NASA/TP-2008-215111

Radio Frequency Compatibility of an RFID Tag on Glideslope Navigation Receivers

Truong X. Nguyen
Langley Research Center, Hampton, Virginia

John J. Mielnik
Lockheed Martin, Hampton, Virginia

February 2008

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TP-2008-215111

Radio Frequency Compatibility of an RFID Tag on Glideslope Navigation Receivers

Truong X. Nguyen
Langley Research Center, Hampton, Virginia

John J. Mielnik
Lockheed Martin, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

February 2008

Acknowledgments

This work was funded by the NASA Aviation Safety Program (Integrated Vehicle Health Management) and the Federal Aviation Administration as part of FAA/NASA Interagency Agreement DFTA03-96-X-90001, Revision 9.

Available from:

NASA Center for AeroSpace Information (CASI)
7115 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Table of Contents

List of Tables

List of Figures

Acronyms and Symbols

ASK	Amplitude-shift-keying modulation
CDI	Course Deviation Indicator
dB	Decibel
dBm	Decibel relative to one milliwatt power
Emission	Maximum RF emission from a device in dBm
GHz	Gigahertz
GS	Glideslope
$GS_{3dB>Sensitivity}$	Glideslope signal level set to 3 dB above GS receiver's sensitivity
$GS_{ICAO/OLC}$	Glideslope signal level at the receiver at the ICAO airspace outer-limit-of-coverage
I	In-phase baseband component of a wireless signal
ICAO	International Civil Aviation Organization
IPL	Interference Path Loss
IPL_{Target}	Desired minimum aircraft Interference Path Loss value to avoid interference
IQ	In-phase and quadrature baseband components of a wireless signal
kHz	Kilohertz
MHz	Megahertz
msec	milliseconds
NAV/COM	Navigation/ Communication
OLC	Outer-limit-of-coverage
Q	Quadrature baseband component of a wireless signal
RBW	Resolution bandwidth
RF	Radio Frequency
RFID	Radio Frequency Identification
RTCA	RTCA Inc.; formerly Radio Technical Commission for Aeronautics
$T_{25\mu A}$, T_25uA	Interference threshold using 25-microampere course deviation error criteria
TEM	Transverse ElectroMagnetic (test cell)
T_{Flag}, T_Flag	Minimum interference power to cause flag condition
Threshold	Minimum interference signal level at the receiver's antenna port to cause interference effects
T_{noFlag}, T_noFlag	Maximum interference power below which the receiver recovers from flag condition interference
VSG	Vector Signal Generator
µA	Microampere
µV/m	Microvolts per meter

This page was intentionally left blank

Abstract

A process is demonstrated to show compatibility between a radio frequency identification (RFID) tag and an aircraft glideslope (GS) radio receiver. The particular tag chosen was previously shown to have significant spurious emission levels that exceeded the emission limit in the GS aeronautical band. The spurious emissions are emulated in the study by capturing the RFID fundamental transmission and playing back the signal in the GS band. The signal capturing and playback are achieved with a vector signal generator and a spectrum analyzer that can output the in-phase and quadrature components (IQ). The simulated interference signal is combined with a GS signal before being injected into a GS receiver's antenna port for interference threshold determination. Minimum desired propagation loss values to avoid interference are then computed and compared against actual propagation losses for several aircraft.

1 Executive Summary

Applications of radio frequency identification (RFID) have grown in exponential fashion in the recent years in many fields. In the aviation industry, RFID has been promoted to help improve cargo, luggage and part tracking, potentially resulting in better efficiency and safety.

In RFID technologies, a radio frequency (RF) signal is used to communicate between a data storage device (a tag) and a reader. RFID tags come in two main types: active or passive. Passive tags are less of a concern from an aircraft compatibility perspective. They rely on the impinging encoded RF power from the reader to supply power for the response. Without an active reader, these tags cannot transmit and are not expected to be a safety concern.

Active tags have internal batteries to power transmission bursts. In many designs, tags can transmit in beacon mode without first being interrogated. Due to low cost designs, many tags have high unintended transmissions in aircraft radio bands that can potentially interfere with aircraft radio receivers. Wide use of these tags on aircraft could be an interference concern. This study focuses specifically on interference risks due to active tags. The term RFID tag refers only to active tags in the remainder of this document.

A past study was conducted to measure unintended emissions in many aircraft radio bands from ten different active tag models. A significant finding was that peak spurious emissions from a tag occurred in the glideslope (GS) band and were 35 dB higher than the level permitted for typically installed aircraft systems.

The tag could be a cause for concern if allowed on aircraft, since its high peak emission level may interfere with the critical GS landing system operations. However, most intentional and spurious emissions from RFID tags are in bursts with very low duty factors. Interference risks to aircraft receivers are not expected to be the same as a continuous interference signal, as assumed in many aircraft equipment emission limits.

This study illustrates the process to address the interference concern for very low duty factor interference signals. The tag with high emissions in the GS band is used as an example. The validity of the process is not limited to this specific tag or the GS system.

For applicability to a wide variety of aircraft models, the end goal of this process is to determine the desired minimum interference path loss. Interference path loss, or IPL, is a measure of signal propagation loss between tag locations and the victim receiver's antenna port. An aircraft model with the IPL exceeding the desired minimum value would have little concern for receiver interference. The desired minimum IPL value can be determined from the tag's peak emission level and the GS receiver interference threshold, or the level to cause interference. The desired minimum IPL results are then compared against aircraft measured IPL data.

With the tag's peak emission level known from a previous effort [1], a significant part of the current effort was to determine the interference threshold for a GS receiver. A desired GS signal and an interference signal with a varying level were injected into the receiver's antenna port. The interference threshold was the lowest interference signal level to cause interference.

A method to emulate the RFID interference signals was based on the observation that the tag's spurious and fundamental emissions were similarly modulated. As a result, a laboratory setup captured the RFID signal at the fundamental transmission frequency, with the signal playback in the GS band. This approach resulted in significantly higher signal-to-noise ratio than by capturing the spurious signal directly.

The testing was performed using combinations of two interference criteria and two GS signal levels. The two GS signal levels included 1) the minimum signal strength at the edge of GS coverage airspace, and 2) near the receiver's sensitivity. The interference conditions included a flag condition and a 1-dot deflection on the course deviation indicator. RFID burst rate was a test variable. The interference threshold was determined by varying the interference signal power until an interference criterion was observed.

With the interference thresholds determined and the RFID tag peak spurious emissions known, the desired IPL was determined and compared with aircraft data. The comparison showed that with the quantity of one tag, there was a minimum 20 dB safety margin for large aircraft models, such as Embraer EMB-120 or larger, and at least 8 dB for small general aviation aircraft.

It was also shown that the GS receiver model used in the testing was more sensitive than most others models surveyed. The results were therefore considered more conservative than most other receiver models with respect to the desired IPL and the safety margin.

2 Introduction

The use of radio frequency identification (RFID) has grown exponentially in the recent years in many industries and countless applications. RFID is an automatic identification technology that provides information about and allows tracking of cargo, people, animals and products in transit. In RFID technologies, radio frequency (RF) is used to communicate between a data storage device (a tag) and a reader/scanner. RFID is fast, reliable, and does not require line-of-sight or contact between the reader and the tags.

At the minimum, a RFID system must have a reader and a tag. A tag contains data to be read, and is typically attached to goods and personnel that are mobile or in transit. A tag may also contain sensors for various environmental sensing and logging functions. A reader decodes the information from the tag and communicates with the rest of the system for interpretation.

There are two main groups of RFID systems classified according to tag power supply: passive and active. A passive tag does not have an integrated power supply and must draw all required power from the electric, magnetic, or electromagnetic field of the reader. A passive tag can have very long life since its operations do not depend on a battery. On the contrary, an active tag uses a battery to power part or all functions. The usefulness of an active tag is closely related to battery life, cost and serviceability. To maintain battery life, the transmission power from the tags should be at the minimum for achieving the desirable read range.

Both passive and active tags are being considered for aircraft applications. It is known that RFID tags have been shipped with cargo on many commercial flights. Without a reader onboard, passive tags are considered less of an interference risk since they require a strong encoded field from the reader for activation. Active tags are of higher interference risk with built-in batteries and many can transmit with out being interrogated by the reader. Low-cost designs may not suppress spurious emissions beyond the regulatory requirements and may result in high spurious emissions in aircraft radio bands.

In a previous study [1], measurements of spurious emissions in aircraft radio bands of ten different active tags showed that many have higher peak emission levels than several RTCA/DO-160 aircraft equipment emission limits. In one case, the peak emissions exceeded the limits in the glideslope (GS) band by as much as 35 dB. Considering only the peak emission level, this is a cause for concern if the particular tag is allowed to transmit during flight. However, like most other tags, the tag has very low duty factors (about 0.06 percent at its maximum transmission rate). The interference effect on GS receivers may not be as severe as for continuous interference transmissions assumed in the RTCA/DO-160 limits [2]. It is desirable to characterize the GS interference threshold subjected to the RFID signal of interest, and to determine whether interference can occur on many existing aircraft.

A follow-up study was performed by Honeywell Inc. [3] to determine analytically the tag's interference risks to GS and other narrowband navigation systems. Simulation of GS signal processing was performed. The results indicated that the effects on a GS system were *probably* negligible on large cargo aircraft.

In addition to referencing the Honeywell Inc. study, it is also desirable to address the compatibility issue with an emphasis on laboratory testing. The testing should include actual RFID signals and real aircraft GS radio receivers. Furthermore, it is advantageous to determine the tag's suitability for a wide variety of aircraft models. These goals are being addressed in this study.

2.1 Objective

The main objectives of this paper are to demonstrate an experimental methodology to characterize aircraft GS radio receiver interference thresholds for a RFID signal, and assess the RFID tag compatibility with the GS system on many aircraft models. In this study, the minimum GS receiver interference threshold is determined. The minimum signal propagation loss to avoid interference is then computed and compared against measured aircraft data. The result of which is used in the compatibility assessment.

2.2 Scope

Discussions in this paper are limited only to measurements and analysis in the GS band. Interference thresholds are determined using one specific RFID signal and one specific GS radio receiver. However, the approach is applicable to other interference signals and radio receivers.

2.3 Approach

Assessment of aircraft radio receiver interference is typically accomplished by addressing the *source – path loss – victim* components of the equation:

$$IPL_{Target} = Emission - Threshold, \quad \text{where} \qquad \text{Eq. (2.3-1)}$$

- "*Emission*" is the maximum RF emission from a device in dBm,
- "*Threshold*" is victim system's interference threshold to the specific interference, in dBm. It is the minimum interference signal level at the receiver's antenna port to cause interference effects,
- "IPL_{Target}", if positive in dB, is the desired minimum signal propagation loss to avoid interference. A negative IPL_{Target} value indicates the emission level is below the *Threshold*, and interference is not possi*ble.*

All three variables in Eq. 2.3-1 are technically functions of frequency, and application of Eq. 2.3-1 should be performed with all variables at the same frequency. However, for a simplified and conservative first order analysis, it is universally acceptable that the band's worst case data be used for the variables. RTCA/DO-199 and DO-294B [4][5] illustrate the analysis processes using the band's worst case data.

In this report, the worst case "*Emission"* and "IPL_{Target}" values are used in Eq. 2.3-1. The "*Emission*" is the maximum value over the GS frequency band reported in Figure 3.1-2. Similarly, the "IPL_{Target}" is the desired minimum IPL value over the same band for all aircraft RFID locations. In contrast, the "*Threshold*" is measured in this study only at the GS band center frequency, and the result is assumed to be valid for the entire band. For a given desired GS signal strength, the "*Threshold*" value correlates with the receiver's performance parameters, which are typically constant across the GS band by design.

A significant part of this report addresses the measurement of *Threshold* value for a GS receiver. Along with the known *Emission* data previously reported in [1] (summarized in Figure 3.1-2), IPL_{Target} is determined from Eq. 2.3-1. Comparing IPL_{Target} with actual aircraft IPL data, interference risk may be assessed.

In determining the *Threshold* values, the process involved simulating the interference signal (in the GS band) for injection into the GS receiver's antenna port. To achieve a high quality signal simulation, the tag's transmission was captured at the fundamental transmission frequency. This process resulted in significant signal-to-noise advantage compared to capturing the spurious emissions directly. This key step was possible since the spurious emissions and the fundamental transmissions were found to have similar modulation characteristics using a spectrum analyzer.

The steps below illustrate the process in determining receiver interference thresholds:

a. Emulation of interference signal burst in GS band:

   - High fidelity capture of RFID tag fundamental transmission

   - Emulate (playback) the same signal in GS band

b. Determine Interference Threshold:

   - Inject into the receiver's antenna port the simulated interference signals and the desired GS signal

   - Determine interference thresholds from receiver's responses by varying interference signal level

c. Apply Eq. (3.2-1) and determine IPL_{Target}

d. IPL_{Target} values are compared against the minimum aircraft IPL data previously reported.

2.4 Report Organization

Section 3 describes the tag's operation characteristics, the signal capturing, and the interference signal emulation in the GS band. Section 4 details the GS receiver test setup. Section 5 explains the selection of the GS signal strength and receiver's interference criteria. Also in this section, the test procedure is described and the interference threshold results are presented. Desired IPL values are computed and compared against actual aircraft IPL data.

3 RFID Signal Simulation in the Glideslope Band

This section describes the details regarding simulating the RFID signal in the GS band. The tags' transmission characteristics are briefly discussed. The information is useful in the signal simulation and results analysis. This section also describes the equipment used in the signal capturing and playback. Comparison of the original and the emulating signals are also shown.

Tags Characteristics

The tag of interest is a RF Code's Mantis motion tag similar to the model illustrated in Figure 3.1-1. This tag activates and transmits when it senses physical motions or vibrations are exerted on it. The fundamental tag transmission frequency is 303.82 MHz with 5 milliwatts (mW) nominal peak power.

In normal operations, the RF Code tag transmits three 113 milliseconds (msec) amplitude-shift-keying (ASK) modulated bursts whenever it senses physical motions. The burst-to-burst interval is 610 msec. There are 37 pulses in each burst for the specific tag considered; however, the number of pulses per burst varies slightly with each individual tag. Each pulse is approximately 0.01 msec in pulse-width.

Figure 3.1-1: A sample of tag used.

When sensing continuous motions, the burst is transmitted continuously at a 610 msec burst-to-burst interval. This is the fastest rate an individual tag can transmit. At this rate, the transmission duty cycle is about 0.06 percent (percent duty cycle = 100 *37 * 0.01 msec / 610 msec). Figure 3.2-3 illustrates a sample burst pattern captured on a spectrum analyzer. The amplitude data are not calibrated.

The tag's peak emission data were previously measured in a reverberation chamber and reported [1]. The data included the measurement results for many aircraft radio bands. The GS band data were measured between 325 MHz and 340 MHz, with the peak spurious emissions being about 35 dB above the RTCA/DO-160 Categories L and M emissions limits [2]. These two categories are appropriate for the expected RFID tag locations such as the passenger cabin or the cargo bays. The limit values used in the comparison are the effective isotropic radiated power, in dBm, computed from the maximum field strength limits. A summary chart is repeated in Figure 3.1-2 in this report.

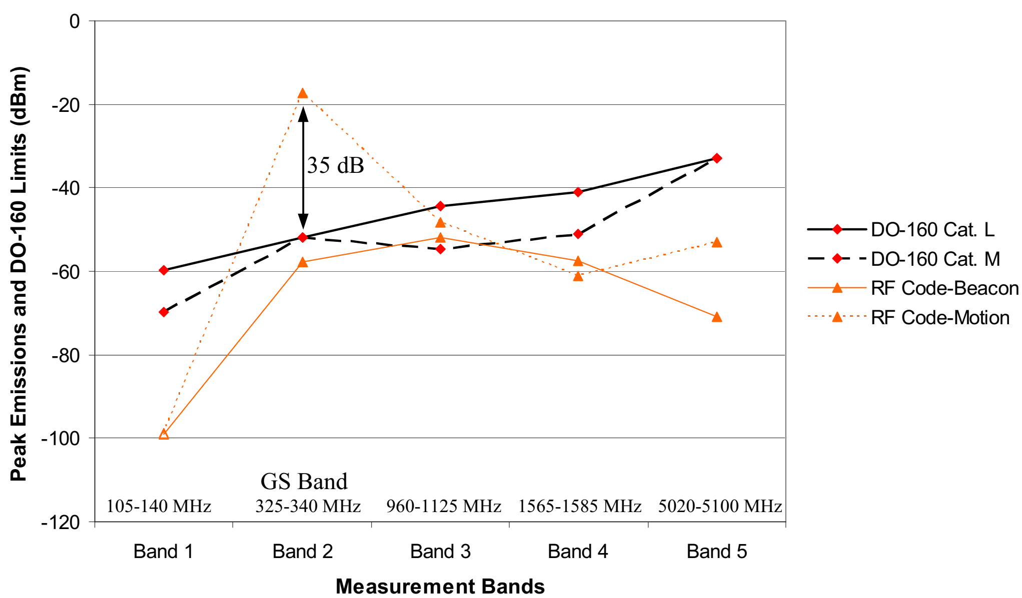


Figure 3.1-2: Tag emissions exceeded RTCA/DO-160 limits by 35 dB in GS band (Band 2) [1].

In DO-160, the Category L is defined for aircraft installed equipment and wiring located far from apertures, such as windows, and from radio receiver's antenna. The Category L may suitable for equipment installed in the electronic bay of an aircraft. The Category M is defined for equipment located in areas where apertures are electromagnetically significant and not directly in view of radio receiver's antenna. The Category M is suitable for locations in the passenger cabin or in the cockpit of a transport aircraft.

Capturing and Emulating Interference Signal

Capturing and emulating the interference signal was performed with a spectrum analyzer, a RF vector signal generator (VSG), and data format conversion software utilities. The spectrum analyzer was capable of performing vector measurements and recording the in-phase (I) and quadrature (Q) baseband components, or IQ data. From the IQ data, the VSG could regenerate the signal either at the original frequency or at any frequency within its operating range. Software utilities were necessary to convert the captured binary IQ data to a format suitable for the VSG. The basic setup is illustrated in Figure 3.2-1.

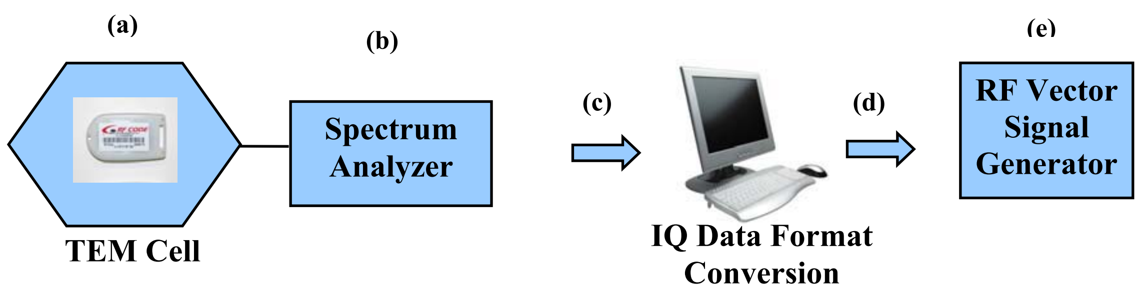


Figure 3.2-1: Setup for capturing and emulating interference signal.

Elements of the Figure 3.2-1 are described below

(a) Transverse ElectroMagnetic (TEM) cell as a shielded enclosure with the RFID tag inside for the signal capturing

(b) Tektronix RSA3408A Real-Time Spectrum Analyzer with IQ data output saved to file

(c) Binary-IQ to text conversion via a Tektronix's software utility

(d) Text to binary-IQ conversion and upload via Rohde & Schwarz's software utilities

(e) Rohde & Schwarz SMU200A VSG

In the illustration, the TEM cell served mainly as a shielded enclosure for isolation from ambient noises or transmissions from other nearby tags. It conveniently had coaxial outputs for connection with the spectrum analyzer. No other antenna was needed. The TEM cell was selected to have the upper frequency range sufficiently high to include the tag's operating frequency. Inside the TEM cell, the RFID tag was oriented to maximize the measured signal strength, thereby maximizing the measurement signal-to-noise ratio. Since the VSG could faithfully reproduce both the captured signal and the noise floor, a high signal-to-noise ratio was necessary for a high quality emulating signal. Figure 3.2-2 illustrates the (a) and (b) blocks of the Figure 3.2-1.

For an accurate emulation of the interference signal, it was desirable to capture the spurious emissions in the GS band. However, it was elected that the signal capture be made on the fundamental transmission, while the playback is made at the test frequency in the GS band as previously discussed. Using a spectrum analyzer, the fundamental transmissions were observed to have similar modulation characteristics as the spurious emissions, but were much stronger. Capturing the fundamental transmissions would result in much better quality signal. After the signal capture and baseband conversion, the signal could be played back at any frequency of interest within the capability of the VSG.

The spectrum analyzer settings included time domain capture with a 115.2 msec duration and an equivalent of 2 MHz resolution bandwidth (RBW). An external preamplifier was used to increase signal-to-noise level. A gentle tap on the TEM cell was sufficient to trigger the tag located inside. The spectrum analyzer triggered upon receiving a signal, and the data were saved to a file in a binary IQ format. A laptop computer downloaded the data for processing.

The IQ data produced by the Tektronix RSA 3408A spectrum analyzer were in a special binary format that could not be used directly by the Rohde & Schwarz SMU200A VSG. Thus, data conversions were necessary. Both equipment manufacturers provided the necessary utilities to perform data conversion between binary, text and several other formats. For this study, only the binary and text data conversion were utilized. The data were first converted to text format and edited to remove manufacturer specific header information. The data were then converted to another binary format and uploaded to the VSG. The specific utilities used include Tektronix's IQT-to-Text and Rohde & Schwarz's IQ-Wizard.

After the IQ data were uploaded to the VSG, the captured signal could be emulated. Figure 3.2-3 illustrates the comparison of the original signal burst captured and the playback burst. Figure 3.2-3 (i) shows the original signal burst captured at 303.8 MHz at location (b) in Figure 3.2-1. Figure 3.2-3 (ii) shows the emulation at the VSG's output (e), this time at the 334.25 MHz GS test frequency.

The comparison shows the signals were nearly identical, indicating the original signal was faithfully reproduced. There were differences in the signal amplitudes; however, this was not an issue since the interference signal strength was to be adjusted during the testing. The same signal could also be played back in other aircraft radio bands for future testing if so desired.

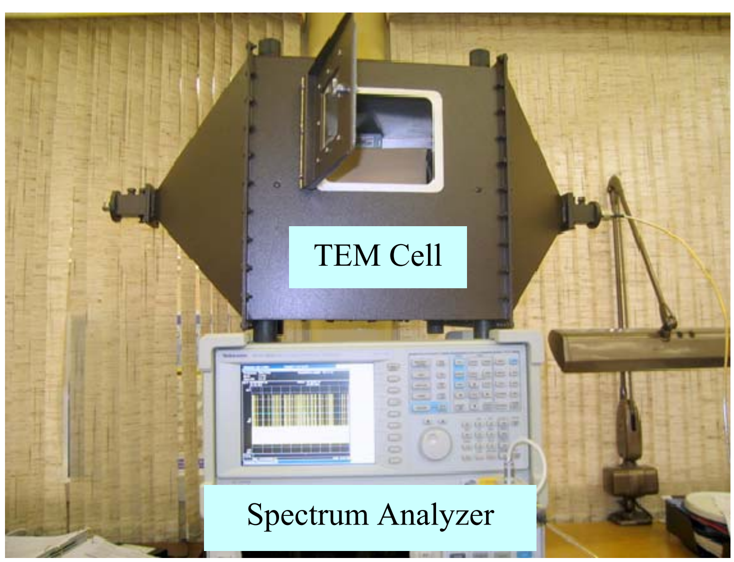
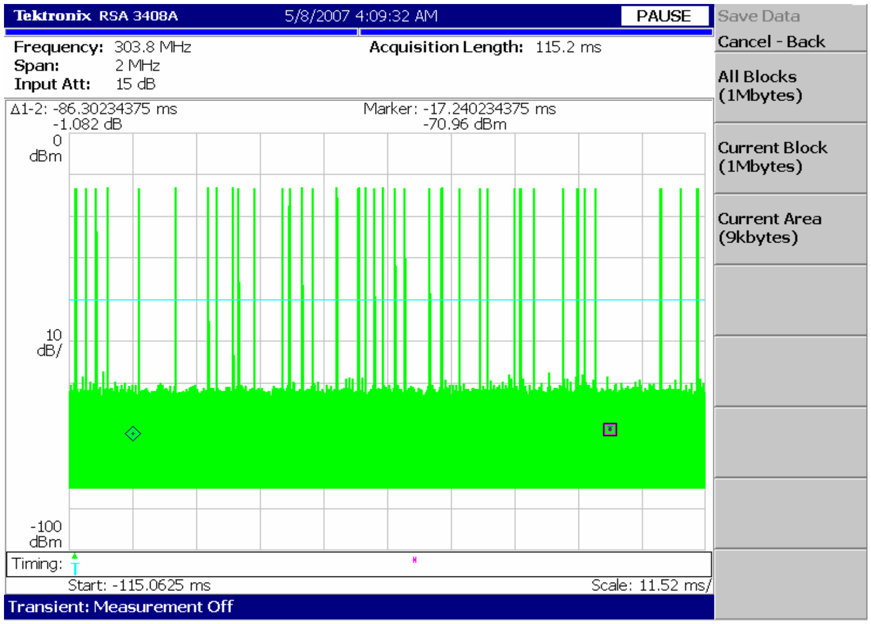
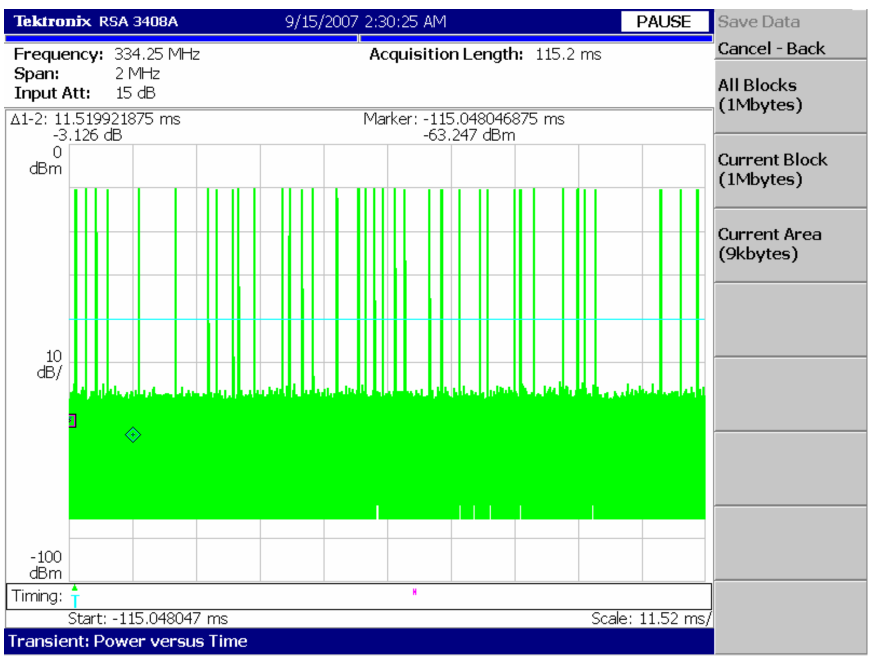


Figure 3.2-2: Capturing RFID signal with tag in the TEM cell.



(i) Original burst at 303.8 MHz center frequency



(ii) Emulated burst at 334.25 MHz test frequency

Figure 3.2-3: Emulated RFID burst at the GS band test frequency (ii) versus the original RFID burst (i).

4 Receiver Interference Test Setup

The setup includes three major groups: (1) equipment for generating interference signal, (2) equipment to generate desired GS signal, and (3) the victim GS receiver and test set. Figure 4-1 illustrates the setup, with the laboratory setup shown in Figure 4-2. As shown, both the interference signal and the GS signal are combined and injected into the GS receiver's antenna port, whose responses would help determine the interference threshold.

An interference threshold is defined as the minimum interference power level required for interference conditions on the GS receiver and its displays. This threshold varies with the desired GS signal strengths, the interference signal characteristics and the interference conditions chosen. These parameters are also described in a later section, along with additional details on the test setup.

For simplicity, this laboratory setup neglects any background noise that may exist at the GS receiver's antenna port. A high background noise level on the GS channel could increase the total interference power and have added effects on the interference thresholds. Due to strict aeronautical spectrum protections, high noise levels in the GS band are not expected to be a concern. The test results should be generally applicable.

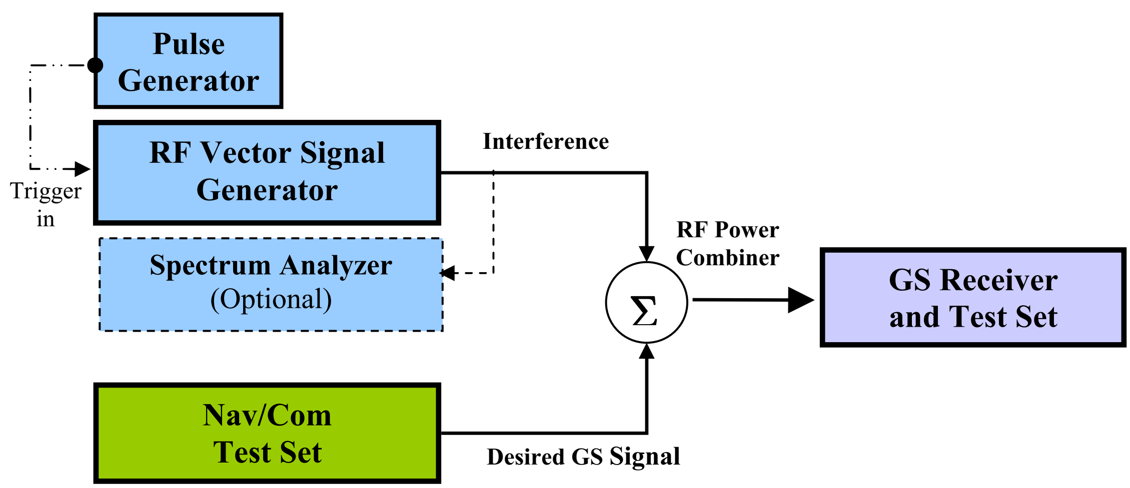


Figure 4.1: Interference test setup.

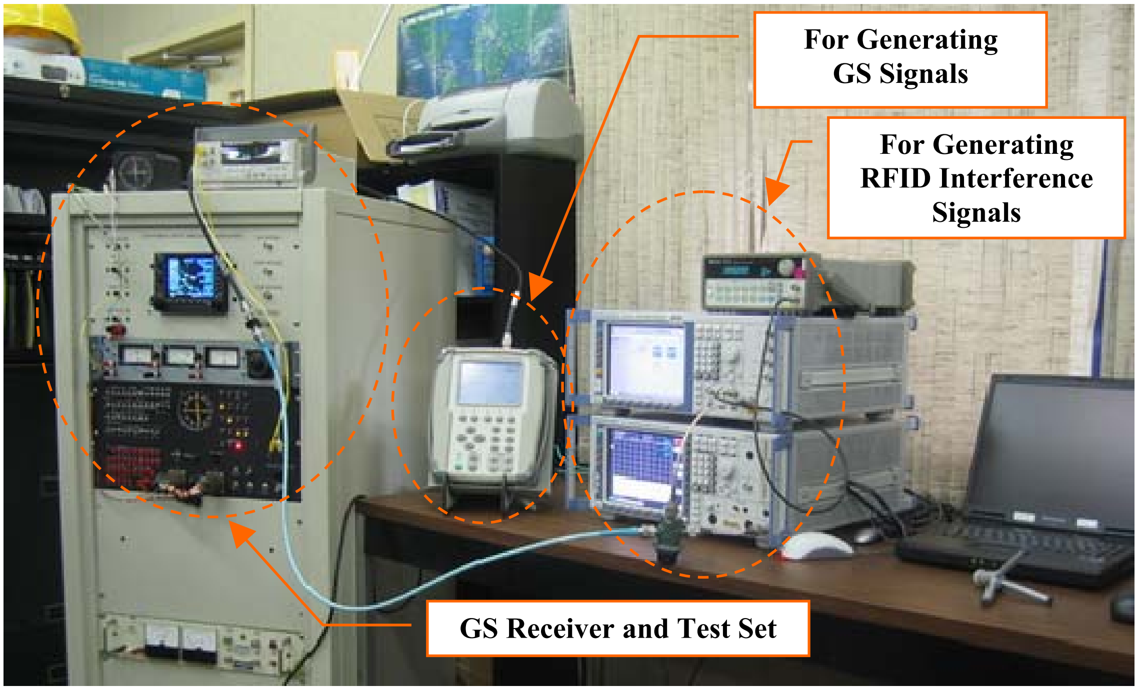


Figure 4.2: Receiver interference test set up.

4.1 Glideslope and RFID Interference Signals Generation

Figure 4.1-1 illustrates key elements for producing the GS and the RFID interference signals. The GS signal was produced using an Aeroflex IFR 4000 Nav/Com ramp test set, with the GS frequency channel set in the middle of the GS band at 334.250 MHz. Output power on the IFR 4000 could be adjusted in 0.5 dB resolution. Instead of relying on the IFR 4000's display, the GS signal output level was set using the spectrum analyzer for better accuracy.

The interference signal in the GS band was emulated using the RF VSG. The signal's peak was set to align with the center of the GS test channel. By varying the output power, GS receiver interference threshold can be determined after accounting for cable loss between the VSG and the GS receiver.

The RFID burst interval was a test variable and subjected to be changed during the testing. The burst interval was controlled via trigger signals from a Hewlett Packard 33120A general-purpose function generator. An optional spectrum analyzer was used to provide signal confirmation before each test.

It was not necessary to perform frequency sweeps with the interference signal. The RFID burst had a relatively wide bandwidth compared to the GS sidebands. The 1-dB signal bandwidth (bandwidth for one dB amplitude reduction) was approximately 75 kHz, which was much wider than the interference-sensitive 90 Hz and 150 Hz GS sidebands. Rather, a single interference signal frequency was used, with the signal's peak centered on the GS channel at 334.250 MHz. Appendix A shows the interference signal bandwidth and its 75 kHz 1-dB bandwidth.

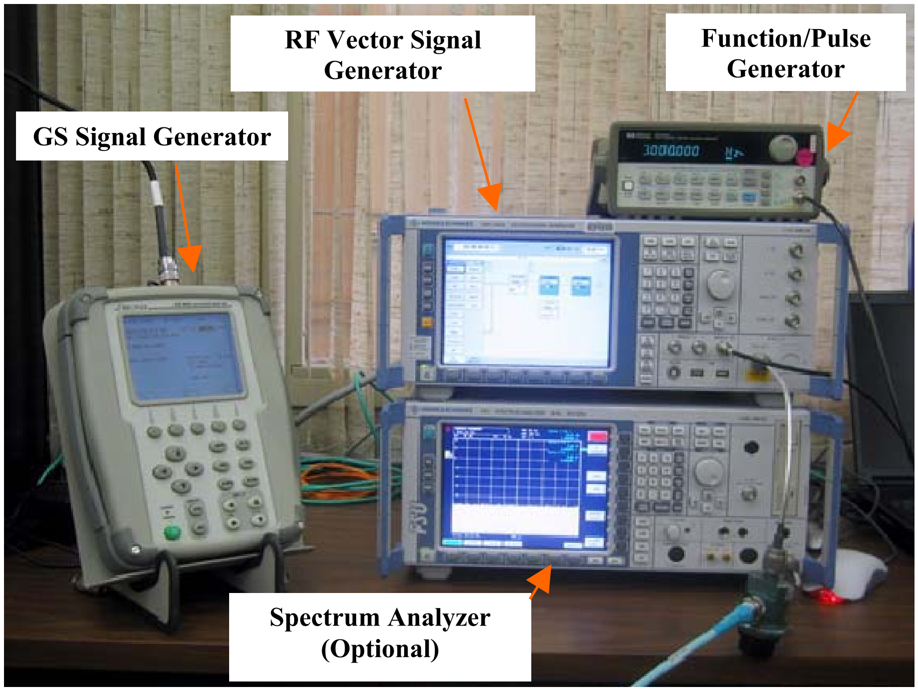


Figure 4.1-1: Desired GS signal and interference signal generators

4.2 Glideslope Receiver and Test Set

The GS receiver used in the test was a Garmin GNS 530 model. This model could also perform many other navigation and communication functions; however, only the GS functions were utilized in this study.

The interference and the GS signals were combined and fed into the receiver's GS antenna input port. This port was connected via a 1-meter RG-400 coaxial cable (hidden) to the test rack's front panel connector labeled in Figure 4.1-2.

The GS receiver interfaces with a test panel that is coupled with an ASI-190B Universal Precision Track Selector and Indicator. The latter provides indicators for monitoring GS flag and course deviation current. In addition, an external course deviation indicator (CDI) and a digital voltmeter were also used to provide additional flag and course deviation monitor functions. They were connected to the ASI-190B test set via front panel connectors.

For the testing, the GNS 530 unit was used for setting the GS frequency channel and to provide an interface for the GS and interference signals. Interference conditions and parameters were monitored via the ASI-190B test set, the CDI and the voltmeter. For simplicity, the three instruments together are referred to as the GS receiver test set in this document.

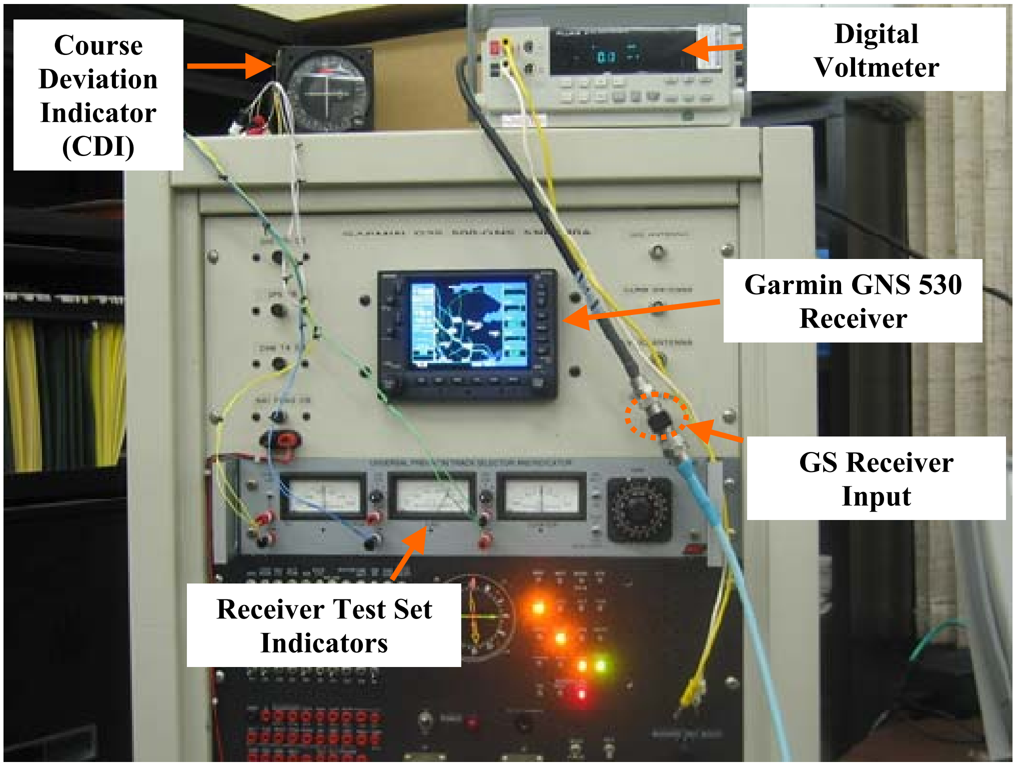


Figure 4.2-1: GS receiver and GS test set.

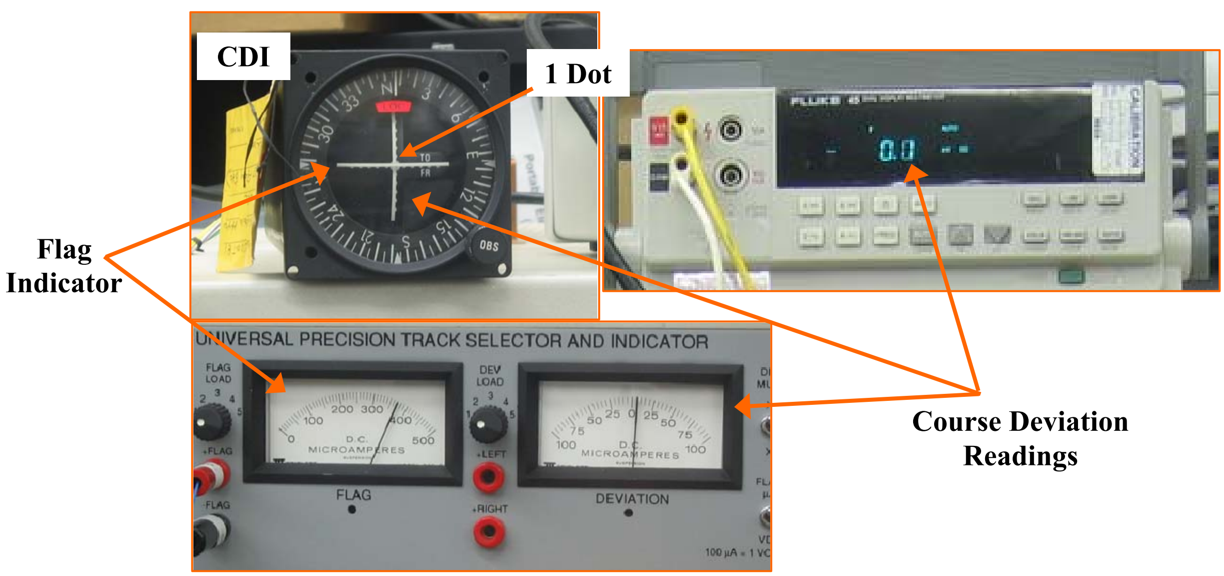


Figure 4.2-2: GS test set indicators for monitoring interference conditions.

5 Interference Threshold Determination

Interference threshold determination involves fixing the GS signal frequency and power while varying the interference signal power and burst interval. With the receiver receiving a valid GS signal, the interference power is slowly increased until an interference condition on the GS test set is observed. The threshold is the minimum interference signal power measured at the receiver. The process is repeated for another burst interval.

For any specific GS receiver, the threshold is a function of the GS signal strength, the interference criteria and signal characteristics. These factors and all their possible values in combination can result in an impractically large test.

In this report, the thresholds were determined for only two GS signal levels and two interference criteria. The signal characteristics were changed by varying the RFID burst interval. This selection resulted in four sets of tests, each with the burst interval being the test variable. Varying the burst interval was accomplished by varying the trigger interval to the VSG. The VSG in turn produced an interference signal burst with each trigger signal.

During the testing, the interference signal power level was adjusted to determine the interference thresholds. In some cases, the interference power was also reduced to determine the threshold at which the GS receiver recovered from interference. The two thresholds were not necessarily the same for a given burst interval, as shown in the test results in Section 5.4.

5.1 Glideslope Signal Level

GS signal strength was known to have a significant impact on the receiver interference threshold. Two GS signal levels were chosen in this study: one computed from the minimum field strength in the GS coverage airspace, and the other being slightly higher than the minimum receiver sensitivity.

In the testing reported in RTCA/DO-199 [4], the GS signal level selected was computed from the 400 microvolts per meter (μV/m) minimum aircraft external field strength in the GS coverage airspace. This field strength was specified at the GS airspace's *outer limit of coverage* (OLC) in an International Civil Aviation Organization (ICAO) document [6]. The resulting power level at the receiver was computed by assuming isotropic aircraft antenna gain and two dB of cable loss. The resulting GS signal level was -78 dBm at the receiver's antenna port. For this study, the same GS test signal level, denoted as $GS_{ICAO/OLC}$, was chosen as one of the two GS test signal levels.

In addition, many GS receiver models can be much more sensitive than required for the airspace and can properly decode a GS signal far outside the ICAO/OLC. Interference that occurs outside of the OLC is also often considered unacceptable, as it can impact the pilots' confidence in the system. Therefore, testing with the GS signal being near the receiver's sensitivity thresholds is also desirable.

The second GS signal level was chosen to be 3 dB above the receiver's sensitivity level. This 3 dB was to avoid marginal GS signal strength that could result in confusing interference conditions even without an interference signal. By slowly increasing the GS signal until the receiver showed a valid GS signal flag, the receiver sensitivity was determined to be -95.5 dBm. The test GS signal was set 3 dB higher, or -92.5 dBm, and is denoted as "$GS_{3dB > Sensitivity}$". Both $GS_{ICAO/OLC}$ and $GS_{3dB>Sensitivity}$ signal strengths were set with the help of a spectrum analyzer having 100 kHz RBW. This bandwidth was chosen to match the RBW used in measuring the tag's emissions [1] so to have a common amplitude reference. It was also wide enough to cover the majority the signal's spectrum.

Only one GS frequency channel was selected. It was chosen to be at middle of the GS band at 334.25 MHz. Both the desired GS signal and the interference signal were set to peak at this frequency.

5.2 Interference Criteria

DO-199 recommended two interference criteria: Flag Condition on the CDI and 7.5 microampere (μA) course deviation error. The CDI shows an invalid GS signal flag by default when not receiving a valid signal. With a valid GS signal, the GS flag disappears on the CDI. When interfered, the flag re-appeared as if the GS equipment was not receiving a valid GS signal. This interference situation is therefore termed as *flag condition*. In addition to the CDI, the flag condition can be monitored using indicators on the receiver test-set.

Deviation from GS course guidance is termed *course deviation error*. When the aircraft deviates from its intended glide-path, or if the GS receiver is interfered, the markers on the CDI should show deflections. The deflections are measured on the receiver test set in microamperes (μA). Ideally, there should be a 0 μA course deviation error. A 25 μA course deviation error is equivalent to 1-Dot deflection shown in Figure 4.2-2.

It was observed from an operation viewpoint in this study that a 7.5 μA course deviation error was too small to concern the pilot or to affect the flight. This is especially true with the aircraft being far from the airport and near the edge of GS coverage airspace or farther. As the aircraft gets closer to the airport, course deviation error becomes increasingly critical. However, the desired GS signal strength also increases significantly, and it becomes much more difficult to cause interference. Interference threshold increases as a result.

For this study, a 25 μA course deviation error is selected as the interference criteria instead of the 7.5 μA criteria. This level conveniently correlates with 1-Dot deflection on the CDI and is considered reasonable for aircraft distance near the GS OLC. For comparison, a 150 μA error represents full-scale deflection, which corresponds to approximately a 0.7 degree deviation from the GS glide-path. A GS receiver is allowed up to a 10 μA centering error when a standard GS signal is applied. Additional information on performance standards for GS equipment can be found in RTCA/DO-192 [7].

In addition to the CDI, a digital voltmeter and an analog meter on the receiver test set were used in monitoring the 25 μA course deviation error criteria during tests. The equipment used is shown in Figure 4.2-2.

5.3 Test Procedure

As previously noted, there were four groups of tests involving combinations of the two GS signal levels and the two interference conditions. The GS signal levels included ICAO/OLC level (-78 dBm), and at 3dB greater than the receiver's sensitivity (-92.5 dBm). For each GS signal level, the interference thresholds were determined for flag condition and for 25 μA course deviation error. Since it was found that the thresholds to cause and to recover from a flag condition could be different, two thresholds were determined for the flag condition tests.

The RFID signal burst rate was the independent variable in each test group. At each burst rate, the test involved:

1. For the flag condition:

    a. Increasing interference power until an interference condition was noted.

    b. Decreasing interference power until the interference condition was removed.

2. For the 25 μA course deviation condition:

    Varying interference power until the peak course deviation current reaches 25 μA. CDI deflection behaviors were noted.

For flag conditions, the chosen RFID burst rates included 9, 8.7, 8, 7, 6, 5, 4, 3, 2, 1.639, 1, 0.5, 0.2, and 0.1 Hz. These rates were selected to provide reasonable representations of the result trends. The 8.7 Hz burst rate corresponded to a 115 msec burst interval, representing nearly continuous burst transmissions with little delay between any two adjacent bursts (the bursts overlap slightly at 9 Hz burst rate). 1.639 Hz equated to a 610 msec burst interval, the fastest a tag under continuous motions could transmit. The rates were converted to burst intervals (in seconds) for plotting results.

For the 25 μA course deviation error criteria, the threshold was found to be highly sensitive to the burst rate; thus, a finer burst rate increment was needed. Either 0.1 Hz or 0.2 Hz step was chosen depending on whether significant change was observed.

5.4 Interference Threshold Results

In addition to the GS signal strengths $GS_{ICAO/OLC}$ (-78 dBm) and $GS_{3dB>Sensitivity}$ (-92.5 dBm) previously defined, the following acronyms are used to denote the interference thresholds in the charts presented in this section:

- T_{Flag}: Interference threshold to cause flag condition ("T_Flag" in charts),

- T_{noFlag}: Interference threshold below which the system recovers from flag interference ("T_noFlag" in charts),

- $T_{25\mu A}$: Interference threshold for 25 μA course deviation error ("T_25uA" in charts).

For the $T_{25\mu A}$, three markers in the test result plots denote the behaviors of the CDI display during test. They include CDI display being "Steady", "Oscillatory", or "Pulsing". "Steady" indicates that the deflections on the CDI were erroneously stable. This is a highly undesirable condition as the aircraft pilot may interpret and correct for the faulty readings.

When the CDI display oscillated relative to a reference position, the behavior was labeled on the plots as "CDI Display Oscillatory". The oscillation speed was found to vary significantly with changes in the RFID burst rates. In addition, when the receiver was interfered-with at very low burst rates, the CDI marker showed momentary deflections. This behavior was labeled as "CDI Display Pulsing" in the plots. Both forms of interference could be easily detected by the pilot.

For the flag condition, thresholds were also found to fluctuate in time. Five different test runs were performed, and the average of the results is shown with the individual data.

Figures 5.4-1 and 5.4-2 show the T_{Flag}, T_{noFlag}, and $T_{25\mu A}$ for GS signal level at the edge of airspace coverage ($GS_{ICAO/OLC}$). Figure 5.4-1 shows the average and the individual results of the five flag condition test runs. Solid and hollow markers indicate individual T_{Flag}, T_{noFlag} data, respectively. The flag condition average data trace is compared against $T_{25\mu A}$ in Figure 5.4-2.

Similarly, Figure 5.4-3 and 5.4-4 show the T_{Flag}, T_{noFlag}, and $T_{25\mu A}$ interference threshold for the GS signal level near the receiver's sensitivity ($GS_{3dB>Sensitivity}$). Figure 5.4-3 shows the individual flag condition test results and the average data. Solid and hollow markers indicate individual T_{Flag}, T_{noFlag} data, respectively. The average data trace is compared against $T_{25\mu A}$ in Figure 5.4-4.

For comparison, the -17.2 dBm tag's peak spurious emissions level is also plotted for one tag having 610 msec or longer burst interval. The data are shown as a flat line at -17.2 dBm. IPL_{Target} values, defined in Equation 2.3-1, are computed and illustrated in Figures 5.4-1 to 5.4-4. These values must be lower than aircraft IPL to avoid potential for interference.

Course deviation error is a concern only if the thresholds are below that for the flag condition. Otherwise, the pilot could recognize the flag condition and simply ignore the deflection error. A highly undesirable condition is having a stable CDI display without a flag warning. The test results having this condition are highlighted in Figures 5.4-2 and 5.4-4.

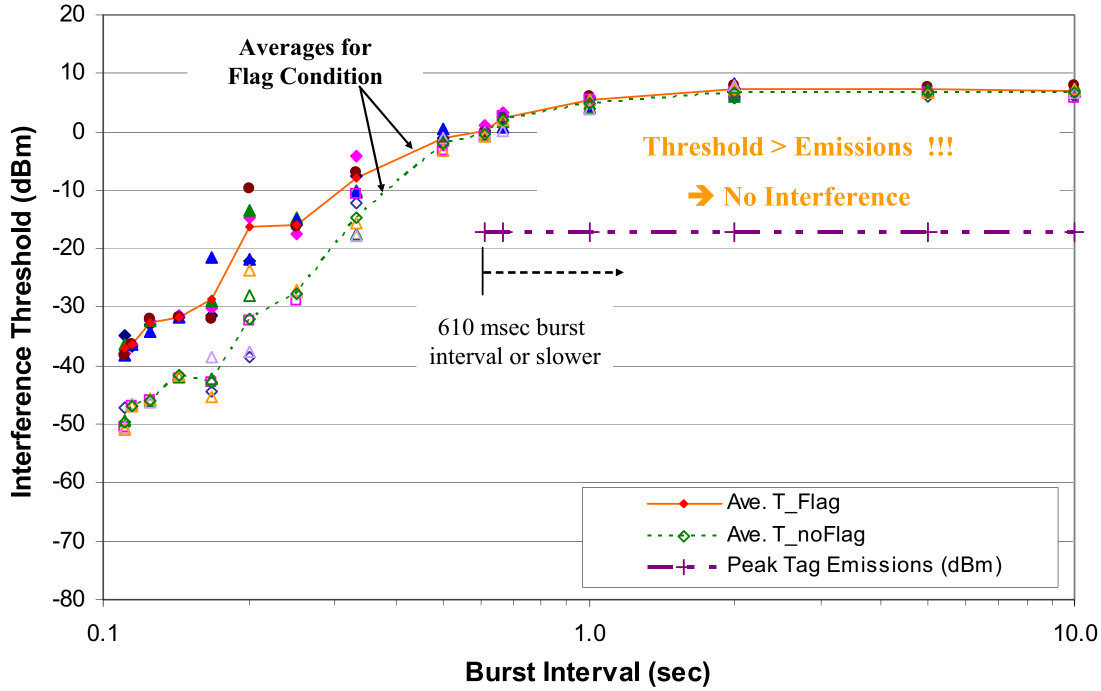


Figure 5.4-1: Individual and average flag condition interference thresholds. GS signal at ICAO/OLC level. Solid markers: individual T_{Flag}. Hollow markers: individual T_{noFlag}.

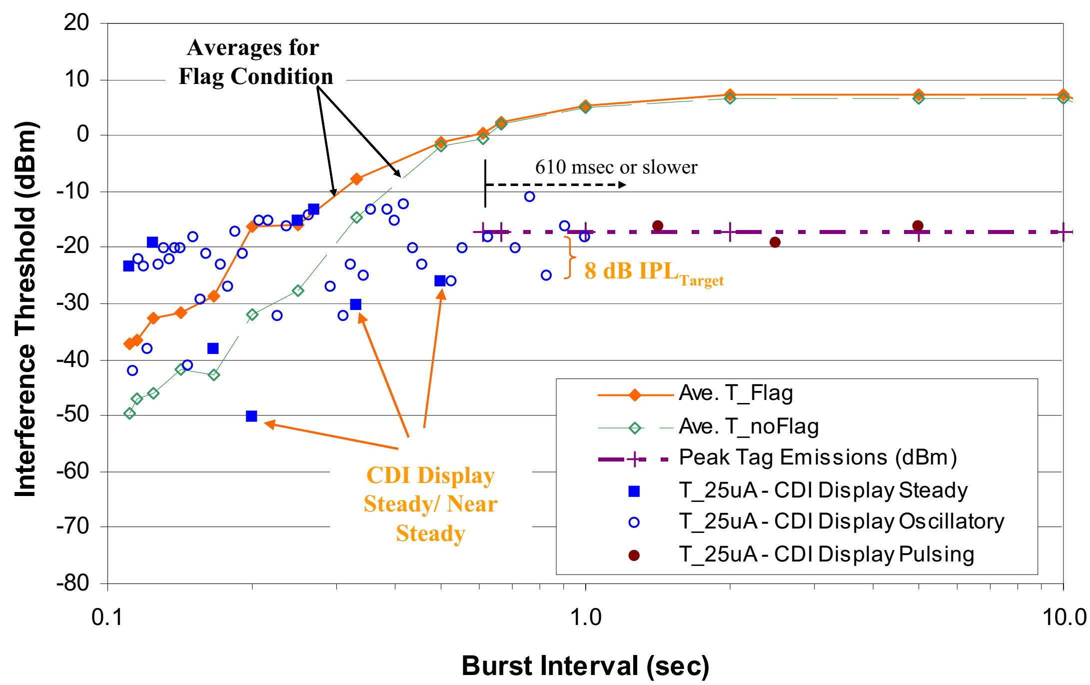


Figure 5.4-2: Interference thresholds for 25 µA course deviation error. GS signal at ICAO/OLC level.

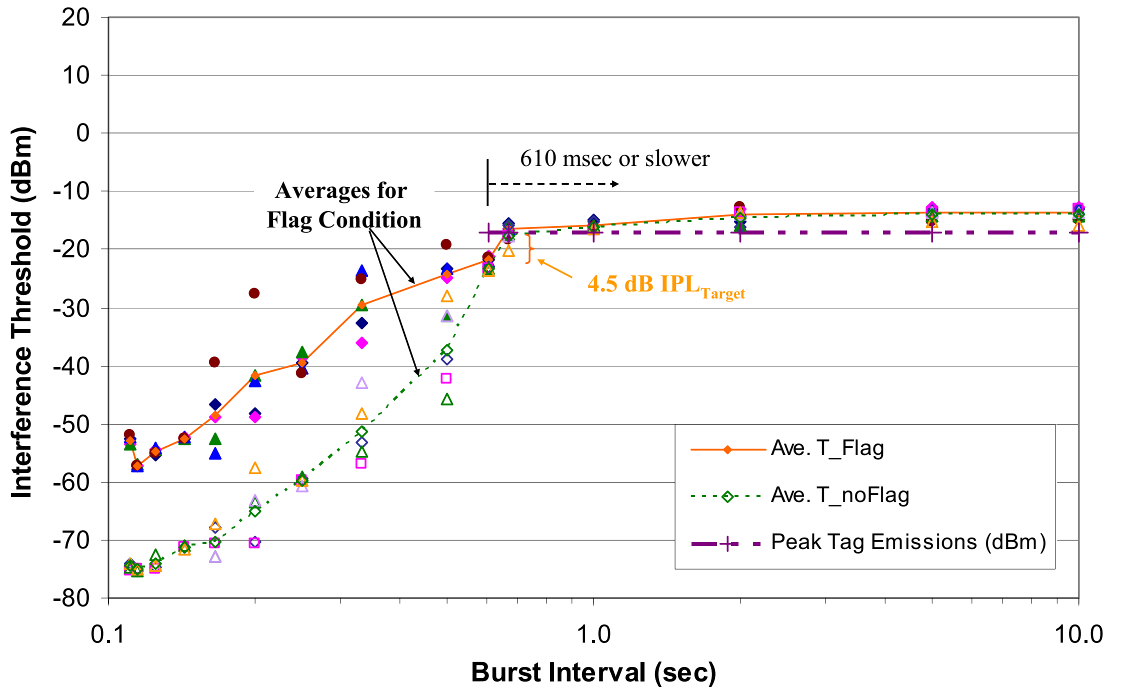


Figure 5.4-3: Individual and average flag condition interference thresholds. GS signal at 3 dB above receiver sensitivity. Solid markers: individual T_{Flag}. Hollow markers: individual T_{noFlag}.

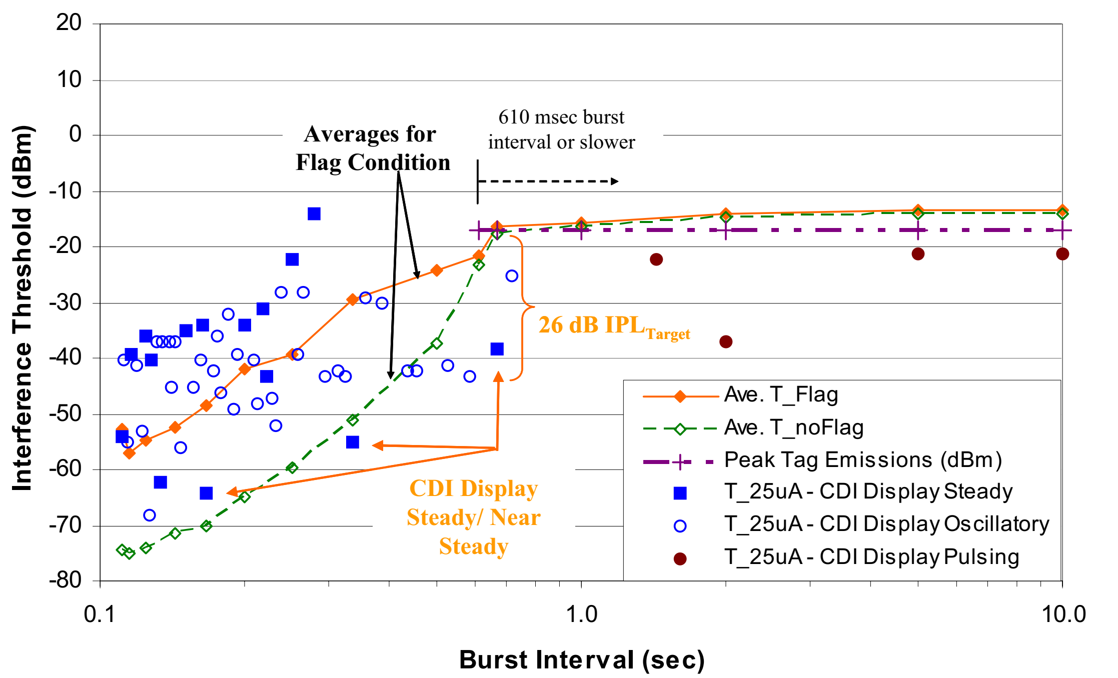


Figure 5.4-4: Interference thresholds for a 25 µA course deviation error. GS signal level at 3 dB above receiver sensitivity.

5.5 Data Summary, Analysis and Observations

With the GS signal at the ICAO/OLC level, Figure 5.4-1 shows there should be little concern of flag condition interference from one tag. The interference threshold level is greater than the -17.2 dBm emission level for a 610 msec burst interval or longer. For the 25 µA course deviation condition, the IPL_{Target} is shown to be 8 dB. Thus, an aircraft should have an 8 dB minimum IPL or more to avoid potential interference.

With the GS signal at 3 dB above the receiver sensitivity level, the IPL_{Target} is 4.5 dB for a flag condition, and 26 dB for a 25 µA course deviation error. Again, these values are for a single RFID tag having 610 msec burst interval or longer.

The Table 5.5-1 summarizes the IPL_{Target} results. Interference from a single tag is highly unlikely if the aircraft has greater than 26 dB minimum IPL value at installation locations. The results should also be valid in case a single tag dominates the interference power at the receiver.

Table 5.5-1: Minimum IPL to Avoid Potential Interference (or IPL_{Target})

GS Signal Level at	Flag Interference Condition	Course Deviation Interference Condition
ICAO/OLC	No Interference	+8 dB
3 dB > Receiver Sensitivity	+4.5 dB	+26 dB

Several observations were made from the measurements and the results:

- Thresholds to cause and to recover from flag interferences are different for burst intervals of approximately 0.5 second or less (faster rate).
- Flag condition thresholds can vary over time by as much as 22 dB for a few burst rates. This was observed by comparing the results for five separate measurements in Figures 5.4-1 and 5.4-3.
- The course deviation error threshold is highly sensitive to RFID burst rate. A 0.1 Hz change can result in 20-30 dB change in the threshold value.
- Certain burst rates can result in erroneous steady course deviations. This condition is highly undesirable.

The results for burst intervals shorter than 610 msec may be useful for assessing the effects of multiple tags. As an illustration, two tags having similar interference powers at the receiver are crudely approximated as one tag having a 305 msec burst interval (610 msec ÷ 2). From the Figure 5.4-4 for the GS signal at 3 dB above receiver sensitivity, the worst case course deviation error threshold is approximately -55 dBm. The resulting IPL_{Target} is about 38 dB (subtracting -55 dBm from -17.2 dBm).

Similarly, four tags having similar interference powers at the receiver can be approximated as one tag having about 150 msec burst interval. This approximation results in about -65 dBm interference threshold, and 48 dB IPL_{Target}. The 48 dB IPL_{Target} value approaches the measured passenger cabin minimum IPL reported in the next section for several large aircraft and is undesirable. Keeping the IPL_{Target} below the measured IPL circumvent potential for interference. Similar estimations can be performed for the flag interference condition and for different numbers of tags. The Figure 5.4-2 may be used for the GS signal power at the ICAO/OLC level.

It is apparent that for multiple tags, the effects on the interference threshold (and the resulting IPL_{Target}) are much more prominent from the reduced burst interval than from the increased interference power. Using the above illustration as an example, reducing the burst interval increases the IPL_{Target} by 12 dB (38 dB – 26 dB) for two tags and by 22 dB (48 dB – 26 dB) for four tags. In contrast, interference power summing would increase the IPL_{Target} by only 3 dB for two tags and 6 dB for four tags. In addition, due to the very low transmission duty factor, the probability is very low for the interference pulses to align in time for the power summing. As the result, it may not be appropriate to account for multiple tags by simply summing the interference powers at the receiver. The effects on the receiver interference threshold from the reduced burst interval should be considered.

5.6 Aircraft Interference Path Loss Comparison

It is desirable to compare the determined minimum IPL_{Target} against actual aircraft minimum IPLs to determine if interference should be a concern. Aircraft minimum IPL is the minimum propagation loss between tag installation locations and the receiver's antenna port.

The measurement of aircraft IPL typically includes transmitting from multiple locations of interest, and the coupled powers are measured at the GS receiver's antenna cable. An IPL value is determined by normalizing the receive power against the transmit power. RTCA/DO-294B [5] and DO-307 [8] provide additional guidance on the IPL measurement process. A dipole antenna is desirable as a standard transmitter; however, different antennas are often used for practical reasons. Past IPL results were often inconsistently calibrated and reported in this aspect.

Cargo-bay data are of interest since tracking cargos and containers are among many initial aircraft RFID applications. The measurements and results of cargo-bay IPLs for a Boeing 747 and an Airbus A320 aircraft models are reported in [1]. The worse case (minimum) GS band IPL data of the two cargo bays for each model are reported in the Table 5.6-1 below.

In addition, Table 5.6-1 provides the minimum passenger cabin IPL data for several large aircraft models [4][9]. Since the data came from different sources, inconsistencies with respect to transmit antenna gain normalization should be expected, but should not be greater than about 5 dB. In a few cases where data were available for multiple similar aircraft model, the results are listed in table 5.4-1as a range rather than the individual values.

Table 5.6-1 shows that the minimum GS band IPL data are greater than the 26 dB IPL_{Target} for all aircraft models. The lowest IPL value in the table, 46 dB, provides at least a 20 dB safety margin. Interference to the GS receiver is therefore not expected from a single tag in the passenger cabins or cargo bays for the aircraft listed.

Table 5.6-2 summarizes the GS band minimum IPL for smaller, general aviation aircraft. These data were measured with the transmit antenna scanned over the entire aircraft volumes, including cockpit areas. Data were normalized to have the effect of a dipole transmit antenna. The minimum value in the table is 34 dB, providing at least an 8 dB safety margin over the 26 dB IPL_{Target}. Data in the Table 5.6-2 came from [10] but were corrected for a small 2.06 dB calibration error. The error, applies specifically to GS band data only, was discovered and corrected by the original authors after the report publication.

Table 5.6-1: Measured Aircraft Minimum IPL (dB) for GS band

Cargo Bay	
Boeing 747	59
Airbus A320	70
Passenger Cabin	
Boeing 747	49 - 53
Boeing 757	58 - 59
Boeing 737	59 - 61
Boeing 727	68
Airbus A320	56-64
Bombardier CRJ	52
Embraer EMB-120	46

Table 5.6-2: General Aviation Aircraft Minimum IPL for GS band (data in dB)

Aircraft	**Minimum IPL**
Cirrus SR-22	39.3
Cessna 172R	34.2
LearJet 35A	36.2
Sabreliner 65	44.6
Citation II	39.0
Baron B-58	41.6
Piper Saratoga	44.3
Gulfstream GII	50.1
King Air 200	38.2

5.7 Application to Other Glideslope Receivers

The determined GS receiver interference threshold data are applicable specifically to the GNS 530 model. It is of interest to determine the applicability to other GS receivers without repeating the testing on the large number of receivers.

It is known that the basic GS receiver design has long been stable and shares similarity across multiple platforms and manufacturers. It is believed that GS receivers would have similar interference thresholds if they had similar sensitivity. Table 5.7-1 provides data for comparing sensitivities between different receivers. They were previously reported in [11] with the exception of the Garmin GNS 530 model. Most data shown are the nominal values.

Comparing the sensitivity data, the GNS 530 model is more sensitive than most of the remaining models. Thus, it can be interpreted that the threshold data for the GNS 530 model are more conservative than for most other receivers, especially for the case of the GS signal strength being close to the receiver's sensitivity.

Analysis in DO-199 [4] for continuous-wave interference signals implies that, given the same interference criteria, the interference threshold level varies proportionally with the GS signal strength so that the signal-to-interference ratio remains nearly constant. Similarly, and for noise-like pulsed interference, [3, Eq. 13] shows the interference-to-carrier power ratio is constant given the same interference criteria and signal characteristics.

These findings are valid specifically for the Garmin GNS 530 model. However, it is a reasonable extrapolation to apply the findings to other GS receivers with a similar basic design but with different receiver sensitivities. With the basic design fixed, differences in receiver sensitivities mainly come from different signal amplifications. Thus, if the GS carrier signal level is adjusted to a different receiver sensitivity level, the interference threshold should be adjusted in a similar fashion so that the interference-to-carrier ratio is maintained. As an illustration, a receiver model having a 10 dB higher receiver sensitivity level than the Garmin GNS 530 model is expected to have about 10 dB higher interference thresholds if both models were tested near their respective receiver sensitivities.

Table 5.7-1: GS receivers' sensitivity thresholds (in dBm)

GS Model	Sensitivity
Rockwell Collins	
ILS-700, -700A	-99
ILS-720	-89
ILS-900	-96
GLU-9xx	-89
GNLU-9xx	-89
Honeywell/Allied/Bendix King	
RNA-34A	-87
KNR-6030	-93
RIA-35A, -35B	-87
KN 35	-91.4 (typical) -87 (maximum)
Garmin	
GNS 530	-95.5 *

* Measured in this study

6 Conclusions

An approach to show compatibility of an RFID tag with an aircraft GS receiver was demonstrated. The tag used was previously shown to have the peak spurious emissions in the GS band far exceeding the RTCA/DO-160 standard emission limits for aircraft equipment. The testing approach included simulating the spurious emissions using a vector signal generator and determining receiver interference thresholds using the simulated signals. The minimum desirable IPL values were then computed and compared against several aircraft's measured IPL data for cargo bay and passenger cabin locations.

For a single tag, the result comparison showed at least 20 dB of safety margin for a group of large aircraft. The large margin indicated that a single tag was highly unlikely to cause interference to a GS receiver if installed in the aircraft and the locations listed. The margin was only 8 dB for general aviation aircraft. In addition, the receiver used was more sensitive than most other models surveyed, indicating that the margins were rather conservative.

The interference thresholds to cause and to recover from flag conditions were found to be different for a 0.5 second burst interval or faster. The same thresholds could vary by as much as 22 dB over time. For course deviation error, the threshold was highly sensitive to the RFID burst interval. In addition, certain burst intervals could result in highly undesirable stable and erroneous displays.

The results also provide a means to determine the effects of having multiple tags contributing equally at the receiver. It is observed that the interference thresholds are affected significantly greater from the reduced burst intervals than from the increased in the interference power. With the GS signal power near the GS receiver's sensitivity, a simple illustration shows that as few as four tags can result in the desired IPL approaching the measured passenger cabin IPL for a few large aircraft.

7 References

[1] T. X. Nguyen, J. J. Ely, R. A. Williams, S. V. Koppen, M. T. Salud, "RFID Transponders' Radio Frequency Emissions in Aircraft Communication and Navigation Radio Bands", NASA/TP-2006-214295, March 2006.

[2] RTCA/DO-160E, Section 21 "Emission of Radio Frequency Energy", *Environmental Conditions and Test Procedures for Airborne Equipment*, December 9, 2004.

[3] LaBerge, E. F. Charles, "An Analysis of the Effects of RFID Tags on Narrowband Navigation and Communication Receivers", NASA/CR-2007-214859 (Honeywell NCCSRTC-EFCL-0261B2), March 2007.

[4] RTCA/DO-199, "Potential Interference to Aircraft Electronic Equipment from Devices Carried Aboard", September 16, 1988.

[5] RTCA/DO-294B, "Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft", December 13, 2006.

[6] *Aeronautical Telecommunication,* International Civil Aviation Organization (ICAO), Annex 10, Vol. I, Chapter 3.1.5.3, July 1996.

[7] RTCA/DO-192, "Minimum Operational Performance Standards for Airborne ILS Glide Slope Receiving Equipment Operating Within the Radio Frequency Range of 328.6 -335.4 MHz", July 18, 1986.

[8] RTCA/DO-307, "Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance, October 11, 2007.

[9] T. X. Nguyen, S. V. Koppen, J. J. Ely, R. A. Williams; L. J. Smith, and M. T. Salud, "Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios", NASA/TP-2003-212438, July 2003.

[10] T. X. Nguyen, S. V. Koppen, J. J. Ely, G. N. Szatkowski, J. J. Mielnik and M. T. Salud, "Small Aircraft RF Interference Path Loss Measurements", NASA/TP-2007-214891, August 2007.

[11] J. J. Ely, T. X. Nguyen, S. V. Koppen, J. H. Beggs, and M. T. P. Salud, "Wireless Phone Threat Assessment and New Wireless Technology Concerns for Aircraft Navigation Radios", NASA/TP-2003-212446, July 2003.

Appendix A: RFID Burst Signal Bandwidth

Figure A-1 illustrates the emulated RFID burst signal spectrum captured using a spectrum analyzer. Due to the RFID signal's low duty cycle and short pulse duration, the spectrum analyzer was set on peak hold and the envelope was captured over a period of approximately 10 minutes. The presence of the notches indicated that the envelope was still not completely filled; however, the signal envelope structure was apparent. The 1-dB bandwidth (where signal was reduced by 1 dB from peak) was about 75 kHz. This is significantly wider that the GS receiver's 90 Hz and 150 Hz sidebands from the GS signal center frequency. These sidebands were known to be highly sensitive to interference [4]. Frequency sweeping of the RFID interference signal across the GS channel was therefore not necessary.

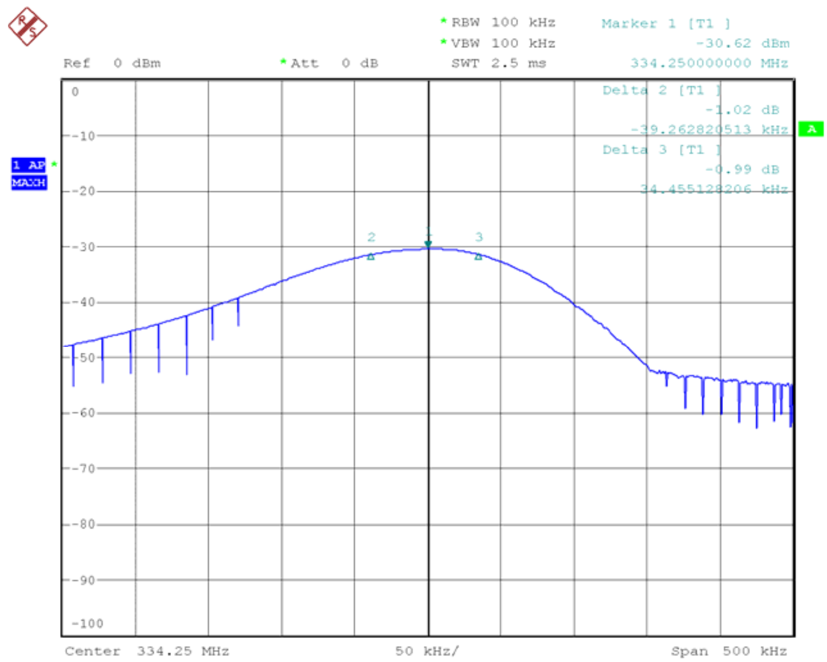


Figure A-1: RFID burst spectrum.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01- 02 - 2008	Technical Publication	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Radio Frequency Compatibility of an RFID Tag on Glideslope Navigation Receivers	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Nguyen, Truong X.; and Mielnik, John J.	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
	645846.02.07.07.05

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
NASA Langley Research Center Hampton, VA 23681-2199	L-19434
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
National Aeronautics and Space Administration Washington, DC 20546-0001	NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
	NASA/TP-2008-215111

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 04
Availability: NASA CASI (301) 621-0390

13. SUPPLEMENTARY NOTES
An electronic version can be found at http://ntrs.nasa.gov

14. ABSTRACT

A process is demonstrated to show compatibility between a radio frequency identification (RFID) tag and an aircraft glideslope (GS) radio receiver. The particular tag chosen was previously shown to have significant spurious emission levels that exceeded the emission limit in the GS aeronautical band. The spurious emissions are emulated in the study by capturing the RFID fundamental transmission and playing back the signal in the GS band. The signal capturing and playback are achieved with a vector signal generator and a spectrum analyzer that can output the in-phase and quadrature components (IQ). The simulated interference signal is combined with a GS signal before being injected into a GS receiver's antenna port for interference threshold determination. Minimum desired propagation loss values to avoid interference are then computed and compared against actual propagation losses for several aircraft.

15. SUBJECT TERMS
RF Interference; Aeronautical Navigation; Glideslope; GS; RFID; Interference Path Loss; Interference Threshold

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	34	(301) 621-0390