WIRLESS AVIONICS INTRA-COMMUNICATIONS SYSTEMS AND BAND SHARING

A Thesis

by

JOSHUA THOMAS RUFF

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Co-Chairs of Committee,	Dr. Gregory H. Huff
	Dr. Jean-Francois Chamberland
Committee Members,	Dr. Robert Nevels
	Dr. Darren Hartl
Head of Department,	Head of Department

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1. INTRODUCTION

1.1 Motivation

Over the past two decades, wireless digital communication systems have become ubiquitous in the public life. As the technologies have become more proven, a broad range of players in the aerospace industry developed a significant interest in deploying these systems to electronics on airplanes. Specifically, these companies are interested in radiocommunication between devices on a single aircraft related to the regularity and safety of flight, rather than communications outside an aircraft or for passenger entertainment [1].

Avionics manufacturers are interested in the development, sale and deployment of sensors and devices in areas on a plane that were difficult or impossible to reach with wireless systems. Examples might include placing sensors to monitor a landing gear or internal to an engine, where rotating parts make monitoring difficult [1]. Airframers, Aircraft OEMs and Airlines all have a vested interest in any development which could reduce the amount of copper wiring on planes, thus reducing weight and fuel costs [2]. Regulators are interested in wireless avionics systems from a safety perspective. Critical avionics systems have redundant paths wired in in case of failure, and some or all of these redundancies may eventually be replaced with wireless ones [2] [1]. This type of dissimilar redundancy is always appealing from a safety perspective. The classic example of an engine fire which destroys the physical connection to a controller (and so can't be shut off) demonstrates the utility of a wireless backup [1].

1.2 History

With these diverse motivations spanning across the industry, various aerospace companies sponsored a series of working groups to implement wireless communications systems on aircraft. This systems used in this class of applications were alternatively called Wireless Sensing Networks (WSN's) in early literature, and Wireless Avionics Intra-Communications (WAIC) systems later on. WAIC related projects were sponsored and conducted through the Aerospace Vehicle Systems

Institute (AVSI), which also directed this project. AVSI projects are funded through independent grants known as Authorizations For Expenditure (AFEs)

Three AVSI projects directly relate to WAIC: AFE 56, AFE 73, and AFE 76. AFE 56 studied the feasibility of potential WAIC systems and investigated the suitability of various bands to WAIC applications. AFE 73 took the analysis done by AFE 56 and used the work to advocate to regulators for spectrum allocation for WAIC.

1.3 Project Goals

This work was funded through AVSI and managed under AFE 76. The goal of this project is to perform a band sharing study for WAIC with radio altimeters, and to develop a prototype for WAIC systems. The technical challenges in this project directly result from both the technical studies and the inherently political interactions with regulators performed under its predecessors. Because of this, a brief summary of the work done by the two preceding AVSI projects will be presented here, emphasizing the portions of each most relevant to this study.

1.4 WAIC Feasibility Study

The WAIC Feasibility study was conducted through AFE 56, and the results of this study were published in [3]. The report is summarized here for background with significant focus placed on the search for a suitable WAIC band.

AFE 56 had three primary goals [3]:

- ”Identify, Characterize and prioritize the most significant obstacles currently impeding widespread use of wireless communication in flight-critical functions”
- ”Evaluate the current aircraft RF certification process and suggest possible modifications or changes”
- ”Identify the most promising avenues to certify reliable and robust wireless intra-aircraft data transmission”

Toward these ends, investigations were performed into the certification process, suitable spectrum bands, and security concerns related to the implementation of WAIC systems.

1.4.1 Certification

Any device on an aircraft must go through a regulatory certification process, which functions as a way for regulatory bodies to declare the device airworthy [3]. Both civilian and military aircraft are subjected to various certification processes [3]. The AFE 56 working group surveyed the various standards imposed by the DoD, FAA, and ICAO (International Civil Aviation Organization), as well as international treaties governing the aviation industry. The committee took an in depth look at the flight clearance process in use at various agencies [3].

The AFE 56 working group then looked at the specific challenges brought to the forefront by wireless systems. The primary concerns for potential WAIC systems involved the sharing of spectrum with other legal occupants of the band, as well as intentional and unintentional interferers [3]. It was determined that a certification process for WAIC systems would need to account for and provide mitigation strategies for each of these various potential interferers to pass certification. Information security would also need to be guaranteed for critical systems. These considerations would drive the band selection process for WAIC [3].

1.4.2 The Search for a Suitable WAIC Band

Prior to beginning the search for a suitable band, members of the project management committee held discussions with the FCC to gain insight on the regulator's perspective on allocations for potential WAIC systems. Firstly, FCC staff reccommended AVSI pursue an international spectrum allocation before focusing on domestic rule-making. Secondly, the FCC placed significant emphasis on the importance of "picking a winner" as quickly as possible in the frequency selection process [3].

This recommendation was made in light of experience with previous international radio projects. American industry previously coordinated a global effort to upgrade the Weather Fax system which was delayed by more than two years and ultimately only partially successful. The FCC ultimately pinned these issues on the failure of American industry to ”*socialize* their specific solution” with key international players in the international spectrum allocation process [3]. The lessons from this failure would play as important of a role in the evaluating potential WAIC band as technical considerations. The band would need to be one which aerospace could get.

Initially, the committee considered the Industrial, Scientific, and Medical, or ISM bands. ISM bands are subjected to limited regulations, and were quickly eliminated from consideration for WAIC devices [3]. A wide variety of commercial devices already occupy this band, and these devices are allowed to radiate at relatively high powers. Because of the high operating powers, users are afforded no regulatory protection from hamful interference, a condition which would be unacceptable for the safety focused aerospace industry [3]. For this reason the 915 MHz, 2.4 GHz, 5.8 GHz, 24 GHz, and 61 GHz bands were eliminated from consideration for WAIC devices [3].

To find a suitable alternative, the committee stepped through both the US and international tables of frequency allocations. The committee rated alternatives according to two goals. The first was electromagnetic compatibility with wireless sensor applications [3]. The second goal was that a suitable band already be allocated or have potential to be allocated in a manner compatible with WAIC desired properties [3].

A series of criteria were used to rate the suitability of potential alternatives. A band already primarily allocated to an aeronautical service was considered beneficial from the political perspective of spectrum allocations. Benign co-primary users were considered essential [3]. The less sensitive other occupants are to the minimal level of interference from on-aircraft wireless systems, the better. Bands which possessed common allocations across international regions were also considered beneficial, to ease the process of getting approval for WAIC use of the band [3].

It was considered critical that WAIC systems be sufficiently isolated from ISM and unlicensed allotments. The relatively uncontrolled emitters were considered a significant threat to on aircraft wireless [3]. Isolation from terrestrial point to point systems was also considered critical. These systems introduce the possibility of impinging extremely high radiated power levels onto aircraft that pass through [3]. Although this risk is limited to low altitudes, it constitutes a significant safety hazard that can be avoided by the choice of band [3]. A final consideration for allocations is isolation from Satellite (Earth to Space) allocations. Up-link sites require significant RF power to maintain, and therefore consist of a safety hazard similar to point to point systems [3].

1.4.3 Candidate Bands

Based on these criteria, the AFE 56 committee performed a review of major candidate bands for WAIC systems. The committee provided a synopsis of relevant characteristics of each candidate band and rated the band according to it's suitability. AVSI performed this process with a goal of helping future working groups to prioritize future efforts at reserving spectrum allocation.

1.4.4 Channel Modeling and Security

Finally, the AFE56 committee surveyed two more obstacles to a finalized WAIC implementation. The committee looked at channel modeling for wireless sensor networks and gave an overview of security concerns.

Any implementation of WSN's on aircraft has the potential to be critical to the safety of flight. Because of this, the committee stressed the importance of developing a validated channel model for the band and air-frames in use [3]. The channel models would allow for the incorporation of the physical propagation characteristics of the wireless signals in various aircraft and could be used to improve the reliability of real WAIC designs. Because of this, the committee provided an overview of channel modeling efforts in their report and made recommendations for an approach to channel modeling efforts that might follow a new WAIC allocation [3].

Lastly, the committee commissioned a follow up investigation which looked into the security concerns associated with WAIC systems. A report [4] was commissioned through the University of Minnesota, which aimed to analyze the various potential threats to wireless networks on aircraft. The threat vectors considered included physical layer attacks such as jamming, as well as higher layer attacks such as distributed denial of service and hacking risks. The report then looked at potential mitigation strategies for each of these threat vectors. The solutions listed were meant to be a comprehensive overview, but to acquire certification each device would have to provide a detailed overview of their implementation to the relevant certification authority [4].

1.4.5 Summary and Conclusions

The AFE 56 project committee performed a feasibility study for wireless sensing network on aircraft. The committee first looked at the existing path to certification for instrumentation, and came to the conclusion that this path would work for WSN's as well, provided that the applicant for certification perform the necessary extra step of explaining to the FAA the added risks of the wireless device and how these risks were mitigated [3]. The committee then performed an in depth survey of potential bands for WSN use, summarizing the desirable characteristics possessed by any candidate band. The committee provided an in depth overview of the pros and cons of each serious candidate for WAIC allocation, a brief summary of which has been included in this report for reference. Finally, the committee looked at potential channel modeling techniques and security concerns associated with wireless systems on aircraft and outlined how these would need to be addressed for a real WAIC implementation [4].

The committee came to the conclusion that although there were numerous hurdles in the way of fully realizing WAIC systems, WAIC systems were feasible and these challenges could be overcome with industry expenditure and effort. The tasks necessary for WAIC implementation were as follows:

- Acquire spectrum for WAIC use
- Perform a band sharing study for WAIC and existing band occupants
- Develop industry standards for channel modeling of air-frames
- Develop industry standards for addressing security concerns for wireless networks on aircraft
- Work with regulators to develop a streamlined certification process for wireless sensing networks once these standards are developed

With the feasibility study complete, the AVSI partners moved on to the task of acquiring spectrum for wireless networks on aircraft.

1.5 Selecting a Suitable WAIC Band

In AFE 73, AVSI followed up on the work completed in AFE 56. The list of candidate bands was narrowed down to three considered at the World Radio Conference (WRC), which then were the subject of a compatibility study. Following the compatibility study, it was determined that the radio altimeter band would be theoretically compatible, and the occupants were willing to work with AVSI for the acquisition.

1.5.1 Narrowing Down the Candidate Bands

Somehow [Need a source], this list of candidate bands was narrowed down to

1.5.2 WRC-15 Compatibility Study

1.5.3 Selecting the Altimeter Band

The altimeter manufacturers were on board which made acquiring the spectrum in this band politically feasible. [Need a source]

1.5.4 Statement of The Allocation

The 2015 World Radio Conference (WRC-15) made changes to the spectrum allocations in and around the radio altimeter (RA) band. New allocations for 5G systems in the 3.7 GHz (3600-4200 MHz) and 4.5 GHz (4400 - 4900 MHz)

1.6 Overview of Radio Altimeter Functionality

1.6.1 Basic Overview and Applications

The 4.2-4.4 GHz band was previously allocated exclusively to radio altimeters and transponder systems associated with altimetry. The altimeter functions to actively and continuously provide height measurements of an aircraft above the surface of the Earth. The highest degree of accuracy is expected in the approach, landing, and climb phases of flight. This accuracy must be maintained through all types of ground reflectivity. The height measured by an altimeter has a variety of uses in safety critical systems. The height functions as an input The Terrain Awareness Warning System, which gives the pilot a ”Pull Up” warning at a predetermined unsafe altitude and descent rate. The

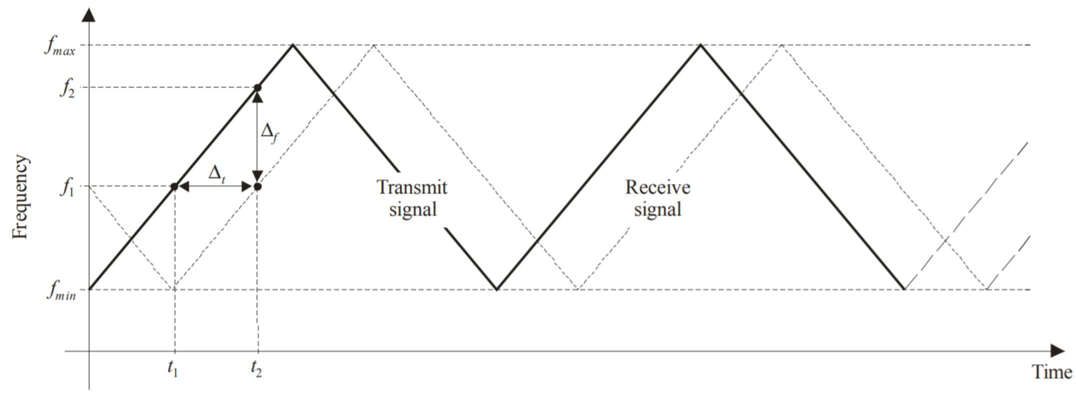

Figure 1.1: Figure from ITU-R M.2059-0

height from altimeters also functions as input for Collision Avoidance, Weather, Navigation, and Autopilot systems. Radio Altimeters are expected to operate in these functions through the lifetime of the Aircraft they are installed on, which results in Altimeters used in excess of 30 years.

1.6.2 Calculating the Height From a Time Delay

There are two primary types of altimeters in use today. The first are Frequency Modulated Carrier Wave (FMCW) Altimeters. FMCW altimeters use a transmitter and receiver with separate antennas. The signal from the transmit antenna travels to the ground, is reflected, and returns to the aircraft. Due to the constant propagation speed, the return time of the signal is proportional to the height of the aircraft above the surface.

The signal travel time is based on the return of a signal of the same frequency as the transmit signal. One method for calculating the travel time of a signal involves taking the difference between the frequency of the return signal at the current time and the frequency of the transmit signal at the current time, Δf. As shown in Figure 1.1, given a constant waveform, the return time of a signal is:

$$\Delta t = \frac{\Delta f}{df/dt}$$

Once Δt is calculated, it the height can be determined using the speed of light:

$$H = \frac{c}{2\Delta t}$$

While not relying on a frequency modulated waveform, pulsed radar altimeters use a series of discrete pulses to track the current height of the aircraft. The Δt between two pulses is used to calculate the height in the same manner that an FMCW altimeter does. Thus, for any altimeter under test in a lab setting, the time delay of the signal between the Altimeter TX and RX must be simulated to provide an accurate representation of real conditions.

1.6.3 Attenuation of the Altimeter Signal in Free Space

A signal traveling from Altimeter Transmit and back to receive passes through multiple different sources of gain and attenuation [5]. There is attenuation from cable losses, gain from the TX antenna, free space path loss as the signal travels toward the ground, loss from the scattering of the signal by the ground, path loss of the return signal, a gain from the receive antenna, and finally the attenuation from return cable losses. The combination of each of these gains and losses comprises the external loop-loss L for a signal leaving an aircraft. DO-155 defines the loop loss as the ratio of the power received by the RX antenna, P_R to the power sent by the transmit antenna, P_T.

$$L = \frac{P_R}{P_T}$$

The DO-155 standards specify loop loss for different heights, standardized antennas, ground scattering environments, and standardized cable attenuations, and expands the formula shown here to derive these.

Like the time delay, any Altimeter lab setup has to simulate the DO-155 attenuation for various heights to be realistic.

1.6.4 Conclusions

Radio Altimeters are a safety critical system in any aircraft, the output of which is used by other important airborne systems. Altimeters use the time it takes a signal to travel to the ground and back to calculate the height of an aircraft off the ground, and must be able to pick up a return signal which has been attenuated significantly depending on the height. To test radio altimeters in a lab setting, both the time delay and attenuation experienced by a real signal must be simulated.

2. METHODS

2.1 Basic Altimeter Test Bed Setup

REFERENCES

[1] D. Redman, "WAIC Overview and Application Examples," 2011.

[2] H. Canaday, "War on wiring," *Aerospace America*, May 2017.

[3] Ferrell, "Feasibility of Intra-Aircraft Wireless Sensors," Final Report AFE 56, Aerospace Vehicle Systems Institute (AVSI), May 2007.

[4] A. Tewfik, M. Heimdahl, N. Hopper, and K. Yongdae, "University of Minnesota Final Report," AFE 56s1 Final Report, University of Minnesota, Mar. 2009.

[5] "Minimum Performance Standards Airborne Low-Range Radar Altimeters," Industry Standard DO-155, Radio Technical Commission for Aeronautics, Washington, D.C., Nov. 1974.