The need for more than one register arises whenever a synchronization occurs while a register is still being filled with bits derived from a previous synchronization. Such a situation could happen for a number of reasons:

1. A new signal which is significantly stronger than the first signal arrives.

2. The signal being demodulated contains a sequence of bits that is sufficiently like the synchronization sequence to pass the threshold (embedded sync).

3. The first signal was a basic ADS-B message, and a new message arrives soon after it is completed.

The receiver has no way of knowing which of these conditions applies in any given situation. If the receiver *did* know it might be able to take some appropriate action, which would obviate the need for more than one register. For example, if it were known that case 1 applied, the best course of action would be to replace the old message with the new one. The second case could occur if some of the information in the message "looked like" the synchronization sequence. This similarity might be relatively static (for example, a way point might persist for long periods of time). Thus, if this case applied, the initial message should not be removed. In the third case, the receiver could pass along an abbreviated message with instructions to the RS decoder to attempt only RS(30, 18) decoding. Because the appropriate actions are much different in each case, it is highly desirable to avoid making a choice prior to the RS decoding process.

P.2 Statistical Model Results

This section will describe a theoretical statistical model used to derive an upper bound for the number of registers required to provide a given probability of message processing. Section P.3 will present the results of using the Multi-Aircraft UAT Simulation (MAUS) to evaluate the message overlaps in the high-density Core Europe 2015 air traffic environment.

A set of scenarios was modeled in which a number (N) of users were assumed to be transmitting ADS-B messages. Although it is expected that some fraction of the messages will actually be basic ADS-B messages, a full complement of long messages was assumed in order to provide a worst-case analysis. From the point of view of any particular receiver, the arrival times of the messages was assumed to be uniformly distributed over the 800 ms portion of each second devoted to ADS-B. The power levels of the messages were chosen randomly from the reverse cumulative distribution shown in Figure P-2. This distribution was derived from MAUS results during the spring of 2001 and was based on the UAT deployment assumptions being used at the time. The markers represent the simulation data, and the line is based on the equation that was used in the model:

$$P(x) = \exp(-0.0046\ (x + 104.7)^2) \qquad (1)$$

for $x \geq -104.7$. $P(x) = 1$ for $x < -104.7$. In this equation, x is measured in units of dBm. The results of this analysis are *not* very sensitive to the exact form of the distribution.

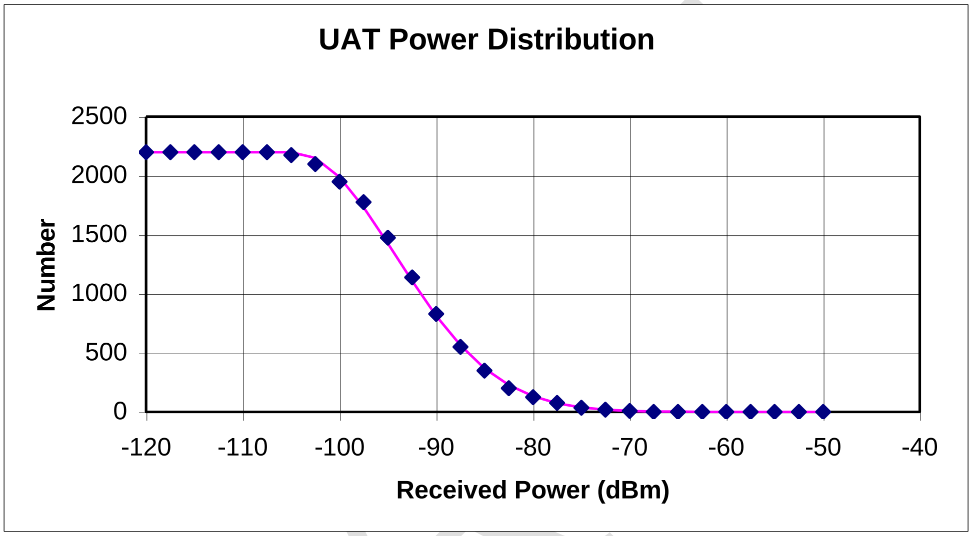

Figure P-2: UAT Received Power Distribution (for 2200 users)

A very simplified version of the model assumes that the synchronization portion of each message always succeeds and every message needs to be placed in one register or another. The register requirements would then depend on the arrival sequence of the messages. A number of possibilities are shown in Figure P-3.

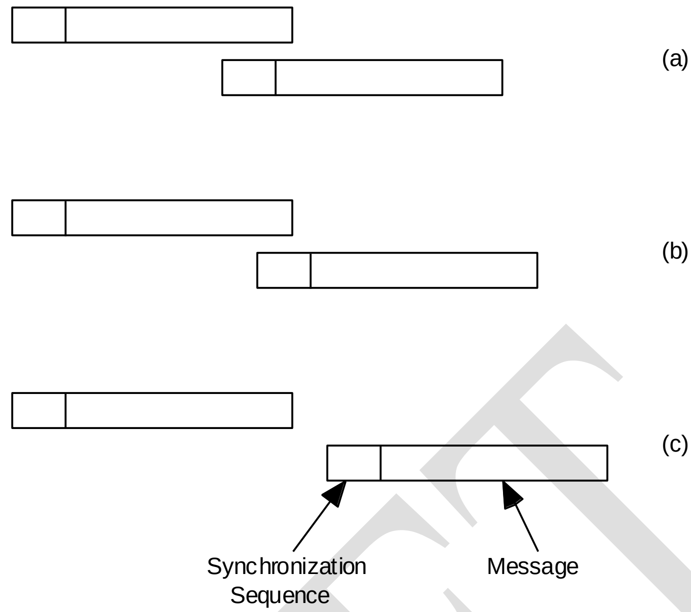

Figure P-3: Message Overlap Possibilities

In case (a) of Figure P-3, the message portions of two bursts are coincident in time, and they require separate registers. If an additional register is not available, the second message is dropped. In case (b), the message portion of one burst overlaps the synchronization portion of another; thus, they can each use the same register. In case (c), the bursts are entirely separate, and one register will clearly suffice.

In this simplified case the probability of requiring a certain number of registers can be calculated by noting that one message can take precedence over another if it precedes it by a number of bit periods between 1 and 384. If there are N users competing with a given burst, the average number of preceding users within the last 384 bit periods is given by

$$\lambda = 384 \times N / 833334 \qquad (2)$$

where 833334 is the number of bit periods in 0.8 seconds. The probability of requiring n registers is given by a Poisson distribution, i.e.,

$$P(n) = e^{-\lambda} \lambda^{n-1} / (n-1)! \quad n \geq 1. \qquad (3)$$

In the real world the probabilities (as shown by the MAUS results presented in Section P.3) will be altered because many of the overlapped signals will not synchronize. For example, many times the second signals in Figure P-3(a) and Figure P-3(b) will not synchronize because of interference from the first signal. It is necessary to have a model of synchronization performance to account for these effects. The simplified model of synchronization performance used in this theoretical analysis is as follows:

1. If the desired signal power is greater than the power of any individual interferer overlapping the synchronization sequence, then the synchronization will succeed.

2. If the desired signal power is less than the power of any interferer overlapping its synchronization sequence, then the synchronization will fail if and only if at least 16 bits of the synchronization sequence are overlapped. [The number 16 relates to a synchronization threshold value of 84 (out of a possible 108). When there are 16 bits overlapped by a strong signal (producing a 50% BER), the average synchronization score is 3x20 + 3x16/2 = 84.]

These criteria overestimate the probability of synchronization. The criteria fail to properly take into account cases where there are multiple interferers. Also, criterion 1 is clearly optimistic even when there is only one interferer. Overestimating the synchronization probability will once again tend to overbound the number of registers required.

With these rules in place, the number of registers required to accommodate all potential messages can be determined by simulation. The results for various values of N are plotted in Figure P-4 through Figure P-11 as the curves labeled “real.” These show the average number of messages per second that require the specified number of registers. For comparison, the results of equation (3) are shown as the curves labeled “ideal.”

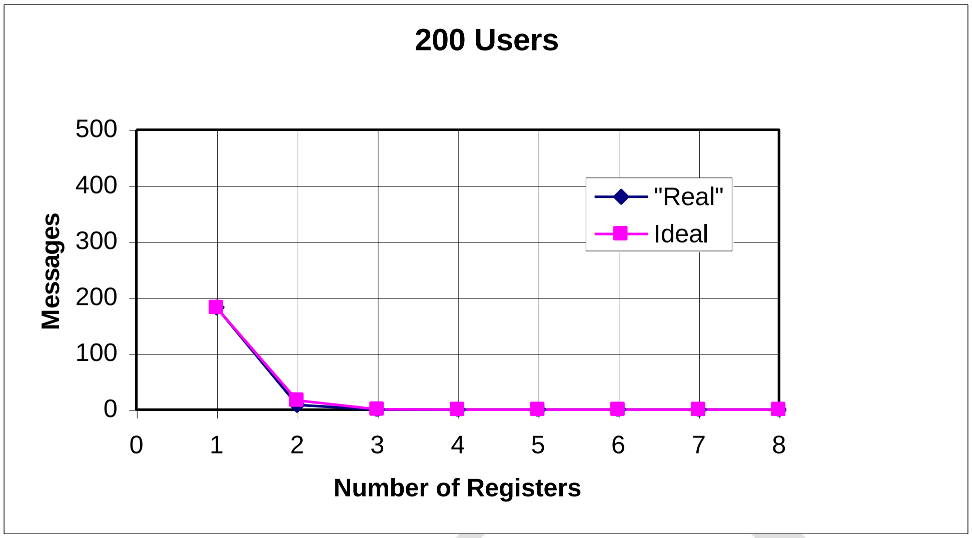

Figure P-4: **Simulation Results for 200 Aircraft**

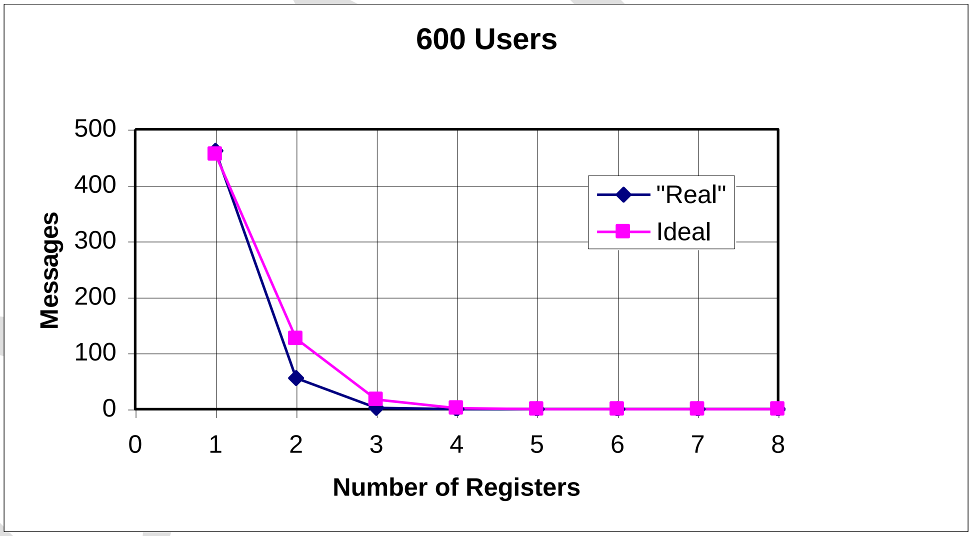

Figure P-5: **Simulation Results for 600 Aircraft**

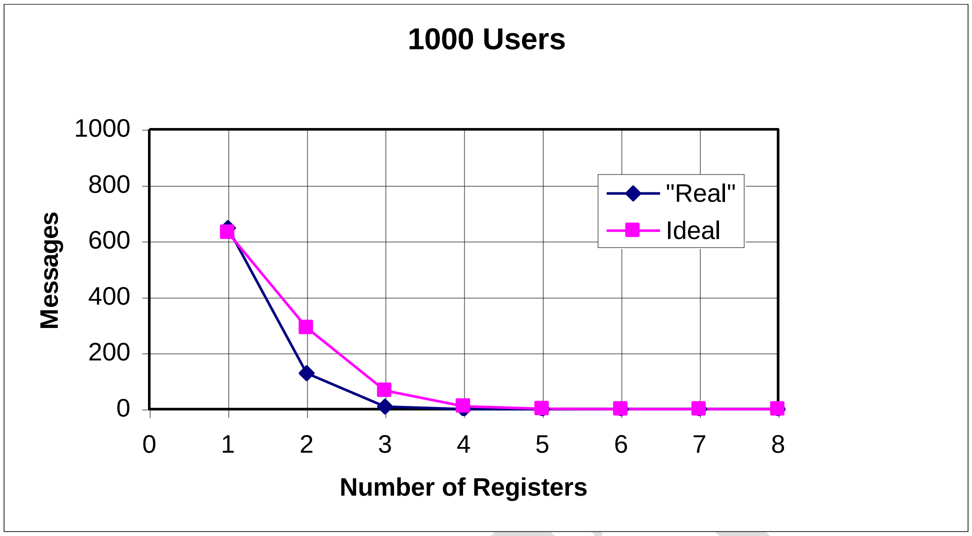

Figure P-6: **Simulation Results for 1000 Aircraft**

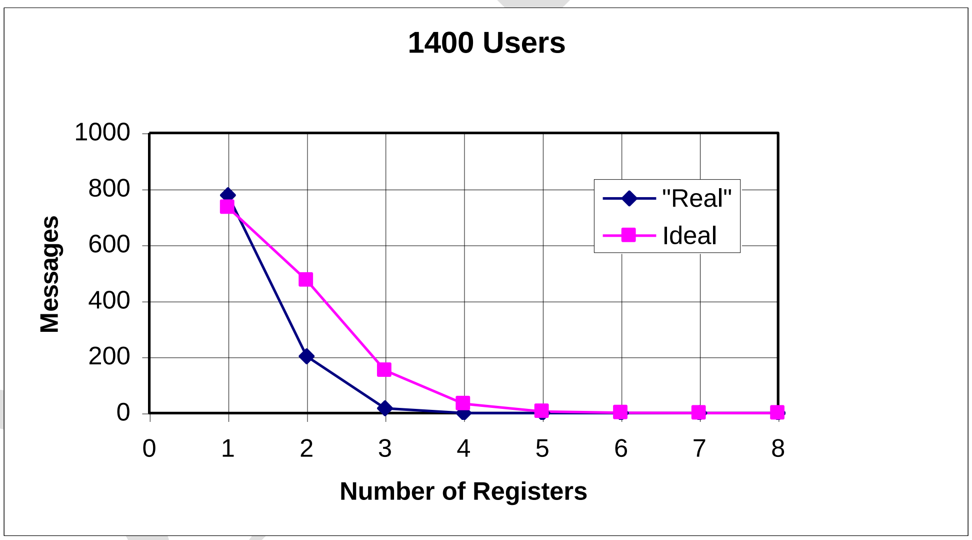

Figure P-7: **Simulation Results for 1400 Aircraft**

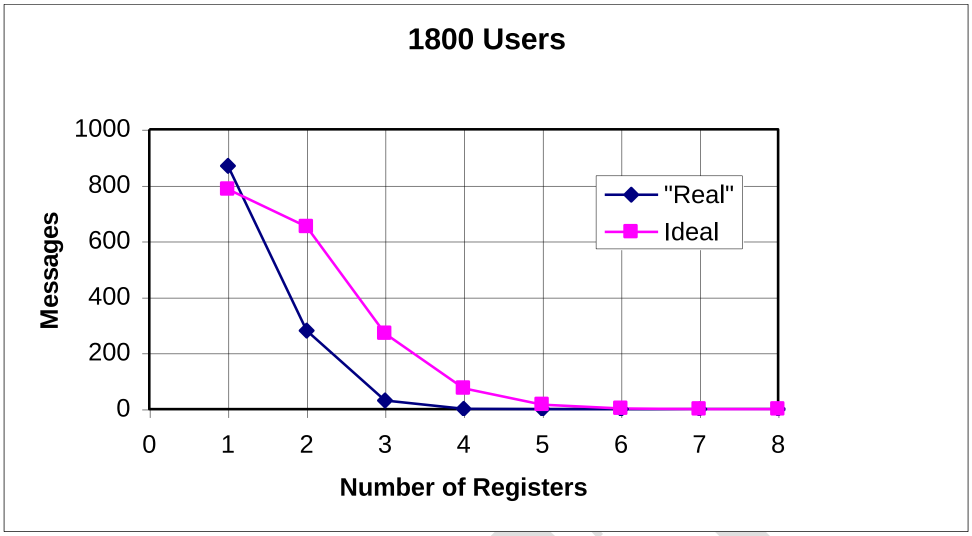

Figure P-8: Simulation Results for 1800 Aircraft

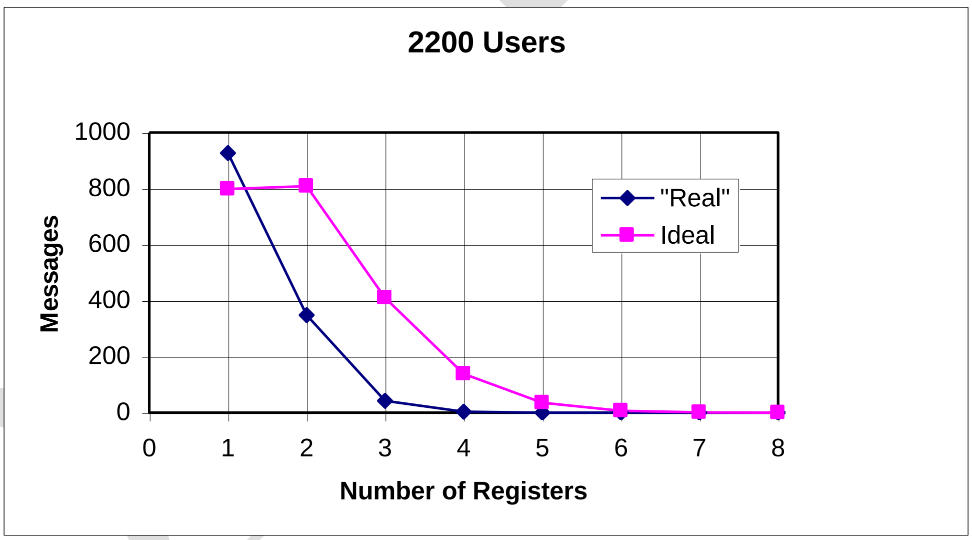

Figure P-9: Simulation Results for 2200 Aircraft

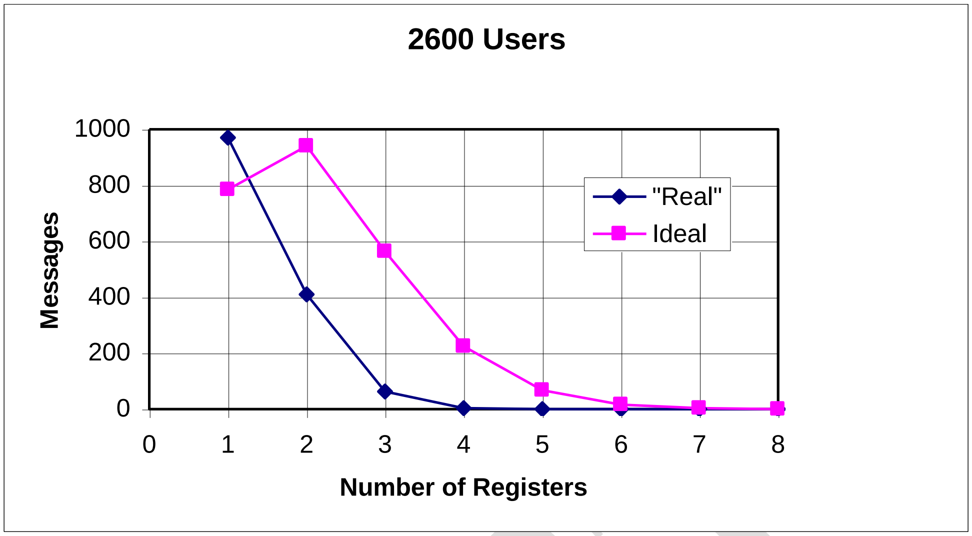

Figure P-10: **Simulation Results for 2600 Aircraft**

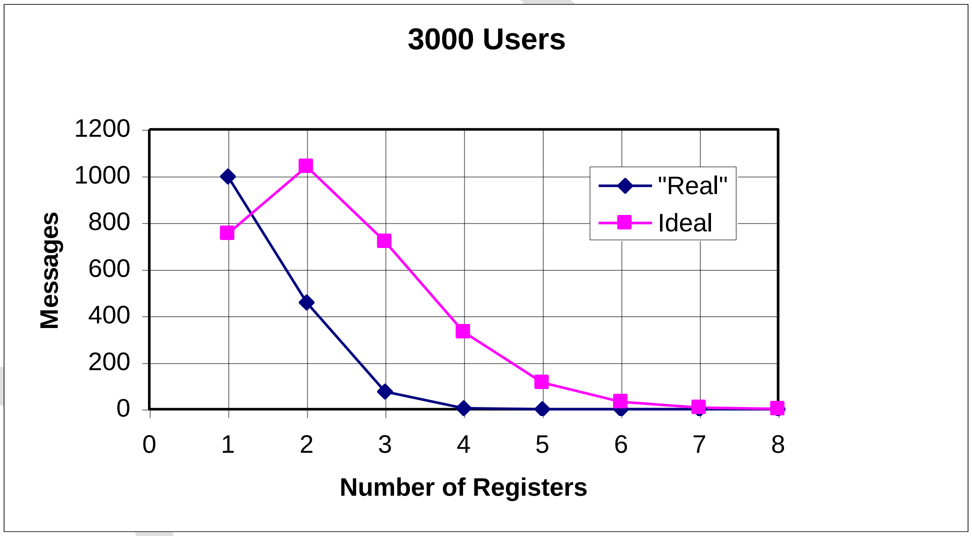

Figure P-11: **Simulation Results for 3000 Aircraft**

P.2.1 Discussion

There are various trends that can be seen in the graphs. For instance, as the number (N) of users increases, the fraction of the messages that actually synchronize decreases. The number of successful synchronizations versus N is plotted in Figure P-12. This is evidence that the system is beginning to saturate. These graphs do not, however, take into account the messages that successfully synchronize but do not survive the error correction process. That information is irrelevant to this discussion because it has no impact on the number of registers used.

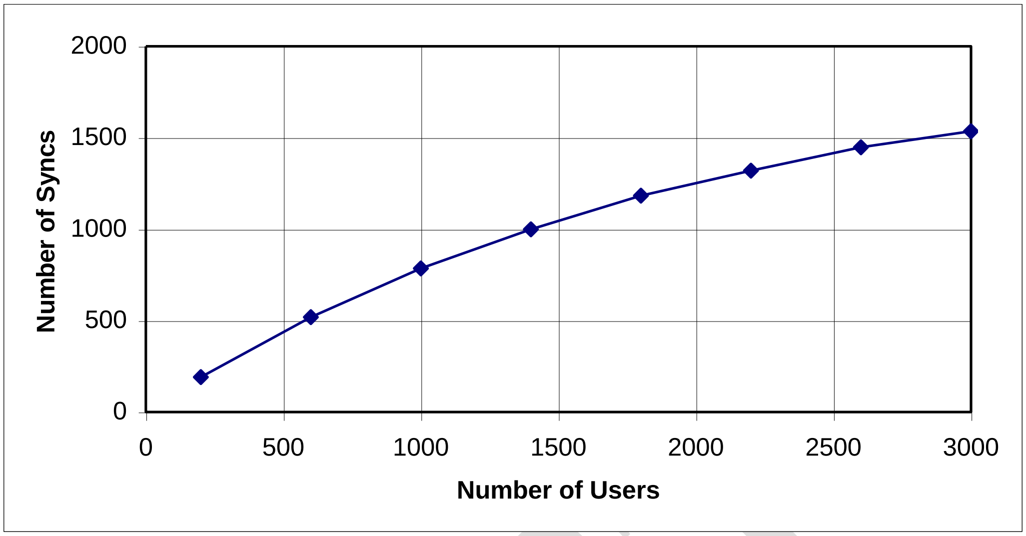

Figure P-12: Overall Synchronization Performance

A second trend that can be seen in the results is that the "real" distributions tend to be much more peaked at the value 1 than the ideal curves. This happens because the signals with multiple overlaps are the ones most likely to be pruned due to synchronization failures. More realistic models of synchronization performance would probably result in distributions with even more peaking. It is interesting to note that as the number of users increases the shapes of the "real" distributions become very similar.

The most important issue for this section is the fraction of potentially successful messages that are rejected if the number of registers is limited. In Figure P-13, this fraction is plotted versus N, assuming 1, 2, or 3 registers are available. The curves tend to flatten out as the number of users increases. This seems to be due to the fact that the shapes of the curves become similar as N increases. (The irregularities in the curves are related to the limited number of cases studied. These curves are based on simulations of 10 seconds' worth of UAT transmissions.) For N = 2200, which is the number used for the LA 2020 scenario, the values are 0.30 for one register, 0.034 for two registers, and 0.0022 for three registers. The use of three registers reduces the probability of rejection to a negligible level.

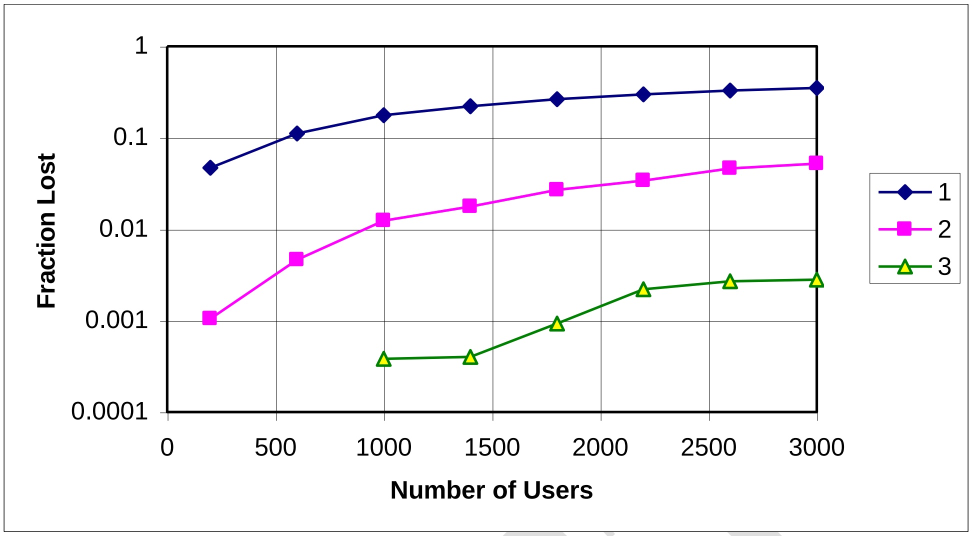

Figure P-13: **Fraction of Rejected Messages (Parameter is the Number of Registers)**

P.2.2 Effect of Uplink Message

In the normal operation of the UAT system, the ADS-B bursts and the uplink bursts are supposed to be transmitted in different time intervals separated by relatively large guard times. Nevertheless, there is a system requirement to continually search for both types of messages simultaneously. If that is the case, then there is some possibility that a receiver can "synchronize' with an uplink message during the time usually reserved for ADS-B messages. This could happen due a false alarm or because something close to the uplink synchronization sequence is embedded in an actual ADS-B message. Either way, the potential uplink message will occupy some receiver resources that would otherwise be available for ADS-B.

Suppose, for example, that at least one of the registers shown in Figure P-1 is actually 4416 bits in length instead of 384. Such a register is just long enough to contain an entire up link message (4416 = 6 x 8 x 92). Whenever there is an uplink synchronization detected the message is placed in such a register, which is then not available for duty receiving ADS-B information. Thus, if the total number of registers is 3, then the effective number available for ADS-B is reduced to 2 for as long as it takes to fill the long memory. If the uplink threshold is set at a value that yields about 1 false alarm or embedded synchronization per second, then the average fraction of time spent on extraneous uplink message processing is 4416/833334 = 0.0053. This can be converted into a revised estimate of the probability of rejecting an ADS-B message. For N=2200 and a total of three registers, the revised probability is 0.0053 x 0.034 + 0.9947 x 0.0022 = 0.0024. In other words, the effects of false uplink synchronization phenomena appear to be negligible if the false alarm rate is reasonably small.

P.3 MAUS Results

The MAUS (see Appendix K) was run in the Core Europe 2015 air traffic environment to determine the distribution of message overlaps on ADS-B messages being received. MAUS looks at the arriving message stream at the receiver and combines the incoming

ADS-B messages, bit by bit, with all other sources of signals (e.g., other ADS-B messages, interference from Link 16 and DME, on-board transmissions) to feed into the receiver performance model. The receiver performance model then computes a bit error rate for each bit and applies the appropriate Reed-Solomon error correction to the bits of the message to determine a message error rate (MER). In the process of calculating this MER, the model must determine the probability of reception of the synchronization sequence. It is this probability that was used to examine the distribution of message overlaps.

For the purposes of this appendix, the analysis focused on the successful synch receptions. The metric that was used was the distribution of the number of successful synchs that occur while the receiver is attempting to decode a previously synched message. This metric was chosen, since the assumption was made that only subsequent successful synch detections during message reception would require additional registers. This assumption ignores unsuccessful synch arrivals, since no register would be required if the synch was not successfully received. (This is true even though the unsuccessful message could interfere with reception of the message associated with the previous successfully received synch.) Therefore, the metric is simply a count of successful synch detections, which arrive within the next 420 microseconds after an initial successful synch detection (for the long ADS-B message).

Figure P-14 shows the distribution of the reception of successful synchs during message reception following a previous successful synch. The overlap distribution is shown for a Class A2 equipped aircraft in the Core Europe 2015 air traffic scenario, flying at FL 400. These results indicate that more than 99.9% of the receivable messages have two or fewer overlapping ADS-B messages.

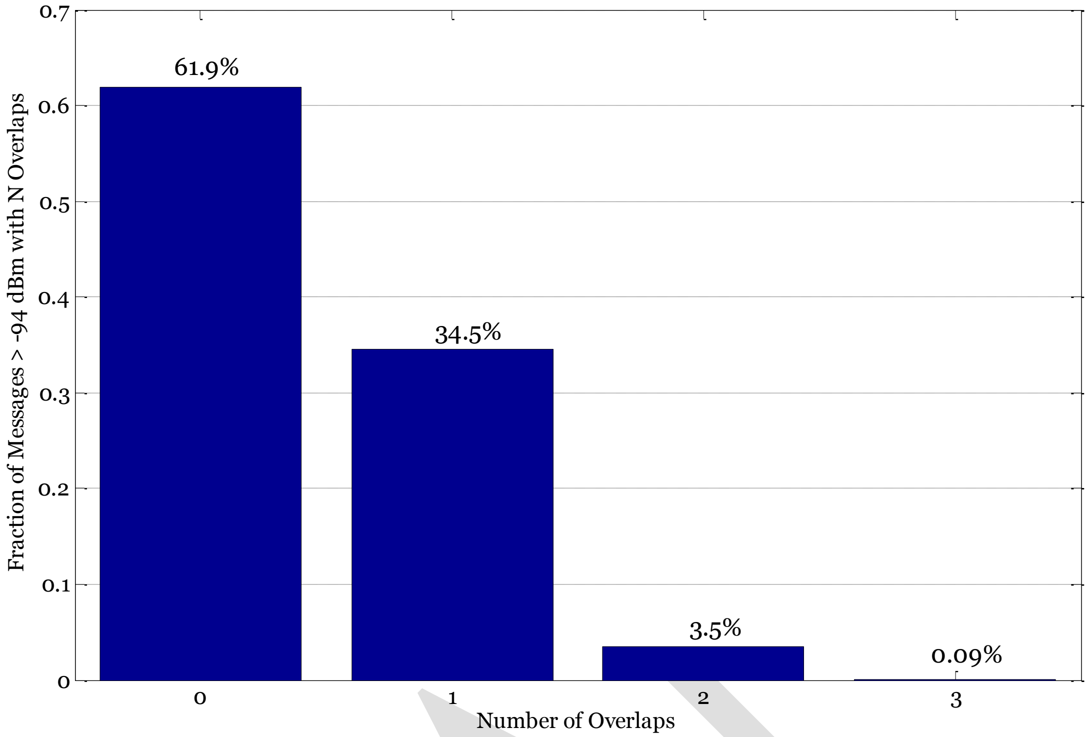

Figure P-14a: **Percentage of Successful Overlapping Synch Sequences for Messages Received > -94 dBm for an A2 at 40,000 ft. in CE 2015 for the Bottom Antenna**

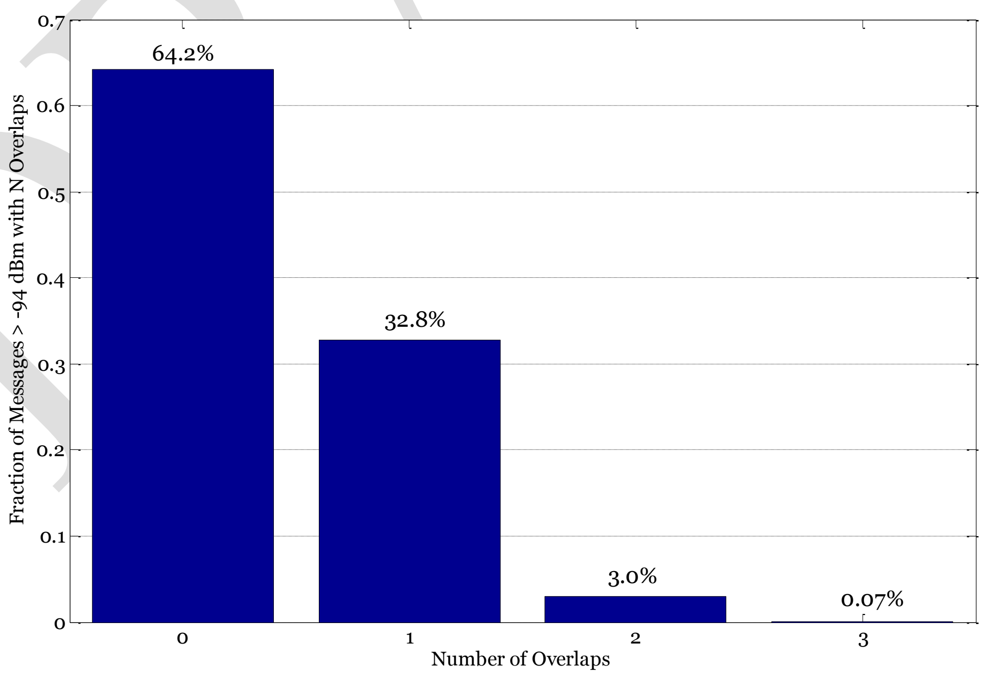

Figure P-14b: **Percentage of Successful Overlapping Synch Sequences for Messages Received > -94 dBm for an A2 at 40,000 ft. in CE 2015 for the Top Antenna**

The results shown in Figure P-14, while differing somewhat from those determined by the theoretical analysis of Section P.2 (which had many simplifying assumptions), confirm the conclusion reached in that section, namely that a receiver that uses three registers will be capable of decoding the vast majority of ADS-B messages.

P.4 Summary

Performance has been simulated using both a simplified system performance model based on using a separate memory register to process each incoming message, and by the Multi-Aircraft UAT Simulation, which performs a more detailed simulation of the high-density environment and is based on measured receiver performance. When the number of messages being received exceeds the number of registers, new messages are dropped. Using this rule, it appears that the ability to handle three overlapped signals will cover almost all cases. (This is not meant to imply that an actual UAT implementation needs to be designed this way.)

Appendix Q

Determining The Navigation Accuracy Category For Velocity (NAC_V)

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Q Determining the Navigation Accuracy Category for Velocity (NAC_V)

Q.1 Purpose and Scope

This Appendix describes the manner in which GNSS position sources which do not output velocity accuracy can be characterized so that a velocity accuracy value associated with the position source can be input into ADS-B equipment as part of the installation process. Section §Q.4 discusses the expected velocity accuracy performance of GNSS during stable flight (the NAC_V is specified in such a manner that it needs to accommodate velocity errors during normal maneuvers of the aircraft).

Q.2 Background

Until recently, acceptable means to substantiate a navigation source's capability to support NAC_V were not clearly established in Global Positioning System (GPS) sensor minimum operational performance standards. In light of this deficiency, a "best-method" was originally established in §2.2.3.2.6.1.5 of RTCA DO-260A (ADS-B Version Number = 1) to utilize the HFOM/VFOM quality indicator as a surrogate for setting the NAC_V value. The rationale for this method was originally documented in Appendix J of DO-260A. However, the use of HFOM/VFOM to set NAC_V was not considered acceptable, since it does not provide an appropriate indication of the true horizontal velocity error as established by the position sensor manufacturer.

To remedy this deficiency, the FAA requested RTCA SC-159 to develop test procedures for a velocity accuracy test to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers as specified in RTCA/DO-229D and RTCA/DO-253B receiver MOPS. These tests can be used to substantiate Global Positioning System (GPS), GPS/Space-Based Augmentation System (SBAS), or GPS/Ground-Based Augmentation System (GBAS) equipment to support an ADS-B NAC_V =1 requirement of horizontal velocity error less than 10 meters/second (95th percentile with HDOP of 1.5 or less) and vertical velocity error less than 50 feet/second (95th percentile, with VDOP of 3.0 or less). Additional test procedures were developed to substantiate equipment that supports a NAC_V =2 requirement of horizontal velocity error less than 3 meters/second and vertical velocity error less than 15 feet/second. However, these tests are not adequate for demonstrating more stringent ADS-B NAC_V levels (i.e., NAC_V = 3, or greater)--such tests are expected to be developed as more demanding ADS-B applications mature.

Navigation equipment manufacturers can submit the results of this testing with their TSO application or as additional information if they have already received TSO approval, for acceptance as approved data. Manufacturers of navigation equipment that pass these tests should document their equipment's 95% figure of merit velocity accuracy in their installation manual (or provide a velocity accuracy quality metric output for direct use by the ADS-B equipment.) The velocity output has no explicit integrity beyond the 95% figure of merit for the stated HDOP and VDOP.

Note: *FAA AIR-100 memorandum dated October 10, 2008 serves as an interim reference describing testing procedures acceptable to the FAA until the procedures are incorporated into more formal GPS MOPS guidance material.*

Q.3 Tests to Determine Velocity Accuracy for Support Setting NAC_V = 1 or 2

The ADS-B installations with a position source capable of providing velocity accuracy should have the NAC_V derived from the position source, and the velocity accuracy should be validated during the position source manufacturer's certification testing. The following procedures, developed by RTCA SC-159, are one means of accomplishing this testing.

The purpose of GNSS velocity accuracy test is to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers as specified in RTCA/DO-229D and RTCA/DO-253B receiver MOPS for equipment intended to support either NAC_V =1 or NAC_V = 2. Test procedures for higher levels are expected to be developed as more demanding ADS-B applications mature.

The tests to verify velocity accuracy performance shall be run for each of the scenarios described below for all operating modes of the receiver where a valid position and/or velocity could be output by the receiver.

Note: *It is possible that a given receiver may use a different velocity algorithm when computing an un-augmented GPS position solution versus computing a solution augmented with differential corrections. In that case, this test must be repeated for both the augmented and un-augmented modes of operation. Even in the case where the velocity algorithm is the same whether in un-augmented or augmented mode, there are still enough variables like the software path, inputs, outputs etc., that it is required to repeat the test. However it is not required to repeat the test for different sub-modes of an un-augmented or augmented mode where the inputs, velocity algorithm and outputs are the same.*

Q.3.1 Horizontal Velocity Accuracy Test Conditions Commensurate with NAC_V = 1

1. Ensure the simulator scenario has enough GPS satellites to provide a HDOP of 1.5 or less.

2. One satellite shall set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).

3. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in DO-229D accuracy test §2.5.8. Broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.

4. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.

5. Platform Dynamics for the horizontal velocity accuracy test shall be as defined in Table Q-1.

Table Q-1: Platform Dynamics for the Horizontal Velocity Accuracy Test

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	**To**		**North**	**East**	**Down**	**Total**	**North**	**East**	**Down**	**Total**
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+72	T+129	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+130	T+194	-0.45g longitudinal acceleration to 125 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.2	0.xx *Note 1*	0.xx *Note 1*	0	0.2
T+195	T+254	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+255	T+325	turn 180° with 0.58g lateral acceleration	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+326	T+420	Straight un-accelerated flight	0	0	0	0	0	0	0	0

Notes:

1. *The components of the jerk in the North and East direction depend on the heading chosen in the scenario. The total jerk is the not to exceed vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25g/s.*
2. *The actual times may vary based on the simulator scenario control settings.*

6. Signal and RF Interference conditions can be modified during static period to aid acquisition. Ensure the receiver enters the desired Operation mode before dynamics and appropriate signal and interference conditions are applied.

7. Use the simulator velocity truth data ($V_i^{east\_truth}$, $V_i^{north\_truth}$) and the GNSS receiver velocity data (V_i^{east}, V_i^{north}) to determine the horizontal velocity error after the GNSS receiver has entered the desired Navigation mode with the specified signal and RF Interference conditions:

$$h_i = \sqrt{(V_i^{east\_truth} - V_i^{east})^2 + (V_i^{north\_truth} - V_i^{north})^2}$$

Q.3.1.1 Pass/Fail Determination

The 95% Horizontal Velocity accuracy statistic shall be computed using the formula given below. The equipment shall pass if the statistic is less than 10 m/s.

$$2 * \sqrt{\frac{\sum_{i=1}^{N} \left(\frac{1.5 h_i}{HDOP_i} \right)^2}{N}}$$

Where:

h_i – is the horizontal velocity error (m/sec)

N – Number of sample points used

For this test, the number of samples shall include all samples where the receiver is in the desired Navigation mode and when in motion.

Note: *The minimum of samples is 420 for 1 Hz solution and 2100 for 5 Hz solution (i.e., 5* 420).*

The receiver velocity data and the $HFOM_V$ data shall be used to determine the percentage of samples bounded by the $HFOM_V$ as shown below. The test passes only if $TS_{h,b}$ is greater than or equal to 0.95.

$$TS_{h,b} = \frac{1}{N}\sum_{i=1}^{N} b_{h,i}$$

$$N = \text{number of samples}$$

$$b_{h,i} = \begin{cases} 1 & h_i \le HFOM_V \\ 0 & h_i > HFOM_V \end{cases}$$

Q.3.1.2 Vertical Velocity Accuracy Test Conditions Commensurate with NAC_V = 1

1. Ensure the simulator scenario has enough GPS satellites to provide a VDOP of 3.0 or less.

2. One satellite shall set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).

3. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in RTCA DO-229D accuracy test §2.5.8. Broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.

4. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.

5. Platform Dynamics for the vertical velocity accuracy test shall be as defined in Table Q-2.

Table Q-2: Platform Dynamics for the Vertical Velocity Accuracy Test

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	**To**		**North**	**East**	**Down**	**Total**	**North**	**East**	**Down**	**Total**
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+72	T+130	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+131	T+131+X	Climb, increasing the vertical climb rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx *Note 1*	0.25	0	0	0.xx *Note 1*	0.25
T+132+X	T+192+X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+193+X	T+193+2X	Descend, increasing the vertical descent rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx *Note 1*	0.25	0	0	0.xx *Note 1*	0.25
T+194+2X	T+274+2X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0

Notes:

1. *The components of the jerk in the North and East direction depend on the heading chosen in the scenario. The total jerk is the not to exceed vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25g/s.*
2. *The actual times may vary based on the simulator scenario control settings.*
3. *The value of X must be at least 63 seconds to have enough samples during vertical acceleration.*

6. Signal and RF Interference conditions can be modified during static period to aid acquisition. Ensure the receiver enters the desired Operation mode before dynamics and appropriate signal and interference conditions are applied.

7. Use the simulator velocity truth data ($V_i^{vertical\_truth}$) and the GNSS receiver velocity data ($V_i^{vertical}$) to determine the vertical velocity error (v_i) after the GNSS receiver has entered the desired Navigation mode with the specified signal and RF Interference conditions: $v_i = | V_i^{vertical\_truth} - V_i^{vertical} |$.

Q.3.1.3 Pass/Fail Determination

The 95% Vertical Velocity accuracy statistic shall be computed using the formula given below. The equipment shall be considered pass only if the statistic is less than 50 ft/s.

$$2*\sqrt{\frac{\sum_{i=1}^{N}\left(\frac{3\left(v_i\right)}{VDOP_i}\right)^2}{N}}$$

Where:

v_i - is the vertical velocity error (ft/sec)

N – Number of sample points used

For this test, the number of samples shall include all samples where the receiver is in the desired Operation mode.

Note: *The minimum of samples is 420 for 1 Hz solution and 2100 for 5 Hz solution.*

The receiver velocity data and the $VFOM_V$ data shall determine the percentage of samples bounded by the $VFOM_V$ as shown below. The test passes if   is greater than or equal to 0.95.

$$TS_{v,b} = \frac{1}{N}\sum_{i=1}^{N} b_{v,i}$$

$$N = \text{number of samples}$$

$$b_{v,i} = \begin{cases} 1 & v_i \le VFOM_V \\ 0 & v_i > VFOM_V \end{cases}$$

Q.3.2 Additional Tests to Demonstrate Accuracy Commensurate with NAC_V = 2

The following procedure is one acceptable means for equipment capable of better accuracy performance to demonstrate compliance with the horizontal velocity error requirement of less than 3 m/s.

1. Run the scenario in Table Q-1 with all satellites set at high power and no RF interference.

2. This accuracy evaluation shall only include those data samples collected during the acceleration period.

3. Find the particular h_i (noted as T_{acc}) so that 95% of h_i samples are less than or equal to T_{acc} .

4. Re-run the scenario in Table Q-1 with the same satellite and RF interference conditions as the 10 m/s (NAC_V=1) test.

5. This time only the data samples during the non-acceleration period with the specified signal and RF Interference conditions are used.

6. Compute $T_{non\_acc} = 2 * \sqrt{\dfrac{\sum_{i=1}^{N_{non\_acc}} \left(\dfrac{1.5\,(\;{}_{i\_non\_acc})}{HDOP_{i\_non\_acc}} \right)^2}{N_{non\_acc}}}$

   Where $HDOP_{i\_non\_acc}$ and N_{non_acc} are the HDOP values for each sample *i* and the total number of samples (non-acceleration period), respectively.

7. The test passes only if $T_{acc} + T_{non\_acc}$ is less than 3 m/s.

8. The velocity FOM is evaluated in the same way as for the 10 m/s test, i.e., the samples during acceleration and non-acceleration periods of the above 2 runs are evaluated together against the 0.95 threshold.

The vertical velocity requirement of 15 ft/s should be tested using the exact same philosophy as the test of 3 m/s above but with the scenario in Table Q-2.

Q.4 Expected GNSS Velocity Accuracy in Stable Flight

Although NAC_V will accommodate derived velocity lags at turn rates of up to 0.5g, it over-bounds by a substantial amount the 95% velocity error of about 0.2 m/s per axis which should be expected in stable flight[1]. This conservative bounding of expected GPS velocity quality has led application designers and simulators to incorrect impressions of the potential value of the instantaneous velocity provided in the GPS state vector.

Velocity lag errors have long been an issue in the use of ATC automation derived velocity with radars as the sensor input. Assurance that better velocity is available when flight dynamics permit is obtained by separately specifying acceptable ATC tracker errors for stable and turning tracks. The STARS requirement on estimated heading error is indicated by values in Table Q-3.

Table Q-3: Heading Accuracy (RMS degrees)

Speed (knots)	**Stable Flight Heading error**	**Transient Tracks Heading error**
100	12	51
250	6	30
400	3	31

[1] NAVSTAR GPS User Equipment Introduction, 1996, Page 3-7 and "Measurement of Aircraft Velocity Using GPS", Institute of Electronics, Information and Communication Engineers Technical Report, Japan, 2005.

Based on experience with GPS, and without requiring changes to the GPS receiver acceptance test requirements, there seems to be no risk in adding some clarification to the use of NAC_V by ATC automation systems indicating that considerably better than the high turn rate limiting encoded error value should be expected in the normal flight conditions which apply for the supported application. Normally experienced velocity errors at the 95th percentile should be on the order of one tenth of the encoded maximum value, for NAC_V equal to 1 or 2.

Appendix R

Proposed DO-282B Provisions for Backward Compatibility with DO-282A Message Formats

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R Proposed DO-282B Provisions for Backward Compatibility with DO-282A Message Formats

R.1 Background

This Appendix provides guidance for decoding of information from messages transmitted by Version 1 installations when received by a Version 2 system. Table R-1 shows the UAT Message fields whose encoding or interpretation has changed between Version 1 and Version 2. Those fields not mentioned here are unchanged.

Table R-1: Version 2 versus Version 1 Message Fields

Version 2 Message Fields that are Changed Relative to Version 1	Version 2 Receiving System Interpretation of Corresponding Bits from Version 1 Message
Uplink Feedback (§2.2.4.5.2.9)	Ignore these bits (for A-G use only)
SIL (§2.2.4.5.4.6)	See Section 1 of this Appendix
SDA (§2.2.4.5.4.8)	Ignore these bits (reserved bits set to ALL ZERO in Version 1)
Capability Codes (§2.2.4.5.4.12)	Ignore these bits (no backward compatibility)
Operational Modes (§2.2.4.5.4.13)	Ignore these bits (for A-G use only)
SIL_{SUPP} (§2.2.4.5.4.16)	Ignore this bit (no backward compatibility)
Geometric Vertical Accuracy (§2.2.4.5.4.17)	Ignore these bits (reserved bits set to ALL ZEROs in Version 1)
Single Antenna Flag (§2.2.4.5.4.18)	Ignore this bit (reserved bit set to ZERO in Version 1)
Target State Element (all fields) (§2.2.4.5.6)	Ignore these bits (no backward compatibility)
GPS Antenna Offset	Ignore these bits (reserved bits set to ZERO in Version 1)

R.2 Version 1 SIL Field Definition

The Surveillance Integrity Level ("SIL") field is a 2-bit (bits 7 and 8 of byte 24) field used to define the probability of the integrity containment region described by the "NIC" field, being exceeded, for the selected geometric position source, including any external signals used by the source. The encoding of the "SIL" field shall be as indicated in Table R-2. The probability specified by the SIL parameter is the largest likelihood of any one of the following occurring when a valid geometric position is provided by the selected position source:

a. a position source equipment malfunction (per hour),

b. the per sample probability of a position source error larger than the horizontal or vertical integrity containment region associated with the NIC value(s), or,

c. for GNSS, the probability of the signal-in-space causing a position error larger than the horizontal or vertical containment region associated with the NIC value(s) without an indication (see note 2 below Table R-2), within a time period determined by the positioning source, as indicated in Table R-2.

Table R-2: Version 1 "SIL" Encoding

SIL (binary)	SIL (decimal)	Probability of Exceeding the Horizontal Integrity Containment Radius (R_C) Without an Indication	Probability of Exceeding the Vertical Integrity Containment Region (VPL) Without an Indication	Corresponding Hazard Classification
00	0	Unknown	Unknown	No Safety Effect
01	1	$\leq 1 \times 10^{-3}$ per flight hour or per sample	$\leq 1 \times 10^{-3}$ per flight hour or per sample	Minor
10	2	$\leq 1 \times 10^{-5}$ per flight hour or per sample	$\leq 1 \times 10^{-5}$ per flight hour or per sample	Major
11	3	$\leq 1 \times 10^{-7}$ per flight hour or per sample	$\leq 2 \times 10^{-7}$ per 150 seconds or per sample	Severe Major/ Hazardous

Notes:

1. *It is assumed that SIL is a static (unchanging) value that depends on the position sensor being used. Thus, for example, if an ADS-B participant reports a NIC code of 0 because four or fewer satellites are available for a GPS fix, there would be no need to change the SIL code until a different navigation source were selected for the positions being reported in the State Vector report.*

2. *"An indication" may include, for example, a flag for invalid position report, or a change in NIC, or switching to another data source.*

3. *The vertical integrity containment column only applies to NIC values greater than 8.*

4. *The SIL encoding is the most stringent of the horizontal or vertical values.*

5. *At the time of publication of these MOPS, it is recognized that there are three possible derivations of SIL: (a) the integrity value provided by navigation sensors with self-monitoring capability (e.g., GPS), (b) the reliability of aircraft systems given as indicated by a failure rate commensurate with the equipment design assurance, and (c) the integrity of other navigation systems, (e.g., RNP) that rely on ground-based self-monitoring equipment for integrity assurance, and for which no specific hourly integrity value can be ascribed. These three values are not readily interchangeable. Selection of the largest of the values as specified in Table 2-44 is felt to provide a reasonable bound on the order of magnitude of the probability of possible failures affecting ADS-B applications. Future revisions of this document may refine the SIL definition as more is understood.*

6. *Since the SIL is intended to reflect the integrity of the navigation source of the position information broadcast, the SIL value transmitted should be indicative of the true integrity of the ADS-B position data. A problem for installations that include currently available GNSS receivers and FMS systems is that SIL is not output by these systems. With the lack of SIL information being provided by the navigation source, implementers should not arbitrarily set a SIL value of ZERO (0) indicating unknown integrity. It is suggested, unless there is a tightly coupled navigation source where SIL can be unambiguously determined and set dynamically, that the ADS-B Transmitting Subsystem should provide for the static setting of SIL as part of the installation procedure. Most implementers are expected to determine SIL by off-line analysis of the installed configuration. This off-line analysis can be performed on the various primary and alternate means of determining the reported position. SIL is a static value for each of these configurations.*

APPENDIX S

PROVISIONING FOR POTENTIAL WAKE VORTEX AND ARRIVAL MANAGEMENT ADS-B APPLICATIONS

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S PROVISIONING FOR POTENTIAL WAKE VORTEX AND ARRIVAL MANAGEMENT ADS-B APPLICATIONS

S.1 Introduction

This Appendix discusses the potential UAT broadcast of Meteorological (MET) data and Air-Reference Vector (ARV) data for potential next generation Automatic Dependent Surveillance – Broadcast mode (ADS-B) applications such as wake vortex based separation procedures and implementation of next generation arrival management systems. These applications are anticipated to provide capacity benefits, enhanced safety, and efficiency through future ground-based and airborne solutions. This section provides justification for introducing such broadcast data into a future UAT Minimum Operational Performance Standards (MOPS). Later sections provide initial estimates of desired data elements, update rates, and signal provisioning for future versions of the UAT MOPS. This informative appendix to RTCA DO-282B is intended to facilitate the investigation of a range of applications enabled by the proposed data broadcasts, with the goals of (1) advising aircraft operators on how they can provision their aircraft at present to support these potential ADS-B applications and (2) laying the groundwork for international agreement on the inclusion of support for these applications in a future revision of these MOPS.

The UAT capability has been designed to provide an efficient framework for message transfer for air-to-ground, air-to-air, and ground uplink communications. The use of aircraft conducting routine operations as real-time sources of weather data via data link has been among the envisioned uses of UAT. This appendix describes potential meteorological message formats for UAT and the received update rates for UAT-transmitted meteorological information desired to enable emerging wake vortex and arrival management applications. However, the message content and data transmissions rates developed for these specific applications are further envisaged to support a variety of additional Next Generation Air Transportation System (NextGen) applications. Moreover, the message content, received update rates, and supporting infrastructure described in this appendix are targeted to support potential far-term airborne applications to provide real-time onboard wake turbulence avoidance information to flight crews.

Wake turbulence constraints have been identified as a major contributing factor to inefficient use of the Nation's airspace capacity, especially when Instrument Flight Rules (IFR) operations are in effect (Ref 1). Concept exploration research by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) has indicated that greater utilization of the nation's airspace could be accomplished if the location of wake turbulence from aircraft could be known with sufficient fidelity to allow following aircraft to fly paths that are free of hazardous turbulence. Significant potential increases in airport capacity, as much as a 40 percent increase at several airports during some periods of Instrument Meteorological Conditions (IMC), are achievable.

Mid-term wake avoidance solutions will most likely employ ground-based systems to receive and process down-linked meteorological and aircraft data potentially provided by ADS-B. These data will be integrated with flight plan and National Airspace Systems (NAS) data received through ground networks. Ground-based processors will compute wake safe four dimensional (4D) trajectories for individual aircraft and recommend traffic flow management options for arrival and departure operations. These data will become inputs to decision support tools (DSTs) for controllers and traffic flow management to optimize NAS operations. As envisioned by NextGen and Single European Sky ATM Research (SESAR) concepts of operation, individual 4D wake-safe trajectories will be communicated to appropriate flight crews to provide a high level of shared situational awareness.

NextGen and SESAR concepts for arrival management and associated trajectory synthesis functions are also critically dependent on more real-time aircraft data. Specific data elements are needed to enhance reliability of medium term (~ 40 minute) prediction of aircraft trajectories during the descent and arrival phase of flight, for scheduling the arrival of successive aircraft at critical entry points into the terminal area and to the final approach fix of congested runways. These include real-time winds aloft and aircraft weight data. The envisioned concepts include both ground based and air-to-air applications of broadcast MET and ARV data.

S.1.1 Proposed Wake Turbulence Applications

The FAA Wake Turbulence Program has proposed initial ground-based wake turbulence avoidance applications that require the availability of near real-time meteorological data that is not available from current sensors. These applications will determine wake-free trajectories for aircraft based on analysis of meteorological data and calculation of the resulting movement of hazardous wakes. These initial applications will be based on the lateral transport of wakes by crosswind and will not rely on any wake decay mechanisms to ensure safety. Wake-free trajectory information will be an input to ground-based Air Traffic Management (ATM) automation that allows Air Traffic Control (ATC) to separate aircraft from hazardous wakes while meeting other trajectory constraints.

Wake avoidance applications planned for the mid-term and far-term will require near real-time atmospheric profile information in order to accurately determine the spatial extent of a wake hazard. **ADS-B equipped aircraft, with appropriate provisioning, have the potential to measure and report meteorological data at a high resolution, under all weather conditions, and over regions of operational interest**.

The temporal and spatial scales of hazardous aircraft wake turbulence are dependent on ambient atmospheric conditions. Highly turbulent atmospheres can result in wakes decaying more quickly, sometimes in as little as 40-60 seconds. Stable atmospheric conditions promote longer wake lifetimes wherein heavy aircraft may generate hazardous wake turbulence that persists for more than two minutes. This difference in wake lifetime is correlated with phase of flight and aircraft speed to determine the spatial dimensions of the wake hazard which must be avoided. If a wake decays in 60 seconds or 120 seconds, a hazardous wake area 2-4 miles long at typical final approach speeds or 8-16 miles long at en route cruise speeds may exist. There are two aspects of wake turbulence that are important for wake avoidance, the location and strength of the wake. The location and lifetime of a wake is determined by the ambient atmospheric conditions and the characteristics of the generating aircraft. The wake strength at the time of encounter and the type of trail aircraft encountering the wake are critical factors in determining safety risks.

Two mid-term applications based on potential ADS-B OUT capabilities are under development:

1. The wake turbulence mitigation for arrivals system (WTMA-S) provides additional capacity at airports with closely spaced parallel runways (CSPR)1 when instrument flight rules are being applied. The WTMA-S predicts operationally significant periods of time when stable crosswinds permit reduced separations between pairs of aircraft arriving on the two parallel runways. Crosswinds along the arrival flight path transport the wake turbulence generated by a lead aircraft out of the flight path of a following aircraft. WTMA-S complements the recently enacted FAA Order 7110.308 by enabling heavy aircraft and Boeing-757 aircraft to participate in a CSPR arrival procedure as lead aircraft and by enabling reduced wake turbulence separations at additional airports. WTMA-S requires meteorological data that potentially could be transmitted from aircraft via ADS-B as inputs to a crosswind prediction algorithm and as part of a real-time monitoring function to ensure safety.

2. Crosswind-based reductions in en route separations are envisioned for more efficient flight operations. This application would utilize meteorological data transmitted from aircraft to enable safe reductions in en route separations controllers must apply for wake turbulence when aircraft climb or descend through the altitude of a proximate aircraft and when faster aircraft overtake a slower aircraft. Currently, controllers must maintain a minimum separation of 5 nautical miles (nm) between co-altitude aircraft or 1000 foot/feet (ft) vertical separations to protect against potential collisions and wake turbulence encounters. However, much smaller lateral separations can potentially provide avoidance of wake turbulence when the flight path of the maneuvering aircraft is offset. The en route wake avoidance application will use meteorological data transmitted from aircraft potentially via ADS-B to generate wake-free trajectories for maneuvering aircraft. It will be integrated with emerging ADS-B surveillance capabilities to enable an overall reduction in en route separations. Smaller deviations to preferred flight paths will be required, resulting in savings in time, fuel burned, and emissions.

A high level system diagram of these applications is shown in Figure S-1, assuming that the proposed use of ADS-B becomes a reality. A processor in the aircraft will obtain required meteorological data from on-board sensors and computer systems and format this data for transmission via ADS-B. These data will be broadcast by ADS-B in the formats and at the frequencies described in §S.3. Ground receivers will provide these data to an ADS-B ground processor, which will parse the data messages and provide required data elements to a ground-based wake processor. The meteorological data algorithm in this processor will construct atmospheric profiles based on data provided by aircraft via ADS-B and other meteorological data available via ground data networks. A 4-D wake-free trajectory will be determined for each aircraft and provided to a trajectory processor. These trajectories will be processed and provided to ATC ground automation for use in ATC separation functions.

[1] Closely spaced parallel runways are defined here as parallel runways with centerlines separated by 2500 ft or less.

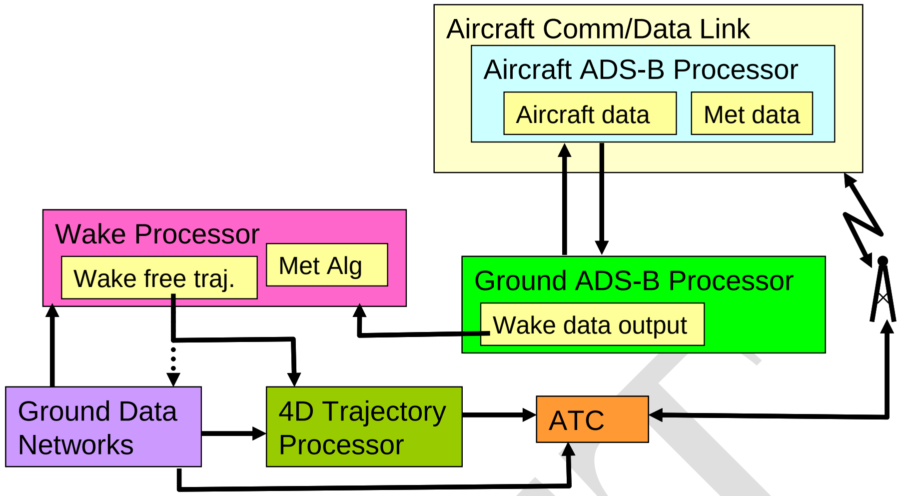

Figure S-1 System Diagram for Initial and Mid-Term Ground-Based Wake Applications Using ADS-B

This is a first step in the development of a series of potential ADS-B supported wake avoidance applications that will enable transition to far-term NextGen and SESAR operational concepts. Subsequent enhancements to the initial applications may also include the consideration of wake decay and sink in computing wake-free trajectories. Follow-on ground-based applications can use the same data elements recommended in this proposal to enable additional wake avoidance capabilities.

The initial applications being proposed have a high potential to produce early benefits for users. There are, however, multiple wake capabilities planned for the mid and far-term that can leverage better knowledge of winds. The Wake Turbulence Mitigation for Departures (WTMD) is one such capability. It is currently being developed for implementation in the 2012-2014 timeframe. WTMD is a crosswind-based departure capability that relies on the accurate forecast of periods when winds will not allow wakes to drift between the departure path of Heavy aircraft and that of another aircraft departing from an upwind closely spaced parallel runway. During these periods, departures off the upwind parallel runway do not require the current 2-3 minute wake delay resulting in a safe increase in departure capacity. Wind data is required from the surface up to 1000 ft for this application. WTMD currently utilizes the hourly Rapid Update Cycle (RUC) wind product provided by the National Weather Service. The WTMD wind forecast algorithm is necessarily very conservative due to the fact that the RUC winds are only available on an hourly basis. Even with this limitation, benefits for WTMD are estimated at approximately $158 million. If information on winds above the airport surface were available from ADS-B, the available periods would likely increase by at least 30%, resulting in an additional benefit of $47 million, based on deployment of WTMD at ten major airports.

S.1.2 Additional Capabilities

In addition to supporting future applications that enable wake avoidance and potential reductions in aircraft separation, a number of other important capabilities will also be enabled should airborne derived meteorological data and air-reference data becomes readily available through ADS-B. These include:

- Improved arrival management scheduling and more accurate aircraft trajectory synthesis
- Increased wind field prediction accuracy, and
- Better situational awareness of current weather

S.1.2.1 Improved Arrival Management Scheduling and Aircraft Trajectory Synthesis

A key component in NextGen and SESAR concepts is the use of arrival management scheduling and path synthesis, such as provided by current and next generation NASA Center TRACON Automation System (CTAS), Traffic Management Advisor (TMA) and En Route Descent Advisor (EDA) controller decision support tools. These tools are built on an aircraft trajectory synthesis function that uses path routings, descent profile, and winds aloft to strategically schedule aircraft in an arrival sequence and provide required arrival times at critical TMA arrival fixes. Broadcast of ARV and MET data is recommended to support such applications, since this capability provides (1) A means to estimate airspeed for constant Indicated Air Speed (IAS)/Calibrated Airspeed (CAS) descents from cruise, and (2) Wind vector updates for enhanced estimation of the ground vector along the selected arrival path to scheduled arrival fixes. Current NASA trajectory synthesis algorithms use nominal descent speeds based on aircraft type rather than planned airspeed descent profiles, which are typically only available on the Flight Management System (FMS) flight plan, and are not available to current ground automation systems. Similarly, the use of hours-old forecast winds can lead to unreliable sequencing and scheduling of in-bound aircraft. Aircraft derived winds and meteorological data broadcast can be used to update winds-aloft in near real-time, resulting in enhanced reliability of arrival management systems under development for NextGen and SESAR implementation.

There are several different concepts for implementing next generation arrival management systems, each with somewhat different functional requirements. Generally, such systems can be classified as Open Loop arrival management systems if the controller provides explicit descent path and profile instructions which are flown by the pilot or airplane FMS system to the specified arrival fix, or as Closed Loop systems if the airplane avionics provides dynamic inputs such as airspeed guidance to the FMS to achieve desired in-trail sequencing and merging of inbound aircraft prior to reaching the specified arrival fix. Based on simulations and limited flight trials, Open Loop systems typically require more accuracy in the trajectory synthesis function, and controller monitoring of intended path and airspeed compliance, to assure that the aircraft is able to implement the desired arrival trajectory and time schedule. By contrast, Closed Loop systems typically are more tolerant to trajectory synthesis and path following errors, but may require greater pilot situation awareness to assure that in-trail separation with nearby aircraft is achieved.

One means of implementing Closed Loop arrival management is based on ADS-B IN surveillance of nearby aircraft. Pilots and potential users of ADS-B In-Trail arrival applications such as Visual Spacing on Approach (VSA) and Flight Deck Merging and Spacing (FDMS) have consistently recommended the broadcast and display of lead aircraft airspeed for enhanced situation awareness when maintaining desired in-trail spacing. In the event that the lead aircraft slows down for merging or as needed for an arrival procedure, the trail aircraft can easily see the difference in airspeed with the lead aircraft, and verify the consistency of speed guidance provided by the ADS-B application. Broadcast of airspeed in this arrival application, allows a pilot to verify, modify, or reject the ADS-B derived speed guidance based on enhanced situation awareness of lead aircraft airspeed.

S.1.2.2 Increased Wind Field Prediction Accuracy

Although use of arriving/departing and nearby aircraft as sensors for measuring wind vector and other MET parameters is an idea that has been around for some time, it is often not economically feasible to use existing data links for this purpose. ADS-B is better structured for regular broadcast of such data. For wind data, it has been shown (Ref 2) that regular wind updates on the order of minutes rather than hours is essential for reliable arrival management, and for consistency in implementing arrival procedures such as Continuous Descent Arrivals (CDA's). Moreover, earlier studies (Ref 3) have shown that mixed equipage with 10 percent or more aircraft broadcasting along path wind data may be sufficient to provide substantial enhancement in local wind field estimation.

S.1.2.3 Better Situational Awareness of Current Weather

One proposed application of the meteorological data in UAT messages (i.e., winds, temperature, air pressure, humidity) is to improve the current generation of atmospheric models for aviation. This application is envisioned as a form of automated Pilot Report (PIREP) that provides a large volume of timely data to users of meteorological data for weather forecasting.

A second proposed application of meteorological data in UAT messages (i.e., winds, aircraft weight, aircraft configuration) is to improve the prediction of aircraft flight trajectories in spacing and queuing tools. Having real time data available (rather than the inferred values currently used) could improve the performance and benefits of these tools.

A third proposed application of meteorological data in UAT messages (i.e., turbulence, icing, wake vortex, windshear/microburst) would be to provide proximate aircraft up-to-date information about hazardous weather conditions in their vicinity. This is envisioned primarily as an air-to-air application, although air-to-ground transmission could also provide alerting of hazardous atmospheric conditions and turbulence to ground users. An airborne user in turbulent air could use the data provided via UAT to determine where a smoother ride might be found.

S.2 Data Requirements for Wake and Arrival Management Applications

This section describes the data that are needed to support the proposed wake turbulence applications, including initial and envisioned long-term wake avoidance applications. There is general scientific agreement that real-time predictions of the movement and decay of aircraft wake vortices can be developed if the following data elements can be obtained from the wake-generating aircraft:

- Wind speed
- Wind direction
- Static temperature
- Static barometric pressure[2]
- Aircraft emitter category
- Aircraft position
- Pressure altitude
- Aircraft speed and heading
- Aircraft weight
- Atmospheric turbulence (normally eddy dissipation rate, but total kinetic energy can also be used)
- Aircraft configuration data, e.g., flap setting, for potential future applications

For the mid-term and long-term ground based wake avoidance concepts, these data elements are required to be received such that there is a 95 percent probability of a successful update at the appropriate rate specified in Table S-1. These same data elements provided at the higher air-to-air reception rates shown in Table S-1 will also enable farther-term flight deck-based applications. Aircraft emitter category[3] and position are available from existing ADS-B messages. Aircraft heading and speed can be obtained from existing ADS-B messages, but current rules require it to be sent only in the absence of ground velocity data. These data elements can potentially be obtained from interleaved broadcast of ARV data, or alternately, reconstructed by the user from ground velocity data and wind vector data as discussed in §S.3.2.

Data parameters to be used in wake vortex applications (the first four application columns in Table S-1) will need to be provided to the transmitting ADS-B equipment by avionics with a design assurance level appropriate to spacing/separation applications (hazard level of MAJOR or higher). Arrival management applications (fifth column of Table S-1), however, are envisaged as being advisory in nature (hazard level of MINOR) and can accept data inputs with less stringent certification. The data elements of Table S-1 will further need to be supplied with appropriate resolution and accuracy for the applications. Requirements in this area will be specified as part of the Safety and Performance Requirements for future ADS-B applications.

[2] It may not be necessary to broadcast static barometric pressure since it can be derived from pressure altitude broadcast in ADS-B messages.
[3] ADS-B emitter category includes the ICAO weight categories.

Table W-1 Data Element Received Update Frequency Requirements

Data Element	Update Period (95% probability) Ground-based Wake System Requirements (surface to 10,000ft profile) See Note 1	Update Period (95% probability) Ground-based Wake System Requirements (above 10,000ft) See Note 2, Note 9	Update Period (95% probability) Air-Air Wake system terminal area requirements (Far-Term) See Note 3 (up to 10 nm range between aircraft)	Update Period (95% probability) Air-Air Wake system en route requirements (Far-Term) See Note 4, 8 (up to 20 nm range between aircraft)	Update Period (95% probability) Arrival Management Ground-based and Air-to-Air System Requirements (Mid-Term) See Note 5	Source
Wind Speed	60 seconds	40 seconds desired (to be refined Note 10)	15 seconds (to be refined, Note 10)	30 seconds (to be refined, Note 10)	30 seconds (to be derived on user or receive side)	New
Wind Direction	60 seconds	40 seconds desired (to be refined, Note 10)	15 seconds (to be refined, Note 10)	30 seconds (to be refined)(Note 10)	30 seconds (to be derived on user or receive side)	New
Static Temp.	60 seconds	40 seconds desired during atypical atmospheric conditions (to be refined)	60 seconds nominal (15 seconds non-nominal Note 6, Note 7)	120 seconds nominal (30 seconds non-nominal Note 6, Note 7)	N/A	New
Static Pressure	60 seconds	40 seconds desired during atypical atmospheric conditions (to be refined)	60 seconds	120 seconds	N/A	New
Aircraft Emitter Category	Existing UAT Message Types 1 and 3	Existing UAT Message Types 1 and 3	Existing UAT Message Types 1 and 3	Existing UAT Message Types 1 and 3	Existing UAT Message Types 1 and 3	Existing UAT Message Types 1 and 3
Aircraft Position	All Existing UAT Messages	All Existing UAT Messages	All Existing UAT Messages	All Existing UAT Messages	All Existing UAT Messages	All Existing UAT Messages
Pressure Altitude	Existing UAT Messages	Existing UAT Messages	Existing UAT Messages	Existing UAT Messages	Existing UAT Messages	Existing UAT Messages

Data Element	**Update Period (95% probability) Ground-based Wake System Requirements (surface to 10,000ft profile) See Note 1**	**Update Period (95% probability) Ground-based Wake System Requirements (above 10,000ft) See Note 2, Note 9**	**Update Period (95% probability) Air-Air Wake system terminal area requirements (Far-Term) See Note 3 (up to 10 nm range between aircraft)**	**Update Period (95% probability) Air-Air Wake system en route requirements (Far-Term) See Note 4, 8 (up to 20 nm range between aircraft)**	**Update Period (95% probability) Arrival Management Ground-based and Air-to-Air System Requirements (Mid-Term) See Note 5**	**Source**
Aircraft Speed and Heading (Note 11)	60 seconds Potentially can be derived from aircraft velocity and winds	40 seconds (Note 10)	15 seconds (Note 10)	30 seconds (Note 10)	30 seconds received ARV messages (air to ground) For air-to-air application, 15 seconds received ARV messages at a range of 10 nm, 24 seconds received ARV messages at a range of 20 nm, and 30 seconds received ARV messages at ranges within the application domain above 20 nm	New ARV message elements
Aircraft Weight	120 seconds	120 seconds	120 seconds	120 seconds	120 seconds desired	New
Atmospheric Turbulence	60 seconds	60 seconds during atypical atmospheric conditions	60 seconds	60 seconds	N/A	New
Aircraft Config.	120 seconds	120 seconds	120 seconds nominal, 15 seconds on change (Note 7)	120 seconds nominal, 15 seconds on change (Note 7)	N/A	New

Notes:

1. *Assume moderate to high density traffic environment. Received rate is for a single aircraft. Resolution of approximately 500 ft along altitude profile is achieved through receiving transmissions from multiple aircraft. 10,000 ft and below requires higher sampling rate to capture wind field for downwind, base, and final.*
2. *Received rate is for individual aircraft. Assume climb and descent rates of 2000-3000 fpm. (updates received at least once every 2000 ft at desired update rate), at least every 5 NM laterally. 40 NM range (lower limit) between aircraft to be assisted by ground system needs to be supported (limit due to opposite direction climb/descend thru).*
3. *Closely spaced parallel approaches, in-trail spacing on final to single runway. Measurement, every 1000 ft nominally.*
4. *Cruise.*
5. *Need weight within 2%.*
6. *Logic to detect temperature inversions would increase the transmission rate.*
7. *For a maximum of 24 seconds*
8. *Values in this column apply to in-trail geometries only. Update requirements for crossing and head-on geometries need to be considered further and those values added.*
9. *Further refinement and more frequent, event-driven, transmission of meteorological messages under specific detected conditions may be needed.*
10. *Potentially could be estimated from ARV, if such use of ARV data is appropriately certified.*
11. *It will be known whether true airspeed and true heading are broadcast or whether the airspeed and heading values are calibrated airspeed and magnetic heading. Section W.6 contains conversion equations to derive the desired speed and heading.*

The received update rates in Table S-1 are driven by the need to support various wake vortex and arrival management applications. Flight data is required every 1000 ft vertically or less during departure and arrival phases of flight and every 500 ft or less on takeoff and final approach, where wake turbulence encounters can be the most hazardous.

It should be noted that the current wake categories for aircraft in the UAT message set will need to be updated to account for changes that have occurred or will occur over the next few years in the aircraft fleet mix. A new weight category, Super, has been established to accommodate the Airbus A380 aircraft. Additional changes to the current wake categories are under development.

§S.3 describes how UAT message formats can be used to enable the broadcast of data elements required for the initial wake and traffic flow management applications.

S.3 Message Formats and Transmission Rates

Current UAT Message Types could be employed in several alternative ways to transmit the meteorological information discussed in §S.2. For example, UAT Message Types 1, 2, 5, and 6 provide reserved "AUX SV" fields which may be used for the provision of ARV data. As a second example, Message Type 2 further contains 12 bytes of payload which could be used to encode other meteorological fields discussed in §S.2. As a third example, Message Type 4 (which is presently transmitted by Class A2 and A3 UAT equipment) and Message Type 5 additionally contain 12 bytes of payload currently reserved for Trajectory Change Point information – these reserved fields could potentially be shared for the transmission of meteorological information.

Specific encodings and confirmed transmission rates for potential UAT messages containing meteorological parameters can be developed when the message elements and received update rates of Table S-1 are finalized.

S.4 Provisioning of MET and ARV Data

In this section the output variables identified in §S.2 for potential future UAT messages including MET and ARV data are examined for feasibility and potential for provisioning, i.e., the extent to which these output variables have been defined and are available on standard avionics buses for input to a RTCA DO-282B or later version UAT equipment. In addition, related guidance material on data signal update rates and minimum provisioning data sets for mid-term wake vortex and arrival management applications are specified, as currently envisioned. Further development and standardization work is needed for provisioning and output of the full set of MET and ARV message elements identified in §S.2 for mid-term and long-term wake and arrival management applications.

§S.2 identified eleven data elements required for envisioned wake vortex and arrival management applications. The provisioning status of these data elements (circa 2009) is summarized below:

- Wind speed - feasible for provisioning on standard data buses
- Wind direction - feasible for provisioning on standard data buses
- Static temperature - feasible for provisioning on standard data buses
- Static pressure - feasible for provisioning on standard data buses
- Aircraft emitter category – current ADS-B output element
- Aircraft position – current ADS-B output vector
- Pressure altitude – current ADS-B output element
- Aircraft speed and heading – currently provisioned ADS-B output elements
- Aircraft gross weight – needs further development
- Atmospheric turbulence – needs further development
- Aircraft configuration – needs further development.

Eight of the eleven data elements identified for envisioned high-value applications are available or provisioned currently. The last three data elements need further work to enable long-term wake and traffic flow management applications.

The following Table S-5 identifies ARINC labels and data buses that are potential sources of MET and ARV data outputs. In some cases multiple data sources are potentially available for a specific data output and the preferred data source(s) are highlighted in yellow. For MET format 1 broadcasts, a minimum useful data set for data provisioning for FMS aircraft with Inertial Reference System (IRS) and Air Data Computer (ADC) capability consists of four of the first eight labels shown below, i.e.,

- Wind Speed (ARINC label 315)
- Wind Direction (ARINC label 316)
- Static Air Temperature (ARINC label 213)
- Roll Angle (ARINC label 325).

In the event that static air temperature is not available or convenient for input to the UAT equipment, then Total Air Temperature (ARINC label 211) can be substituted for static air temperature above. In addition, Static Air Pressure (ARINC label 217) is an optional parameter for MET broadcasts, or can be derived from Pressure Altitude using standard atmosphere equations (Ref 6). Total Air Pressure (ARINC label 242) may be available as an output from the aircraft avionics, but is not required for MET provisioning, since it can be derived from other MET and ARV outputs if needed, e.g., from static air pressure and Mach number. The reason for Roll Angle in the above minimum data set is to compute wind data quality, i.e., wind data is generally not reliable at roll angles exceeding 5 degrees. One minute averaged Atmospheric Turbulence is also specified for MET format 1 messages, but will require further development work such as specification of a standard ARINC label and data bus characteristics Seven out of eight ARINC labels needed for MET format 1 provisioning are available today (circa 2009), and an atmospheric turbulence metric could be made available on standard data buses for next generation (RTCA DO-282C) UAT systems.

For aircraft that do not have an IRS or FMS avionics, it may only be feasible to provision outputs from an onboard ADC system, or from avionics buses used for pilot displays. For these aircraft, a minimum useful data set for ARV provisioning consists of airspeed and heading angle outputs, i.e.,

- IAS/CAS Airspeed (ARINC label 206)
- Magnetic Heading Angle (ARINC label 320).

Alternative output variables, if available for ARV provisioning, are True Airspeed (ARINC label 210) rather than CAS Airspeed, and True Heading (ARINC label 314) rather than Magnetic Heading. The CAS Airspeed and Magnetic Heading outputs are preferred, however as they are directly used for controller-to-pilot coordination such as vectoring and speed instructions. Mach number (ARINC label 205) could also be substituted for CAS airspeed in future versions of UAT avionics. Other desirable, but optional data outputs for MET provisioning for such aircraft include static air temperature and roll angle as specified above. Static air temperature is desirable for computing true airspeed, and roll angle to compute wind quality, when deriving wind vector from ARV outputs and ground vector as indicated in Figure S-3.

As indicated in Table S-5, standardized ARINC labels are needed to provision for the broadcast of several identified meteorological message elements. Fortunately, these messge elements are not essential for initial wake vortex and arrival management applications anticipated for mid-term implementation. However, variables such as gross weight and true airspeed may be essential outputs for longer-term wake vortex applications, where wake intensity could potentially be used as the basis for advanced wake avoidance procedures. Further standardization of MET outputs and avionics buses such as ARINC 702A are needed to provision for future broadcast of meteorological messages.

In Table S-5, the maximum transmit interval for any data outputs is 500 msec (0.5 second). We here argue that up to 0.5 second latency is compatible with the desired accuracy of wind components for initial wake and arrival management applications assuming:

1. Desired Wind Vector accuracy <= 6 knots (95%) (roughly equivalent to ground vector NAC_V >=2),
2. Climb and Descent vertical rates <= 3000 ft/min = 50 ft/sec, and
3. Vertical Wind Shear <= 10 knots per 100 ft vertical change.

With the above assumptions, a ½ second latency in reporting wind vector (or estimating wind via ARV and ground vector differencing) can result in a 25 ft vertical error due to UAT equipment input latency, which could result in a 2.5 knot wind error in the assumed vertical shear condition. Given the need to accommodate both sensor measurement error and ADS-B latency to achieve a 6 knot accuracy (95%) overall, a latency error budget on the order of 3 knots is likely acceptable for the intended mid-term ADS-B applications.

Table W-2 Availability of Meteorological and State Vector Data for ADS-B OUT Data Broadcasts

AVAILABILITY OF METEOROLOGY DATA FOR ADS-B_OUT (from ARINC 429 Part1-16 and ARINC 718A-2)											
Label	**Equip. ID (HEX)**	**Equipment Name**	**Parameter Name**	**Units**	**Range (Scale)**	**Sig Bits**	**Positive Sense**	**Resolution**	**Min. Transmit Interval (msec)**	**Max. Transmit Interval (msec)**	**Comment**
315	**002**	Flight Management Computer (ARINC 702)	Wind Speed	Knots	A256	8	Always +	1.0	50	100	See Note 1.
	004	Inertial Reference System (ARINC 704)									
	005	Attitude and Heading Reference System (ARINC 705)									
	038	ADIRS (ARINC 738)									
	056	GNSS Navigation Landing Unit (GNLU) (ARINC 756)									
	060	GNSS Navigation Unit (GNU) (ARINC 760)									
316	002	Flight Management Computer (ARINC 702)	Wind Direction (True)	Deg/ 180	+180	12	CW from North	0.05	25	50	See Note 2.
	004	Inertial Reference System (ARINC 704)	Wind Angle		+/-180	8		0.7	50	100	
	038	ADIRS (ARINC 738)	Wind Angle		+/-180	8		0.7	50	100	
	056	GNSS Navigation Landing Unit (GNLU) (ARINC 756)	Wind Direction (True)		+180	12	CW from North	0.05	25	50	
	060	GNSS Navigation Unit (GNU) (ARINC 760)	Wind Direction (True)		+180	12	CW from North	0.05	25	50	
211	002	Flight Management Computer (ARINC 702)	Total Air Temperature	Deg C	512	11		0.25	250	500	See Note 3.
	003	Thrust Control Computer (ARINC 703)	Total Air Temperature								
	006	Air Data System (ARINC 706)	Total Air Temperature								
	01A	Electronic Supervisory Control	Total Air Temperature								
	038	ADIRS (ARINC 738)	Total Air Temperature								
	0AD	ADIRS Air Data Module	Total Air Temperature Indicated								
	140	Supersonic Air Data Computer	Total Air Temperature (TAT)								

AVAILABILITY OF METEOROLOGY DATA FOR ADS-B_OUT (from ARINC 429 Part1-16 and ARINC 718A-2)

Label	Equip. ID (HEX)	Equipment Name	Parameter Name	Units	Range (Scale)	Sig Bits	Positive Sense	Resolution	Min. Transmit Interval (msec)	Max. Transmit Interval (msec)	Comment
213	002	Flight Management Computer (ARINC 702)	Static Air Temperature	Deg C	512	11		0.25	250	500	See Note 4.
	006	Air Data System (ARINC 706)	Static Air Temperature								
	038	ADIRS (ARINC 738)	Static Air Temperature								
	140	Supersonic Air Data Computer	Static Air Temperature (SAT)								
217	006	Air Data System (ARINC 706)	Static Pressure. Corrected (In. Hg.)	In. Hg	64	16		0.001	62.5	125	Preferred sources are highlighted in "Yellow."
	038	ADIRS (ARINC 738)									
	140	Supersonic Air Data Computer									
242	006	Air Data System (ARINC 706)	Total Pressure	mb	2048	16		0.03125	62.5	125	Preferred sources are highlighted in "Yellow."
	01A	Electronic Supervisory Control									
	038	ADIRS (ARINC 738)									
	0AD	ADIRS Air Data Module	Total Pressure. Uncorrected. mb								
	140	Supersonic Air Data Computer	Total Pressure								
Data is currently provided to ADS-B Transmit Subsystem (Therefore, it is not addressed in this table)			Aircraft Type	**Data is already provided to ADS-B Transmit Subsystem**							
			Aircraft Position								
			Pressure Altitude								
			Aircraft Speed								
			Aircraft Heading								
325	004	Inertial Reference System (ARINC 704)	Roll Angle	Deg/ 180	+/-180	14		0.01	10	20	See Note 5.
	005	Attitude and Heading Reference System (ARINC 705)									
	025	Electronic Flight Instruments (ARINC 725)				10		0.2	125	250	
	038	ADIRS (ARINC 738)				14		0.01	10	20	

AVAILABILITY OF METEOROLOGY DATA FOR ADS-B_OUT (from ARINC 429Part1-16 and ARINC 718A-2)

Label	Equip. ID (HEX)	Equipment Name	Parameter Name	Units	Range (Scale)	Sig Bits	Positive Sense	Resolution	Min. Transmit Interval (msec)	Max. Transmit Interval (msec)	Comment
113	**TBD**	**To Be Determined**	Humidity	%	100	9		0.1953125	TBD	TBD	See Note 6.
			Landing Gear Configuration								See Note 7.
			Flap Settings								See Note 8.
075	002	Flight Management Computer (ARINC 702)	Gross Weight	Lbs.	1,310,720	15		40	100	200	See Note 9.
	003	Thrust Control Computer (ARINC 703)	Gross Weight								
	02C	Digital Fuel Gauging System (A310)	Gross Weight								
	037	Weight and Balance System (737)	Gross Weight								
	03E	Center of Gravity Control Computer	Gross Weight								
	114	Fuel Unit Management System (A330/340)	Aircraft Gross Weight								
To Be Determined			Turbulence Metric Data	To Be Determined							See Note 10.
			Icing Data								
			Wake Vortex Data								
			Windshear Data								
			Microburst Data								

Notes:

1. ***Wind Speed:*** *Preferred sources are highlighted in "Yellow." FMS will need to comply with ARINC 702A, Supplement 3 to provide the data.*
2. ***Wind Angle****: Preferred sources are highlighted in "Yellow." FMS will need to comply with ARINC 702A, Supplement 3 to provide the data.*
3. ***Total Air Temperature:*** *Preferred sources are highlighted in "Yellow." Currently, ARINC 702A, Supplement 3, does not include Total Air Temperature output. Therefore, Supplement 3 would need to be updated in order to use the FMS as an input to the ADS-B Transmit Subsystem*
4. ***Static Air Temperature:*** *Preferred sources are highlighted in "Yellow." Currently, ARINC 702A, Supplement 3, does not include Static Air Temperature output. Therefore, Supplement 3 would need to be updated in order to use the FMS as an input to the ADS-B Transmit Subsystem*
5. ***Roll Angle:****Preferred sources are highlighted in "Yellow." Roll Angle is needed to determine Wind Quality.*
6. ***Humidity****, Label "113," information shown above is taken from ARINC 718A-2, Attachment 3A, where it is shown as being used in BDS Register* 44_{16}*. Note that to date, there are no known available sources on the aircraft that would be able to provide humidity data. Therefore, the sensor and method of providing the data to the ADS-B Transmit Subsystem remains to be developed as of July 1, 2009.*
7. ***Landing Gear Configuration*** *is provided on some aircraft but there is no uniform standard label assigned for all aircraft. Activity with ARINC would be needed to establish a standardized method.*
8. ***Flap Setting*** *information is provided on some aircraft but there is no uniform standard label assigned for all aircraft. Activity with ARINC would be needed to establish a standardized method.*
9. ***Gross Weight*** *information is provided but there is no uniform standard label assigned for all aircraft. Activity with ARINC would be needed to establish a standardized method. Also, ARINC 429 indicates that the FMC (ARINC 702) should be providing Gross Weight data. To date, there are no known FMS systems that do so. ARINC 702A, Supplement 3, does not include Gross Weight information output. Therefore, ARINC 702A Supplement 3 would need to be updated.*
10. ***Weather Data:*** *Appropriate methods of providing the data to the ADS-B Transmit Subsystem would need to be developed and standardized.*

S.5 References

[1] Wake Turbulence: An Obstacle to Increased Air Traffic Capacity: National Research Council, Anthony J. Broderick, Chair, Committee to Conduct and Independent Assessment of the Nation's Wake Turbulence Research and Development Program ISBN: 0-309-11380-6, 2008

[2] R.E. Cole, S.Green, et al., "Wind Prediction Accuracy for Air Traffic Management Decision Support Tools," 3rd USA/Europe Air Traffic Management R&D Seminar, Napoli, Italy, June 2000.

[3] D.A. Forrester and G.C. Dean, "Improvement of Meteorological Data for Air Traffic Management Purposes," Air Traffic Control Quarterly, Vol. 2, No. 2, pp 85-101, 1994.

[4] J.W. Burrows and A. Chakravarty, "Time-Controlled Aircraft Guidance in Uncertain Winds and Temperatures," 1984 American Control Conference, San Diego, Ca., 1984.

[5] R. Slattery and Y. Zhao, "Trajectory Synthesis for Air Traffic Automation," Journal of Guidance, Control, and Dynamics, Vol. 20, No.2, March 1997.

[6] User Manual for the Base of Aircraft Data (BADA) Revision 3.7, EEC Technical Report No. 2009-003, Section 3.2, March 2009. (Available on www.eurocontrol.int/eec/public/standard_page/proj_BADA_documents_37.html)

S.6 Addendum on CAS, Mach, and TAS Relationships

The primary purpose of this Addendum is to provide equations that relate CAS to Mach and TAS that are appropriate to use for ADS-B receive side derivation of air-reference velocities, consistent with the generating equations used in a standard ADC for subsonic aircraft. The reason that this appears to be necessary is that most, but not all of the standard atmosphere equations such as those in Ref (6) are valid when using measured static temperature data or non-standard temperature approximations such as use of delta_ISA to compute intermediate variables such as pressure ratio (delta) and temperature ratio (theta) for converting CAS to Mach to TAS, and vice-versa. The appropriate equations for non-standard atmosphere calculations are easily derived from standardized equations used in current ADC equipment. This assures that equations consistent with the generating aircraft ADC are used to convert from CAS to TAS and vice-versa for data coasting of air-reference velocities. A secondary purpose of this Addendum is to specify computational units that are consistent with the signals transmitted via ADS-B, e.g., knots for CAS, TAS and wind speed, degrees Kelvin for static temperature, mbar for static pressure, and feet for pressure altitude. The physical constants cited here were checked against those specified in Ref (6) and found to be consistent, to the five significant digits cited here.

In a conventional Air Data System, there are three fundamental sensor inputs:

- Static Pressure (Ps) – the pressure of the still air surrounding the airplane,
- Total (pitot) Pressure (Pt) – the pressure of the moving airstream surrounding the airplane, and

- Total Air Temperature (Tt) – the temperature of the airstream surrounding the airplane, including airflow frictional heating and compression.

These inputs are transformed by the ADC into CAS and computed Mach (Mc) airspeed outputs, and subsequently into static temperature (Ts) and true airspeed (TAS) outputs for use by various avionics functions. Also, pressure altitude (hp) is computed, based on the measured static pressure, Ps. The standardized equations for computing CAS, Mach, TAS and hp can be recast to convert from hp to Ps, and from CAS to TAS or vice-versa by an ADS-B user. Although the results of this process are well known in the avionics literature, they are re-derived here, in a form convenient for ARV and MET broadcast usage.

The fundamental equations in the ADC for Mc and CAS, given Total Pressure Pt and Static Pressure Ps are given by:

$$Pt / Ps = (1 + 0.2(Mc)^2)^{7/2} \qquad \text{(S.6-1)}$$

$$1 + (Pt - Ps) / Po = (1 + 0.2(CAS / Cso)^2)^{7/2} \quad , CAS < Cso \qquad \text{(S.6-2)}$$

where Po denotes standard day sea level static pressure = 1013.25 mbar, and

Cso denotes standard day sea level speed of sound = 661.47 knots.

Note: *These equations assume that the indicated static pressure from the pressure sensor are first corrected for static source error. In older systems where the indicated static pressure is not corrected, the Mach number is denoted indicated Mach and the airspeed is denoted indicated air speed (IAS).*

From equation S.6-1 we obtain

$$(Pt - Ps) / Po = [(1 + 0.2(Mc)^2)^{7/2} - 1] * (Ps / Po) \qquad \text{(S.6-3)}$$

Substituting S.6-3 into S.6-2 and solving for Mach yields

$$Mc = \{ 5 [(Po/Ps) \{ (1 + 0.2(CAS / Cso)^2)^{7/2} -1 \} +1]^{2/7} -1 \}^{1/2} \qquad \text{(S.6-4)}$$

Equation S.6-4 yields Mach as a function of CAS and pressure ratio $\delta = Ps / Po$. This is the detailed equation corresponding to the first block in Figure S-3 for computing wind vector from ARV data.

Once Mc is computed in the ADC, then static temperature Ts and TAS are given by

$$Ts = Tt / (1 + 0.2(Mc)^2) \qquad \text{(S.6-5)}$$

$$TAS = Cs * Mc = (38.967 (Ts)^{1/2})* Mc \qquad \text{(S.6-6)}$$

Where Cs denotes the computed speed of sound in knots, as a function of static temperature. The equation for TAS can be recast in terms of the temperature ratio $\theta = Ts / To$,

where To denotes the standard atmosphere sea level temperature, i.e., To = 288.15 K.

Solving for TAS in terms of the temperature ratio θ yields

$$TAS = Cso* \theta^{1/2} * Mc. \qquad \text{(S.6-7)}$$

This equation corresponds to the second block in Figure S-3 for computing TAS from CAS, delta and theta.

We note that S.6-2 and S.6-3 can also be back-solved for CAS given Mach and delta, i.e.,

$$\begin{aligned} CAS &= Cso*\{ 5 [(1 + (Pt - Ps)/Po)^{2/7} -1] \}^{1/2} \\ &= 1479.1 * \{ (1 + (Ps/Po)*[(1 + 0.2(Mc)^2)^{7/2} - 1])^{2/7} -1 \}^{1/2} . \end{aligned} \qquad \text{(S.6-8)}$$

Given TAS and θ, equation S.6-7 can be back-solved for Mach and then converted to CAS using S.6-8.

Finally, from Ref (8), Ps and δ can be computed directly from pressure altitude using the standard atmosphere equations:

For hp < htrop = 36, 089 ft, Ps and δ are given by

$$Ps = Po*((To - L*hp)/To)^{C} = Po*(1 - hp / Ao)^{C} ,$$

$$\delta = Ps / Po = (1 - hp / Ao)^{C} \quad \text{(S.6-9a)}$$

where L = Standard temperature lapse rate = .0019812 K/ ft

Ao = To/ L = 288.15 / .0019812 = 145, 442 ft,

C = 5.2559.

Similarly for hp >= htrop = 36, 089 ft, δ is given by

$$\delta = Ps / Po = \delta_{trop} * \exp (- (hp - htrop) / ko) \quad \text{(S.6-9b)}$$

where δ_{trop} = Ptrop / Po = 226.32 mbar / 1013.25 mbar = 0.22336,

ko = 20, 806 ft.

The above equations are also valid in non-standard atmosphere conditions since the ADC computes pressure altitude directly from delta using standard atmosphere assumptions.