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Minimum Operational Performance Standards For Global Navigation Satellite System (GNSS) Airborne Antenna Equipment

RTCA/DO-228

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SC-159

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Foreword

This document was prepared by RTCA Special Committee 159 (SC-159) and approved by the RTCA Technical Management Committee on October 20, 1995.

RTCA, Inc., 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 Telecommunication 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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1.0 PURPOSE AND SCOPE

1.1 Introduction

This document contains minimum operational performance standards (MOPS) for GNSS airborne antenna equipment designed to use GPS or GLONASS augmented by other systems/equipment/techniques as appropriate to meet the performance requirements for primary means of navigation for en route, terminal, non-precision, and precision approach phases of flight.

The airborne navigation system can be used as a primary means navigation system in an aircraft when approved and an operational GNSS navigation satellite system is available. Incorporated within these standards are equipment characteristics that should be useful to users, designers, manufacturers, and installers of the equipment. This document defines the antenna performance for antennas that will be used with GNSS receiver equipment.

Section 1.0 of this document provides information and assumptions needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment applications and operational goals, and forms the basis for the standards stated in Sections 2.0 through 4.0.

Section 2.0 contains the minimum performance standards for the equipment. These standards define required performance under standard operating conditions and stressed physical environmental conditions. It also details the recommended bench test procedures necessary to demonstrate compliance.

Section 3.0 describes the performance required of the installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4.0 describes the operational characteristics for equipment installations, and defines conditions that will assure the operator that operations can be conducted safely and reliably in the expected operational environment.

Compliance with these standards by manufacturers, installers, and users is recommended as one means of assuring that the equipment will satisfactorily perform its intended function(s) under conditions normally encountered in routine aeronautical operations.

The word "equipment" as used in this document includes all components or units necessary (as determined by the equipment manufacturer or installer) for the equipment to properly perform its intended function.

It is recognized that any regulatory application of these standards is the responsibility of appropriate government agencies.

Inasmuch as the measured values of equipment performance characteristics may be a function of the measurement method, standard test conditions and methods of test are recommended in this document.

1.2 System Characteristics

The 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. The GNSS includes ground control and monitoring stations, satellites, and avionics including antenna(s), and currently consists of the United States Global Positioning System (GPS) and the Russian Federation Global Orbiting Navigation Satellite System (GLONASS).

1.3 Operational Applications

The GNSS antenna equipment is intended to be used in all phases of aircraft operation, including on the surface, approach and landing, departure, terminal, and en route.

1.4 Operational Goals

The operational goal for the GNSS antenna is to provide adequate GNSS satellite signals under a wide range of environmental conditions and installations that will assure safe flight operations. The requirements of this document provide the minimum requirements for antennas designed for GNSS service and employing either passive or active designs.

1.5 Assumptions

It is assumed that the GNSS antenna will be used with GNSS receiver equipment defined in appropriate MOPS.

1.6 Test Procedures

The test procedures specified in this document are intended to be used as one means of demonstrating compliance with the performance requirements. Although specific test procedures are cited, it is recognized that other methods may be preferred. 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 order of tests specified suggests that the antenna 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 2.0 shall have been demonstrated as a precondition to satisfactory completion of the installed systems tests of section 3.0.

Four types of test procedures are specified. These include:

a. Environmental Tests

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

Unless otherwise specified, the environmental conditions and test procedures contained in RTCA/DO-160C, *Environmental Conditions and Test Procedures for Airborne Equipment*, will be used to demonstrate antenna 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 Section 2.2. Test results may be used by antenna manufacturers as design guidance, for monitoring compliance, and, in certain cases, for obtaining formal approval of antenna design.

c. Installed Equipment Tests

The installed equipment test procedures and their associated limits are specified in Section 3.0. Although bench and environmental test procedures are not included in the installed antenna tests, their successful completion is precondition a to completion of the installed tests. In certain instances, however, installed antenna tests may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from, or to, other antenna 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 antenna 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 4.0. These test procedures and their associated limits are intended to be conducted by operating personnel as one means of ensuring that the equipment is functioning properly, and can be reliably used for its intended function(s).

1.7 Definition of Terms

Axial Ratio	The ratio of the major axis to the minor axis of the polarization ellipse.
dBic	dB relative to an isotropic antenna with circular polarization
dBm	dB relative to one milliwatt.
VSWR	Voltage Standing Wave Ratio.
Elevation Angle	The angle between the axis of the measurement line and the installed antenna horizontal plane.
Polarization	That property of a radiated electromagnetic wave describing the time-varying direction and amplitude of the electric field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, as observed along the direction of propagation.

2.0 EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

2.1.1 Airworthiness

The design, manufacture, and installation of the antenna shall not impair the airworthiness of the aircraft.

2.1.2 Intended Function

The antenna 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 Communications Commission.

2.1.4 Fire Protection

All materials used shall be self-extinguishing except for small parts (e.g. seals, grommets) 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 Effects of a Test

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

2.2 Equipment Performance Standard Conditions

Equipment performance is specified for two different antenna configurations: a passive antenna and an antenna integrated with a preamplifier. These two configurations are illustrated in Figure 2-1.

2.2.1 GNSS Antenna - Passive

The output of the passive antenna is the antenna port (point A in Figure 2-1).

2.2.1.1 GPS Operating Frequency

The antenna shall operate over the minimum frequency range of 1575.42 MHz +10 MHz. The gain shall not vary more than 3 dB over the frequency range.

2.2.1.2 GLONASS Operating Frequency (optional)

The antenna shall operate over the minimum frequency range of 1597 to 1605 MHz. The gain shall not vary more than 3 dB over the frequency range.

NOTE: *GLONASS satellites may operate between 1597 and 1610 MHz between the years 1998 and 2005. Up to 1998, GLONASS may also have satellites operating between 1613.8 and 1616 MHz.*

2.2.1.3 Passive Antenna VSWR and Impedance

The VSWR for a dry antenna shall not exceed 1.5:1 over the operating frequency range when interfaced with a nominal 50 ohm impedance transmission line.

The VSWR for an antenna exposed to rain, or an ice accumulation of 0.5 inches, shall not exceed 2.0:1.

2.2.1.4 Antenna Gain

The minimum gain shall not be less than the following for the specified elevation angle, at the operating frequency, above the horizon at any azimuth:

Elevation Angle	Minimum Gain
>15 degrees	-2 dBic
10 degrees	-3 dBic
5 degrees	-4.5 dBic
0 degrees	-7.5 dBic

The maximum gain shall not exceed -2 dBic at 0 degrees elevation angle and 7 dBic above 5 degrees.

The gain of an antenna exposed to rain, or an ice accumulation of 0.5 inches, shall not exceed an average gain-loss of 4.5 dB from dry conditions when measured at an angle of 30 degrees above the horizon.

The antenna gain shall not vary more than 1 dB over the full temperature range for which the antenna is specified.

2.2.1.5 Axial Ratio

The Axial Ratio shall not exceed 3.0 dB for all operating frequencies at elevation angles greater than 10 degrees, nor exceed 6 dB for all operating frequencies at elevation angles between 5 and 10 degrees.

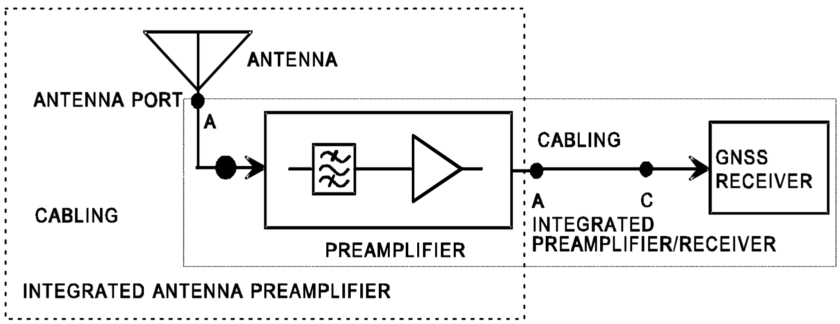
2.2.1.6 Polarization

The polarization shall be nominally right-hand (clockwise) circularly polarized.

2.2.2 GNSS Antenna - With Integrated Preamplifier (optional)

The GNSS antenna, as defined in Section 2.2.1 above, integrated with a preamplifier, as illustrated in Figure 2-1, includes the antenna, cabling between the antenna and preamplifier, burnout protection, selective filtering, and a low-noise-amplifier (LNA).

NOTE: *These preamplifier requirements are defined for GPS only. The*



requirements for GLONASS are under study.

Figure 2-1 Antenna Configurations

2.2.2.1 Preamplifier Gain and Noise Figure

The preamplifier shall provide additional gain of 26.5 dB, minimum, to that specified in Section 2.2.1.4, with a maximum 4 dB noise figure, including all circuitry in the integrated antenna/preamplifier. This additional gain is applicable to points A and B in Figure 2-1, and does not include cabling between the preamplifier and the GNSS receiver at point C.

NOTE: *No maximum gain is specified. Thus, the total gain of the preamplifier and GNSS receiver combination may be installation dependent.*

2.2.2.2 Preamplifier Gain Compression

The preamplifier shall have a 1 dB gain compression point not less than the values shown in Figure 2-2 defined at the antenna port. The CW interference levels below 1500 MHz increases linearly to 25.5 dBm at 1315 MHz, and above 1640 MHz, the levels increase linearly to 21.5 dBm at 2 GHz, accounting for High Intensity Radiation Fields (HIRF).

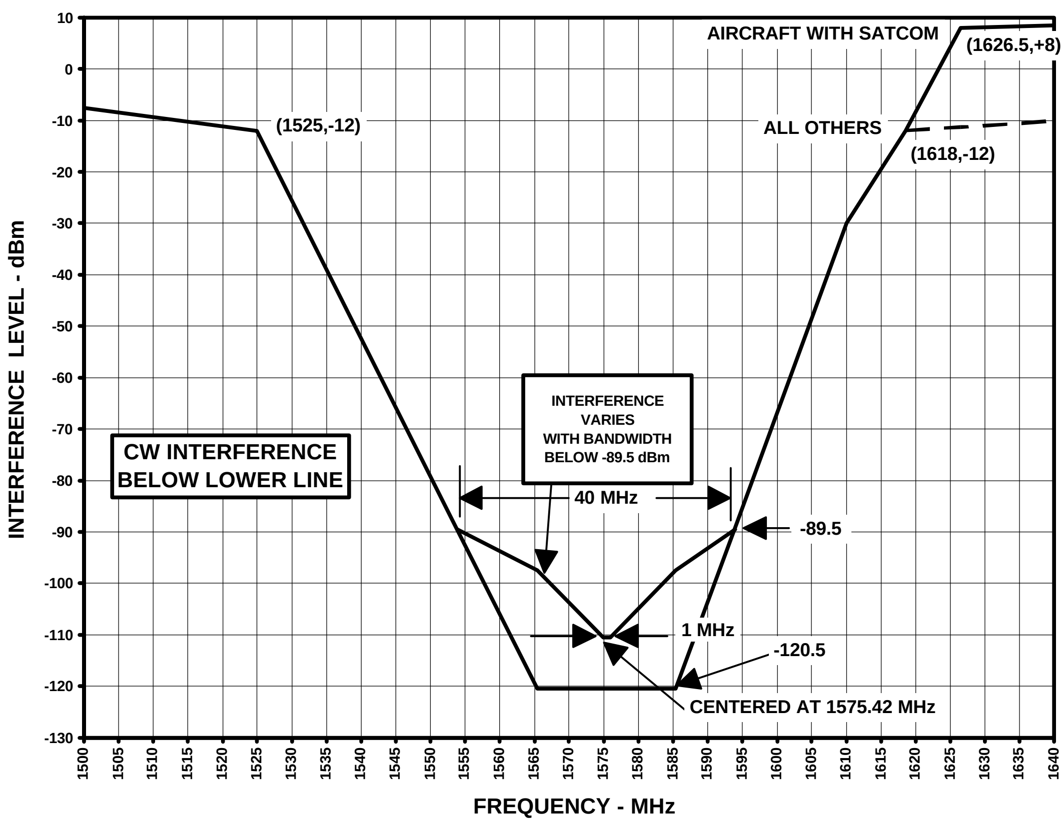


Figure 2-2 Interference Levels at the Antenna Port

2.2.2.3 Preamplifier Stability

The preamplifier shall be unconditionally stable for any source or load impedance.

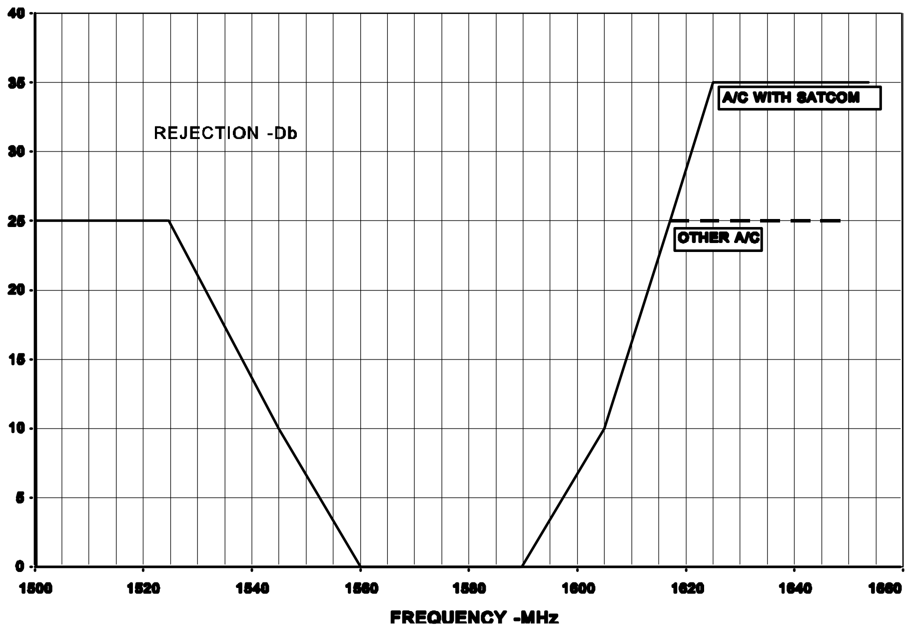
2.2.2.4 Preamplifier Selectivity

The preamplifier with antenna shall have the frequency selectivity specified in Figure 2-3.

2.2.2.5 Burnout Protection

The preamplifier shall withstand a CW input carrier of 30 dBm without damage.

2.2.2.6 Pulse Power Operation



The antenna preamplifier shall resume normal operation within 10 μs of the trailing edge of a pulse with a width of up to 1 ms, a peak power of 30 dBm, and a duty cycle of 10%.

Figure 2-3 Frequency Selectivity Requirements

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 antenna under conditions representative of those that may be encountered in actual operations.

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 antenna performance under environmental test conditions are set forth in RTCA Document DO-160C, *Environmental Conditions and Test Procedures for Airborne Equipment*. General information on the use of DO-160C is contained in Sections 1.0 through 3.0 of that document. Also, a method of identifying which environmental tests are conducted and other amplifying information on the conduct of the tests is contained in Appendix A of DO-160C.

Some of the performance requirements in Section 2.2 are not required to be tested to all of the conditions contained in RTCA/DO-160C. If judgment and experience indicate that these particular performance parameters are not susceptible to certain environmental conditions, and that the level of performance specified in Section 2.2 will not be measurably degraded by exposure to these particular environmental conditions, such tests may be omitted.

In addition to the exceptions above, certain environmental tests contained in this section are not required for minimum performance equipment unless the manufacturer wishes to qualify the antenna for additional environmental conditions. If the manufacturer wishes to qualify the antenna to these additional conditions, then these tests shall be performed.

2.3.1 Specific Environmental Test Conditions

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C as indicated below. Categories are for locations external to the aircraft.

RTCA/DO-160C Section		Category
4	Temperature and Altitude	D2
5	Temperature Variation	A
6	Humidity	B
8	Vibration	C
9	Explosion	E
10	Waterproofness	S
11	Fluids (1)	F
12	Sand and Dust	D
13	Fungus	F
14	Salt Spray	S
15	Magnetic Effect	A or B
16	Power Input	A
17	Voltage Spike	A
19	Induced Signal Susceptibility	Z
20	Radio Frequency Susceptibility	W
21	Spurious Radio Frequencies	Z
22	Lightning Induced Effects	L
23	Lightning Direct Effects	2A
24	Icing (2)	C

NOTES: *1. Fluid susceptibility for solvents, cleaning, and de-icing fluids.*

2. The antenna requires operation with an ice coating of 0.5 inches.

2.3.2 Temperature and Altitude Tests (DO-160C, Section 4.0)

RTCA/DO-160C contains several temperature and altitude test procedures that are specified according to the category specified in the preceding Section 2.3.1. The following Sections contain the applicable test conditions specified in Section 4.0 of DO-160C.

2.3.2.1 Low Operating Temperature Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 4.5.1, and the following requirements of this standard shall be met:

1. Section 2.2.1.1 - GPS Operating Frequency
2. Section 2.2.1.2 - GLONASS Operating Frequency (optional)
3. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
4. Section 2.2.1.4 - Antenna Gain
5. Section 2.2.2.1 - Carrier and Noise (optional)
6. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.2.2 High Short-Time Operating Temperature Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 4.5.2, and the following requirements of this standard shall be met:

1. Section 2.2.1.1 - GPS Operating Frequency
2. Section 2.2.1.2 - GLONASS Operating Frequency (optional)
3. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
4. Section 2.2.1.4 - Antenna Gain
5. Section 2.2.2.1 - Carrier and Noise (optional)
6. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.2.3 High Operating Temperature Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 4.5.3, and the following requirements of this standard shall be met:

1. Section 2.2.1.1 - GPS Operating Frequency
2. Section 2.2.1.2 - GLONASS Operating Frequency (optional)
3. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
4. Section 2.2.1.4 - Antenna Gain
5. Section 2.2.2.1 - Carrier and Noise (optional)
6. Section 2.2.2.2 - Preamplifier Gain (optional)
7. Section 2.2.2.4 - Burnout Protection
8. Section 2.2.2.5 - Pulse Protection and Recovery Time

2.3.2.4 Altitude Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 4.6.1, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain
3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.3 Temperature Variation Test (DO-160C, Section 5.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 5.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.4 Humidity Test (DO-160C, Section 6.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 6.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.5 Shock Tests (DO-160C, Section 7.0)

2.3.5.1 Operational Shocks

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 7.2, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 7.2, and shall meet the requirements specified therein.

2.3.5.2 Crash Safety Shocks

The application of Crash Safety Shock tests may result in damage to the antenna under test. Therefore this test may be conducted after the other tests have been completed. In this case, Section 2.1.9 "Effects of Test" does not apply.

2.3.6 Vibration Test (DO-160C, Section 8.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 8.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.7 Explosion Test (DO-160C, Section 9.0) (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 9.0. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.

2.3.8 Waterproofness Tests (DO-160C, Section 10.0)

2.3.8.1 Drip Proof Test (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 10.3.1, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.8.2 Spray Proof Test (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 10.3.2, and the following requirements of this standard shall be met:

NOTE: This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (Optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.8.3 Continuous Stream Proof Test (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 10.3.3, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.2.2 - Preamplifier Gain (optional)

NOTE: This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.

2.3.9 Fluids Susceptibility Tests (DO-160C, Section 11.0)

The following sections contain the applicable test conditions specified in Section 11.0 of DO-160C.

2.3.9.1 Spray Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 11.4.1, and the following requirements of this standard shall be met:

1. At the end of the 24-hour exposure period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred.

2. Following the 2 hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

    1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
    2. Section 2.2.1.4 - Antenna Gain
    3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.9.2 Immersion Test (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 11.4.2, and the following requirements of this standard shall be met:

1. At the end of the 24-hour immersion period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred.

2. Following the 2-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

    1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
    2. Section 2.2.1.4 - Antenna Gain
    3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.10 Sand and Dust Test (DO-160C, Section 12.0) (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 12.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain
3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.11 Fungus Resistance Test (DO-160C, Section 13.0) (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 13.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain
3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.12 Salt Spray Test (DO-160C, Section 14.0) (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 14.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain
3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.13 Magnetic Effect Test (DO-160C, Section 15.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 15.0, and the equipment shall meet the requirements of the appropriate instrument or equipment class specified therein.

2.3.14 Power Input Tests (DO-160C, Section 16.0)

2.3.14.1 Normal Operating Conditions

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Sections 16.5.1 and 16.5.2, as appropriate, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.14.2 Abnormal Operating Conditions

The application of the low voltage conditions (DC) (Category B equipment) test may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. Section 2.1.9, "Effects of Test," does not apply.

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Sections 16.5.3 and 16.5.4, as appropriate, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.15 Voltage Spike Conducted Test (DO-160C, Section 17.0)

The following Sections contain the applicable test conditions specified in Section 17.0 of RTCA/DO-160C.

2.3.15.1 Category A Requirements (If Applicable)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 17.3, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.15.2 Category B Requirements (If Applicable)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 17.4.1, "Intermittent Transients" and Section 17.4.2, "Repetitive Transients," and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.16 Audio Frequency Conducted Susceptibility Test (DO-160C, Section 18.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 18.0, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.17 Induced Signal Susceptibility Test (DO-160C, Section 19.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 19.0, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.18 Radio Frequency Susceptibility Test (Radiated and Conducted) (DO-160C, Section 20.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 20.0, and the following requirements of this standard shall be met:

1. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.19 Emission of Radio Frequency Energy Test (DO-160C, Section 21.0)

When the equipment is subjected to the test conditions as specified in RTCA/DO-160C, Section 21.0, it shall meet the requirements specified therein.

2.3.20 Lightning Induced Transient Susceptibility (DO-160C, Section 22.O)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 22.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain
3. Section 2.2.2.2 - Preamplifier Gain (optional)

2.3.21 Lightning Direct Effects (DO-160C, Section 23.0)

When the equipment is subjected to the test conditions as specified in RTCA/DO-160C, Section 23.0, it shall meet the requirements specified therein.

2.3.22 Icing (DO-160C, Section 24.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160C, Section 24.0, and the following requirements of this standard shall be met:

1. Section 2.2.1.3 - Passive Antenna VSWR and Impedance (optional)
2. Section 2.2.1.4 - Antenna Gain

2.4 Equipment Test Procedures

The test procedures in this section constitute a satisfactory method of determining that the GNSS antenna meets the required performance stated in Section 2. Although specific test procedures are cited, it is recognized that other methods may be preferred. Such alternative methods may be used if the manufacturer can demonstrate equivalent test procedures. In this case, the test procedures cited herein must be used as one set of criteria in evaluating the acceptability of the alternate procedures.

Table 2-4 indicates the correspondence between the equipment performance requirements in Section 2.2 and the tests in this section.

Table 2-4 Test Cross Reference

Requirement	Subject	Tests
2.2.1.1	GPS Operating Frequency	2.4.2.1
2.2.1.2	GLONASS Operating Frequency (Optional)	2.4.2.2
2.2.1.3	VSWR and Impedance	2.4.2.3
2.2.1.4	Gain	2.4.2.4
2.2.1.4.1	Frequency Stability	2.4.2.4
2.2.1.4.2	Frequency Selectivity	2.4.2.4
2.2.1.5	Axial Ratio	2.4.2.5
2.2.1 6	Polarization	2.4.2.6
2.2.2.1	Carrier and Noise (optional)	2.4.3.1
2.2.2.2	Preamplifier Gain (optional)	2.4.3.2
2.2.2.3	Preamplifier Stability (optional)	2.4.3.3
2.2.2.4	Preamplifier Selectivity (optional)	2.4.3.4
2.2.2.5	Burnout Protection (optional)	2.4.3.5
2.2.2.6	Pulse Power Protection (optional)	2.4.3.6

2.4.1 Test Conditions

The following tests conditions are applicable to the tests specified in this document:

2.4.1.1 Power Input Voltage

Unless otherwise specified, all tests shall be conducted with the input voltage adjusted to design voltage ±2%.

2.4.1.2 Power Frequency

In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g. 400 Hz), the input frequency shall be adjusted to design frequency ±2%.

2.4.1.3 Antenna Installation

The antenna test installation shall include any adapter plates, where used, or other hardware used to interface the antenna to the fuselage. The Antenna Subsystem under test shall include any electronics considered part of the installed Antenna Subsystem. If a radome forms part of the antenna, this shall also be installed during the measurements.

2.4.1.4 Ambient Conditions

Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure, and humidity.

2.4.1.5 Warm-Up Period

Unless otherwise specified, all tests shall be conducted after the manufacturer's specified warm-up period.

2.4.1.6 Connected Loads

Unless otherwise specified, all tests shall be performed with the equipment connected to loads having the impedance values for which it was designed.

2.4.1.7 Antenna Ground Plane

An antenna ground plane shall be used to simulate the conductive mounting surface on the intended aircraft. The ground plane shall be flat and extend at least 3λ at the test frequency beyond any active portion of the antenna under test, and extend beyond any radome used.

2.4.1.8 Antenna Measurement Range

Testing shall be performed in accordance with the Institute of Electrical and Electronic Engineers (IEEE) Standard Test Procedures for Antennas, IEEE-STD-149-1979 . A suitable test range shall be used having a reflectivity level less than -25 dB within a quiet zone containing the antenna under test and the ground plane, and meet the $2D^2/\lambda$ criterion. Figure 2-4 shows a representative test configuration for the test range. "Compact ranges" and/or near-field probing techniques may also be employed if analysis shows that an equivalent accuracy may be obtained.

Other items of standard test equipment are:

Range instrumentation including a 2-axis (minimum) positioner, positioner controller, L-band transmitter, receiver, pattern recorder, and polarization measurement instrumentation.

Reference RHCP or linearly-polarized, standard-gain antenna, with gain calibration traceable to National Institute for Standards and Technology (NIST), or other national standards.

Antenna test set providing power and, if necessary, other signals to the antenna such that it can operate normally.

For an antenna that is purely passive, there is no requirement for an antenna test set and associated electronics.

2.4.1.9 Test Frequencies

Antenna Subsystem measurements shall be performed at a minimum of six frequencies to include:

Test Frequency	Receive
GPS Lower Band-edge	1565.42 MHz
GPS Mid-Band	1575.42 MHz
GPS Upper Band-edge	1585.42 MHz

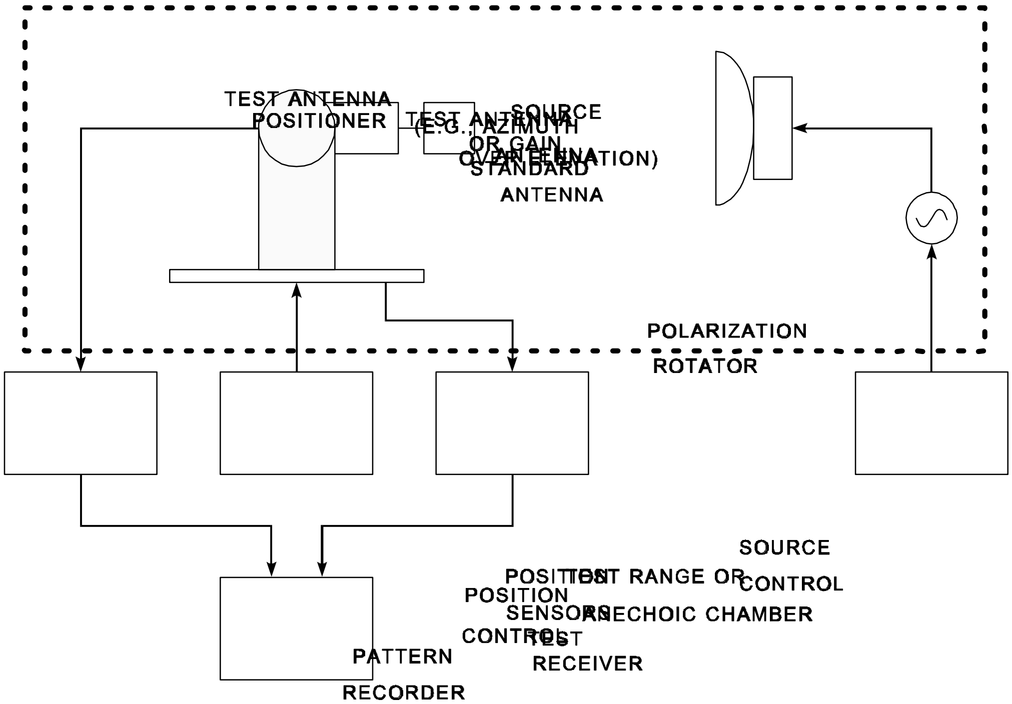

TEST ANTENNA
POSITIONER
TEST ANTENNA
(E.G., AZIMUTH
OVER ELEVATION)
SOURCE
OR GAIN
STANDARD
ANTENNA
POLARIZATION
ROTATOR
SOURCE
CONTROL
POSITION
SENSORS
TEST RANGE OR
ANECHOIC CHAMBER
POSITION
CONTROL
TEST
RECEIVER
PATTERN
RECORDER

Figure 2-4 Antenna Measurement Range

NOTE: *Frequency accuracy shall be within +/- 0.5 MHz.*

2.4.2 GNSS Antenna - Passive

2.4.2.1 GPS Operating Frequencies (Section 2.2.1.1)

Antenna measurements in Sections 2.4.2.3, 2.4.2.4, 2.4.2.5, and 2.4.2.6 shall use the frequencies defined in 2.4.1.9.

2.4.2.2 GLONASS Operating Frequencies (Optional Section 2.2.1.2)

If the antenna is designed to work with GLONASS, then in addition to the requirement of Section 2.4.2.1, antenna measurements in Sections 2.4.2.3, 2.4.2.4 2.4.2.5, and 2.4.2.6 shall be conducted with the following frequencies: 1597, 1601, and 1605 MHz.

2.4.2.3 Passive Antenna VSWR and Impedance Test (Section 2.2.1.3)

Equipment Required:

Ground Plane - refer to Section 2.4.1.7.

Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).

Antenna Test Set (needed for Active Antenna only).

Measurement Requirements:

Connect the equipment as shown in Figure 2-5. For all antennas, measure the VSWR at the RF port of the antenna subsystem in an anechoic chamber or reflectionless environment.

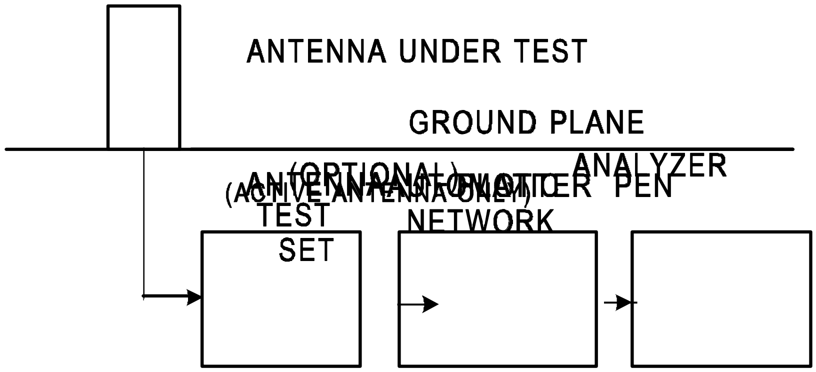


Figure 2-5 Voltage Standing Wave Ratio (VSWR) - Section 2.2.3.5

GAIN - Section 2.2.1.4
AXIAL RATIO - Section 2.2.1.5
POLARIZATION - Section 2.2.1.6

2.4.2.4 Gain Test (Section 2.2.1.4)

Equipment Required:

Antenna Measurement Range - refer to Section 2.4.1.8.
Ground Plane - refer to Section 2.4.1.7.
Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).
Antenna Test Set (needed for Active Antenna only).
Gain Standard Antenna, RHCP source antenna.

Measurement Requirements:

Connect the equipment as shown in Figure 2-4. Measure the antenna gain, per IEEE Standard 149-1979, for azimuth angles of 0, 90, 180 and 270 degrees, and elevation angles of 0, 5, 10, 15, 30, 60 and 90 degrees. Check that for all combinations of azimuth and elevation angles, the antenna meets the requirements of Section 2.2.1.4. Measure the gain at the frequencies defined in Section 2.4.1.9.

2.4.2.5 Axial Ratio Test (Section 2.2.1.5)

Equipment Required:

Antenna Measurement Range - refer to Section 2.4.1.8.
Antenna Ground Plane - refer to Section 2.4.1.7.
Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).
Antenna Test Set (needed for Active Antenna only).
Transmit polarization positioner, or RHCP and LHCP gain standards.

Measurement Requirements:

Connect the equipment as shown in Figure 2-4A. Measure the axial ratio, per IEEE Standard 149-1979, for each of the points designated during the tests in Section 2.4.2.4 for elevation angles defined in Section 2.2.1.5, and the axial ratio at the frequencies defined in Section 2.4.1.9.

2.4.2.6 Polarization Test (Section 2.2.1.6)

Equipment Required:

Antenna Measurement Range - refer to Section 2.4.1.8.
Antenna Ground Plane - refer to Section 2.4.1.7.
Gain Standard RHCP antenna - refer to Section 2.4.1.8.
Gain Standard LHCP antenna
Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).
Antenna Test Set (needed for Active Antenna only).

Measurement Requirements:

Connect the equipment as shown in Figure 2-4. Using the Gain Standard RHCP and Gain Standard LHCP antennas, verify the antenna under test meets the requirements as defined in Section 2.2.1.6 at the frequencies defined in Section 2.4.1.9. The antenna under test is RHCP if the received signals are significantly greater when using the Gain Standard RHCP source antenna when compared to the Gain Standard LHCP antenna. Other methods of determining polarization sense of an unknown antenna are discussed in IEEE Standard 149-1979.

2.4.3 GNSS Antenna - With Preamplifier (optional tests)

For the tests required by Sections 2.4.3.1, 2.4.3.2, 2.4.3.3, 2.4.3.4, and 2.4.3.5 the preamplifier input shall be separated from the antenna element. Proper care shall be taken so that the performance of the preamplifier shall not be changed.

2.4.3.1 RF Gain and Noise Figure Test (Section 2.2.2.1)

Equipment Required:

Antenna Test Set (to provide power as required by the manufacturer to the preamplifier).
Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).
Automatic Noise Figure Meter (Hewlett-Packard 8970A or equivalent)

Measurement Requirements:

Any loss in the RF cables connecting the antenna and the test equipment shall be properly taken into account.

RF Gain:

1. Connect the RF output of the network analyzer to the preamplifier input.
2. Connect the preamplifier output to the network analyzer input.
3. Set the network analyzer to sweep from 1565.42 MHz to 1585.42 MHz, and set the output level to -30dBm.
4. Verify that the gain is at least 26.5 dB over the entire swept frequency band.

Noise Figure Test:

1. Connect the RF output of the noise figure meter to the preamplifier input.
2. Connect the preamplifier output to the noise figure meter input.
3. Verify that the noise figure is no more than 4 dB over the frequency band of 1565.42 MHz to 1585.42 MHz.

2.4.3.2 Preamplifier Gain Compression Test (Section 2.2.2.2)

Equipment Required:

Antenna Test Set (to provide power as required by the manufacturer to the preamplifier)

Two Synthesized Signal Generators (Hewlett-Packard 8662A or equivalent)

Two-Way Power Splitter/Combiner (Mini-Circuits ZSC-2-1 or equivalent)

RF Spectrum Analyzer (Hewlett-Packard 8568B or equivalent)

Measurement Requirements:

1. Connect each of the signal generators to the power splitter/combiner.
2. Connect the output of the power splitter/combiner to the preamplifier.
3. Connect the output of the preamplifier to the spectrum analyzer.
4. Adjust the signal generator frequencies and levels to produce the signals as a function of frequency as described in Figure 2-2.
5. Verify that the output signal meets the specifications as stated in Section 2.2.2.2

2.4.3.3 Preamplifier Stability Test (Section 2.2.2.3)

Equipment Required:

Spectrum Analyzer (Hewlett-Packard 8568B, or equivalent).
Antenna Test Set.
Antenna Test Set (to provide power as required by the manufacturer to the preamplifier).
50 Ohm RF Terminator.
Bridge-T.

Measurement Requirements:

The stability of the amplifier shall be tested in 7 steps:

1. Connect the preamplifier output to the spectrum analyzer. Set the spectrum analyzer to measure signals at least as low as -110 dBm, and with as wide a frequency range as practical.
2. Connect the preamplifier input to a 50 ohm terminator.
3. Apply power to the preamplifier and verify that the preamplifier does not generate any detectable signals.
4. Remove the RF terminator from the preamplifier input. Verify that the preamplifier does not generate any detectable signals.
5. Apply a short across the preamplifier input. Verify that the preamplifier does not generate any detectable signals.
6. Connect the preamplifier input to the spectrum analyzer. Set the spectrum analyzer to measure signals at least as low as -110 dBm, and with as wide a frequency range as practical. Connect a 50 ohm terminator to the preamplifier output. Using a bridge-T to supply power to the preamplifier as necessary, verify that the preamplifier does not generate any detectable signals at the preamplifier input.
7. Connect an RF short circuit to the amplifier output.

NOTE: *One acceptable method of applying an RF short circuit to the amplifier while providing power through the same terminals is to use an open-ended cable of 1/4 wavelength (at 1575.42 MHz) connected to the preamplifier output. Power can be supplied by a normal T or bridge-T connection to the preamplifier output.*

Verify that the preamplifier does not generate any signals at the preamplifier input.

8. Apply an RF open circuit at the preamplifier output terminals. Verify that the preamplifier does not generate any detectable signals at the preamplifier input.

2.4.3.4 Preamplifier Selectivity Test (Section 2.2.2.4)

Equipment Required:

Antenna Test Set (to provide power as required by the manufacturer to the preamplifier).

Automatic Network Analyzer (Hewlett-Packard 8753, 8720, 8510, or equivalent).

Synthesized Signal Generator (Hewlett-Packard 8662A or equivalent).

Measurement Requirements:

1. Connect the RF output of the network analyzer to the preamplifier input.
2. Connect the preamplifier output to the network analyzer input.
3. Adjust the network analyzer to provide a constant, linearly swept signal level of -60 dBm, or as appropriate, over the frequency range of 1500 MHz to 1660 MHz.
4. Verify that the displayed signal meets the levels specified in Figure 2-3, relative to the input signal level.

2.4.3.5 Burnout Protection Test (Section 2.2.2.5)

Equipment Required:

Antenna Test Set (to provide power as required by the manufacturer to the preamplifier).

Synthesized Signal Generator (Hewlett-Packard 8662A or equivalent).

Spectrum Analyzer (Hewlett-Packard 8568B, or equivalent).

RF Amplifier (Hewlett-Packard 8347A, or equivalent).

Measurement Requirements:

1. Connect the RF Amplifier between the signal generator and the preamplifier.
2. Set the RF generator to a frequency of 1575.42 MHz and adjust the level to obtain a signal of +30 dBm at the preamplifier input.
3. Apply power to the preamplifier, and subject the preamplifier input to a test signal of +30 dBm at 1575.42 MHz for 5 minutes.

4. Repeat the tests described in Sections 2.4.3.1, 2.4.3.2, and 2.4.3.3. Verify that the preamplifier still meets the Gain, Noise Figure, and Stability requirements of those Sections.

5. Re-connect the equipment as stated in steps 1 and 2.

6. With power removed from the preamplifier, subject the preamplifier input to a test signal of +30 dBm at 1575.42 MHz for 5 minutes.

7. Repeat the tests described in Sections 2.4.3.1, 2.4.3.2, and 2.4.3.3. Verify that the preamplifier still meets the Gain, Noise Figure and Stability requirements of those Sections.

2.4.3.6 Pulse Power Operation Test (Section 2.2.2.6)

Equipment Required:

Antenna Test Set (to provide power as required by the manufacturer to the preamplifier)
Two Synthesized Signal Generators (Hewlett-Packard 8662A or equivalent)
Spectrum Analyzer (Hewlett-Packard 8568B, or equivalent)
Modulator (Hewlett-Packard 11665B, or equivalent)
Pulse Generator (Fluke 5712, or equivalent)
Linear RF Power Amplifier (500 W peak, minimum)
20 dB Directional Coupler
Variable Attenuator (0-40 dB)
3 dB Power Splitter
Adjustable Phase Delay Line
Phase Detector
Oscilloscope

Measurement Requirements:

1. Connect the equipment as shown in Figure 2-6. Any attenuation of the pulsed RF signal through cable losses, connector losses, losses in the 20 dB directional coupler, etc. shall be taken into account when setting the power of signal generator #1, such that the peak power listed in Table 2-1A shall be present at the preamplifier input.

2. Temporarily disable the pulse power signal from generator #1. Set the signal generator #2 to an output level of 0 dBm and a frequency of 1575.42 MHz. Adjust the variable attenuator such that the preamplifier produces an output power of -10 dB below its 1 dB compression point, with a minimum power of -10 dBm. If the phase detector used will work reliably with a

lower output power, a lower value may be used. Finally, adjust the phase delay line such that the oscilloscope shows a phase difference between the preamplifier output and the delayed signal generator #2 signal of 0N.

3. Set the pulse generator and signal generator #1 to produce the pulsed signal required for test #1 in Table 2-1A.

4. Verify that the preamplifier meets all criteria set forth in Section 2.2.2.6. The recovery time shall be measured as the time needed by the preamplifier to return to a phase difference between its output signal and the delayed signal generator #2 signal of less that +30°, as shown by the oscilloscope.

5. Repeat steps 3 and 4 for tests 2 through 8 using the appropriate settings shown in Table 2-1A for each test.

Table 2-1A Test Settings for the Validation of the Pulse Power Operation Requirement

Test	RF Frequency	Pulse Width	PRF	RF Peak Power
1	1315.00 MHz	1 ms	22 pps	+30 dBm
2	1525.00 MHz	1 ms	100 pps	+30 dBm
3	1565.42 MHz	1 ms	100 pps	+30 dBm
4	1575.42 MHz	1 ms	100 pps	+30 dBm
5	1585.42 MHz	1 ms	100 pps	+30 dBm
6	1610.00 MHz	1 ms	100 pps	+30 dBm
7	1626.50 MHz	1 ms	100 pps	+30 dBm
8	2000.00 MHz	1 ms	56 pps	+30 dBm

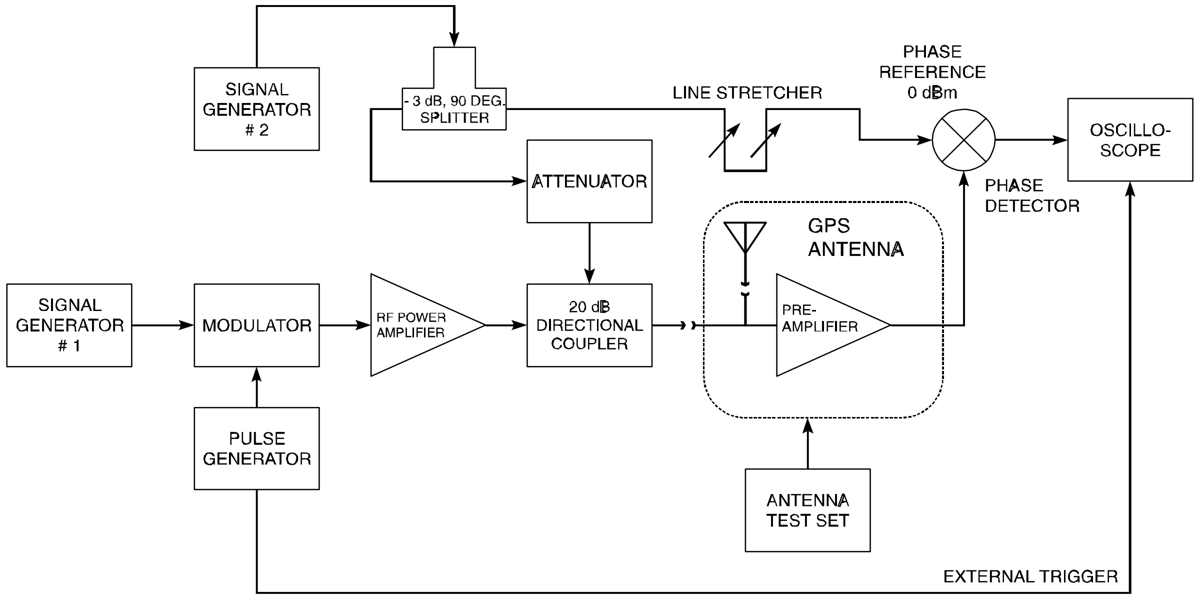


Figure 2-6 Pulse Power Operation Setup

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3.0 INSTALLED EQUIPMENT PERFORMANCE

The installed performance of the GNSS antenna shall be evaluated in conjunction with the installed GNSS receiver equipment to ensure that GNSS performance is met in accordance with the appropriate MOPS.

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4.0 EQUIPMENT OPERATIONAL PERFORMANCE CHARACTERISTICS

The operational performance of the GNSS antenna shall be evaluated in conjunction with the operational tests of the GNSS receiver equipment to ensure that GNSS performance is met in accordance with the appropriate MOPS. Operational tests of GNSS antennas may be conducted as part of normal preflight tests.

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Gene Cangiani	ITT
Martin Capozzoli	AlliedSignal Communications
Eric Carr	Harris Corporation
David Carroll	Motorola, Inc.
Jim Carroll	DOT/Volpe Center
David Carter	Helicopter Association International
Chris Carver	Magellan Systems Corporation
Rick Cassell	Rannoch Corp.
Rebecca Casswell	US Coast Guard
Mark Cato	Crown Communications Inc.
George Chang	Federal Aviation Administration
John Chuang	Litton Aero Products
Howard Clark	Jet Aviation
Kim Class	Honeywell, Inc.
Richard Climie	Consultant
George Cobley	Collins
Clark Cohen	Stanford University
Glenn Colby	US Navy
Rich Cole	Federal Aviation Administration
Robert Conker	MITRE/CAASD
David Correia	Federal Aviation Administration
Edward Cortez	DCS Inc.
Glenn Courtney	Wilcox Electric
Brian Cox	Ball Aerospace
Michael Cramer	Smith Industries
Jim Danaher	3S Navigation

Chris Daskalakis	DOT/VOLPE Center
John Daughtry	AFFSA Instrument Flight Center
James Davis	Universal Avionics Systems
Jerry Davis	Foxfire, Inc.
Keith Davis	JC Air
Gilles De Cevins	Aerospatiale
Bruce DeCleene	Federal Aviation Administration
Michael DeJonge	Smiths Industries
A.J. Delange	Zieta Associates
Don Dement	NOVACOM, Inc
John Diesel	Litton Aero Products
Jim Dill	ITT
Brent Disselkoen	Rockwell-Collins
Dwight Divine	Loral
John Dobyne	ARINC
Eugene Donaldson	Federal Aviation Administration
Chip Dorman	Federal Aviation Administration-SETA
T.M. Dorpinghaus	bd Systems Inc.
David Doyle	NOAA, National Geographic Survey
Dale Dunford	NASA Langley Research Center
Newt Durboraw	Motorola GSTG
Paul Dyer	Federal Aviation Administration
James Earl	Consultant
Paul Ebert	Adsystech, Inc.
Bakry El-Arini	MITRE/CAASD
Rick Ellerdrock	Jeppesen Sanderson
Bryant Elrod	Stanford Telecommunications
Per Enge	Stanford University
Robert Erikson	Federal Aviation Administration
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Victor Foose	Federal Aviation Administration
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Michael Fox	US Air Force
Faye Francy	AERA, Inc.
Bob Frazier	Federal Aviation Administration
James Freidell	Daedalian Technologies Ltd.
Bob Friedman	Tel-Instrument Technologies
Walter Fried	Hughes Aircraft Company
David Frostbutter	JHU/APL
Gerald Frost	RAND
Peter Fyfe	ARINC Research Corporation
Ian Gallimore	Naval Air Warfare Center
Michael Gallistel	Booz Allen & Hamilton
Julie Garcia	Federal Communications Commission
Bill Garner	American Mobile Satellite Corp.
Jim Garoutte	Federal Aviation Administration
Robert Geary	System Resource Corporation
Jeff Geier	Motorola
Alcouffe Gerard	Sextant Avionique
Michael Geyer	TASC
Glen Gibons	GPS World
Bob Gille	Honeywell, Inc.
David Girts	Honeywell, Inc.
David Givens	Honeywell, Inc.
Rocky Gmeiner	Raytheon
Fred Goodrich	Cardion
Francois Goudenove	Aerospatiale
Edward Grenning	ENG Associates
Francis Grimal	EUROCAE
G.N. Gromov	AUSRIRE
Robert Grove	II Morrow, Inc.
Brett Gundlach	BFGoodrich Flight Systems, Inc.
George Gunther	US Coast Guard
Adriana Guy	Amtech Technologies
Lin Haas	Stanford Telecommunications
Bob Hall	Air Line Pilots Association
Richard Hambly	ARINC
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Randolph Hartman	Honeywell, Inc.
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Carol Head	National Academy of Public Administration
Gerry Headley	US Air Force
Christopher Hegarty	MITRE/CAASD
Steve Heppe	Telenergy
Walter Hett	Walter Hett and Associates
Willie Hicks	Joint Spectrum Center
Marc Hinck	Federal Aviation Administration
Don Hiorth	ERI
Hau Ho	Odyssey/TRW
Harry Hodges	Crown Communications, Inc.
Robert Hoech	Rockwell International
Herbert Hoffman	System Resources Corp.
Philip Holmer	SRC
James Howell	Raytheon Co.
Larry Huffman	E-Systems, Inc.
Roger Hughes	US Coast Guard
Warren Hundley	Wilcox Electric, Inc.
Robert Huston	BFGoodrich Avionics Systems
Tom Imrich	Federal Aviation Administration
Nicolay Ivanov	Russian Institute of Space Device Engineering
Thomes Jacob	Deutsche Aerospace
Len Jacobson	GSAM (Intermetrics)
Robert Jeans	United Kingdom Civil Aviation Authority
V.P. Jikharev	All-Union Scientific Research Institute of Radio Equipment
Robert Johns	AlliedSignal ATA
Brian Johnson	Stanford Telecom
Mark Johnson	Rockwell International
Jean-Louis Jonquiere	French Civil Aviation Authority
Greg Joyner	Federal Aviation Administration
John Jubin	Rockwell International
Allen Judkiewicz	SAIC-SCT Group
Rudy Kalafus	Trimble
Elliott Kaplan	The MITRE Corp.
Nick Karanasos	GEC Marconi
Thomas Katri	Federal Aviation Administration
Nelson Keeler	Stanford Telecommunications
Jon Keeneth	Federal Aviation Administration

Robert Kelly	Kelly Systems Engineering
James Kendrick	ARINC
Darrel Killham	Rockwell-Collins
George Kinal	INMARSAT
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George Lyddane	Federal Aviation Administration
Frank Mackowick	SkyComm, Inc.
Brian Mahoney	Federal Aviation Administration
Aziz Makhani	Advanced Hardware Architecture
Steve Malik	FAA Technical Center
Paul Manning	Volpe National Transportation System Center
Kelly Markin	The MITRE Corp.
Anthony Martelli	ARINC
Edward Martin	Rockwell
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Terry McGurn	US Government
David McIntyre	Ashtech, Inc.
Erwin Mercado	Stanford Telecommunications

William Michalson	Worchester Polytechnic Institute
Kevin Milton	Rockwell International
Pratap Misra	MIT Lincoln Lab
Dgnus-Jan Moelker	Delft University of Technology
Neal Molloy	Boeing Commercial Airplane Group
Michael Moore	Aero Consultants
Michael Morrel	Aero Consultants
Mike Morris	US Air Force
Pete Morris	TASC, Inc.
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Hal Moses	RTCA
William Moyer	Qualcomm, Inc.
Heinz Mueller	Federal Aviation Administration
Prem Munjal	The Aerospace Corporation
Tim Murphy	Boeing Commercial Airplane Group
Michael Mussler	Ball Corporation
Mark Mykityshyn	Booz, Allen & Hamilton
Gary Naden	Wilcox Electric
Jim Nagle	INMARSAT
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Ray Nickla	AMTECH
Peter Nicolaides	Mayflower Communications Co. Inc.
Dave Nolte	AlliedSignal Aerospace
Stefan Ochs	DASA
Patti O'Donnell	MITRE/CAASD
Tim O'Grady	ARINC
Mike Peace	Federal Aviation Administration
Terry Pearsall	Aircraft Electronics Associates
Walt Perron	US Army - ASA
Bill Petruzel	Federal Aviation Administration
Jeffrey Pettijohn	Wilcox Electric
William Phaneuf	Air Line Pilots Association
Woody Phlong	Stanford Telecommunications
Andrew Pickens	AvCom, Inc.
Jim Pigg	New Bedford Panoramex Corp.
Lois Pilley	DSDC
Bob Plley	DSDC

Anthony Ploski	ITT Aerospace
Vander Pluym	National Defence Headquarters
Elias Polendo	ARINC
Walter Poor	The MITRE Corp.
Lester Prosser	SRC, Inc.
Jean Provenzano	Alcatel Aerospace
Bill Pryor	Ultra Nav
Gilbert Quinby	G.F.Quinby Associates
B. Rabillier	STNA
Srini Raghavan	The Aerospace Co.
John Rajan	ITT
Jay Ramasastry	Loral Qualcomm Satellite Services
Jerry Reider	Interstate Electronics
Tim Rider	Delta Air Lines
Alan Riemer	Wilcox Electric Inc.
Gary Rixman	Federal Aviation Administration
Si Robin	Sensor System, Inc.
Glyn Romrell	E-Systems-Montek Div.
Charles Rosario	Federal Aviation Administration
Linn Roth	LOCUS, Inc.
Steve Rowson	Wilcox Electric
Rudolph Ruana	Jeppesen Sanderson
Bill Ruhl	Com Air
William Russell	Air Transport Associaiton
Fintan Ryan	INMARSAT
Timothy Ryan	Logistics Development Corp.
Mitch Sams	Wilcox Electric
Edward Sayadian	Stanford Telcommunications
Robert Scheel	Japan Radio Company, Limited
Dave Scull	Interanational Assoc.-Institutes of Navigation
Itchy Sell	ARINC Research
James Semler	Figgle International
Steven Senter	Northern Telecom Europe
Dinyar Sepai	Raytheon
Ralph Sexton	Innovative Solutions International
John Shaw	Airport Systems International
Richard Shin	NAWC
Heywood Shirer	DOT
Timothy Shorts	Loral Federal Systems
Clay Showen	Airport System International
Martin Shuey	Aircraft Owners and Pilots Association

Keith Sketchley	Universal Avionics
Trent Skidmore	Ohio University
Bernald Smith	Soaring Society of America
Michael Smith	US Navy
Steven Smith	Federal Aviation Administration
Sonya Smith	ATC
Jimmy Snow	Federal Aviation Administration
Yedidiah Solowiejclyic	ITT
George Sotolongo	Boeing Commercial Airplane Group
Roger Soucy	Boeing Commercial Airplane Group
Jim Spayd	Delta Air Lines
Donald Spencer	Overlook System Technologies
Richard Stratton	Transport Canada
Robert Striegel	Air Line Pilots Association
Bob Stuckert	Federal Aviation Administration
John Studenny	Canadian Marconi
Abdul Tahir	Litton Aero Products
Donald Taylor	Experimental Aircraft Association & Cumulus Consultants, Inc.
Stewart Teasley	Rockwell Telecommunications
Tom Teetor	DCA, Inc.
Ron Testa	BFGoodrich
David Thompson	Federal Aviation Administration
James Treacy	Federal Aviation Administration
Wai Tsang	SAIC
Maarten Uijt de Haag	Ohio University
David Underwood	Canadian Marconi
Triveni Upadhyay	Mayflower Communications
Bruce Vacey	Honeywell, Inc.
A.J. Van Dierendonck	AJ Systems
Karen Van Dyke	DOT/Volpe Center
Frank Van Graas	Ohio University
Antony Vaudrey	British Embassy, Civil Air Attache
Doug Vickers	Ohio University
Stefan Viewig	Technical University Braunschweig
Chris Villani	NORCOM
Bill Vollestadt	DCS, Inc.
Jim Waid	E-Systems-Montek Division
Scott Wallis	US Air Force
Alan Waltho	ADGA
Rick Walton	COMSAT Mobile Communications
William Wanner	Federal Aviation Administration

Tim Ward	Speedwing-British Airways
Wallace Ward	Airspace Systems Consultants
Nicolas Warinsuo	French CAA
Michael Webb	US Air Force
Robert Weber	Sensor Systems, Inc.
William Wellons	Naval Air Warfare Center
Joel Wichgers	Rockwell-Collins
Jim Wichmann	MIT Lincoln Lab
Lawrence Wiederholt	Intermetrics, Inc.
James Williams	Federal Aviation Administration
Henry Willis	Sierra Research Company
Greg Wilson	Interstate Electronics Corp.
Mark Wilson	Federal Aviation Administration
Robert Wilson	Harris Corporation
Wilburn Wilson	Litton Aero Products
Bette Winer	Volpe Center
Eric Wiswell	TRW
Larry Witmer	Rockwell-Collins
Robert Witulski	ARINC
Chris Wolf	Federal Aviation Administration
K.T. Woo	The Aerospace Corporation
John Wright	Wright=s Landing Avionics Services
Victor Wullshleger	Federal Aviation Administration
Sidney Ying	Rockwell-Collins
William Young	Nav Air Sys Com
Tom Zalesak	US Navy
Mel Zeltser	MITRE/CAASD
Dennis Zvacek	American Air Lines