

Radio Frequency Compatibility of an RFID Tag on Glideslope Navigation Receivers

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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 peak spurious emission levels that far exceeded the emission limits 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 desired 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.

Keywords- *interference threshold; RFID; aircraft; glideslope; navigation; interference path loss;*

I. 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 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 a 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.

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 without being interrogated by the reader. Many low-cost designs may not suppress spurious emissions beyond the regulatory requirements and may have 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 [2]. In one case, the peak emissions exceeded the limits by as much as 35 dB in the glideslope (GS) band (328.6 – 335.4 MHz). 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 device has very low duty factors of about 0.06 percent at its maximum transmission rate. The interference effect may not be as severe as for continuous transmissions assumed in the RTCA/DO-160 limits. It is of interest to determine if this specific tag can be of interference risk to aircraft GS receivers.

A follow-up study to [1] was performed [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 parallel to effort described in [3], it is also desirable to address the issue with an emphasis on laboratory testing. The testing should include actual interference signals and real aircraft GS radio receivers. Therefore, the main objectives of this paper are to demonstrate an experimental method to characterize aircraft GS radio receiver interference thresholds for a RFID signal, and to assess the RFID tag compatibility with the GS system on many aircraft models.

In this study, the minimum GS receiver interference threshold is first 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.

Discussions in this paper are limited only to measurements and analysis in the GS band, using one specific RFID signal and one specific GS radio receiver. However, the approach is

applicable to other interference signals and radio receivers. More detailed discussions on the measurements can be found in [4].

II. APPROACH

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

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

“*Emission*” is the maximum emission level in dBm,

“*Threshold*” is victim system’s interference threshold to the specific interference signal, in dBm. It is the minimum signal level at the receiver’s antenna port to cause interference,

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 possible.

A significant part of this paper addresses the measurement of *Threshold* value for a GS receiver. IPL_{Target} is then determined from Eq. (1). By comparing IPL_{Target} with actual aircraft IPL data, interference risk may be assessed.

All three variables in Eq. (1) are technically functions of frequency, and application of Eq. (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 [5][6] illustrate the analysis processes using the band’s worst case data.

In this paper, the GS band’s worst case *Emission* and IPL_{Target} values are used in Eq. (1). The worse case (maximum) *Emission* data are from [1]. IPL_{Target} denotes the desired worst case (minimum) IPL value over the GS band for all aircraft RFID locations. In contrast, *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.

In determining the *Threshold* values, the process involved simulating the interference signal 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 for playback in the GS band. This approach resulted in significant signal-to-noise advantage compared to capturing the spurious emissions directly. This approach was possible since the spurious emissions and the fundamental transmissions were observed to have similar modulation characteristics using a spectrum analyzer.

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

- Emulate interference signal burst in GS band:
 - High fidelity capture of RFID tag fundamental transmission

- Emulate (playback) the same signal in GS band
- 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
- Apply Eq. (1) to determine IPL_{Target}
- Compare IPL_{Target} against the measured minimum aircraft IPL data previously reported outside of this effort.

III. RFID SIGNAL SIMULATION IN THE GLIDESLOPE BAND

A. Tags Characteristics

The tag of interest is similar to the model illustrated in Fig. 1 (the specific brand and model suppressed). It was chosen for this study due to its significant peak emissions in the GS band. Measurements between 325 – 340 MHz in a reverberation chamber [1] show a -17.2 dBm peak emission level, which exceeds RTCA/DO-160 GS band limits by about 35 dB. The high peak emission level in the GS band is a cause of concern if the tag is permitted on a flight.



Figure 1. The RFID tag model considered.

This tag activates on motions, 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 tag transmits three 113 millisecond (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.

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 = $100 * 37 * 0.01 \text{ msec} / 610 \text{ msec}$). Fig. 3 illustrates a sample burst pattern captured on a spectrum analyzer.

B. 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 specific spectrum analyzer used 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. The basic setup is illustrated in Fig. 2. A TEM cell was used as a shielded chamber for the tag to minimize background noises. Fig. 3 shows the comparison in time domain of the emulated burst generated by the VSG centered at 334.25 MHz against the original signal produced by the RFID tag. The comparison shows that emulated burst is a suitable representation of the original signal.

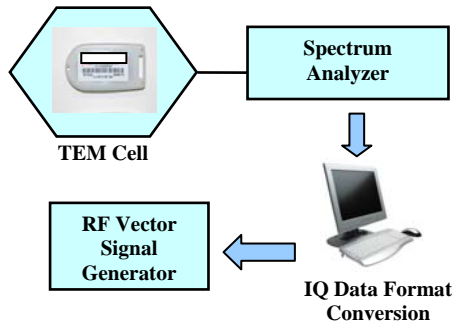


Figure 2. Setup for capturing and emulating interference signal.

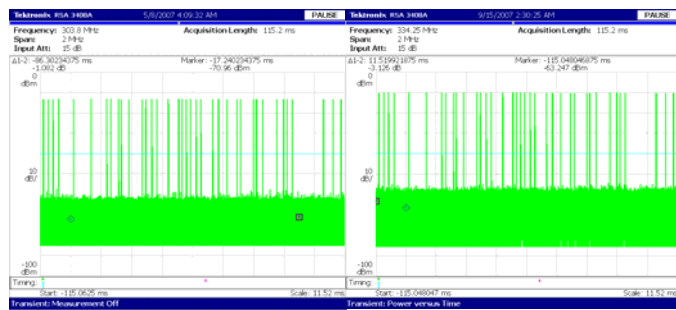


Figure 3. Time domain comparison of RFID burst at 303.8 MHz and emulated burst at 334.25 MHz (center of GS band).

IV. GS RECEIVER INTERFERENCE TEST SETUP

The test 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. Fig. 4 illustrates the setup, with the actual laboratory setup shown in Fig. 5. 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 a number of parameters including the desired GS signal strengths, the interference signal characteristics and the interference conditions chosen. These parameters are described in a later section, along with additional details on the test setup.

For simplicity, this laboratory setup neglects any additional background noise that may exist at the GS receiver’s antenna port. Due to strict aeronautical spectrum protections, high noise levels in the GS band are not expected to be a concern.

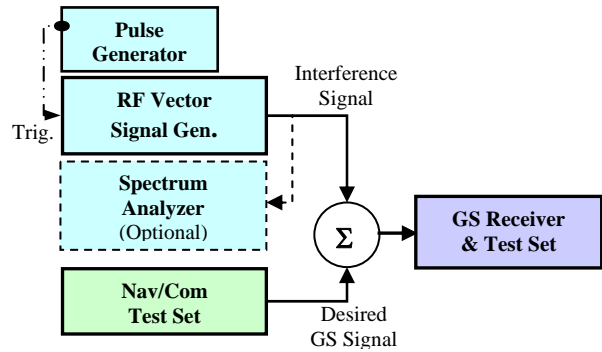


Figure 4. Interference test setup.

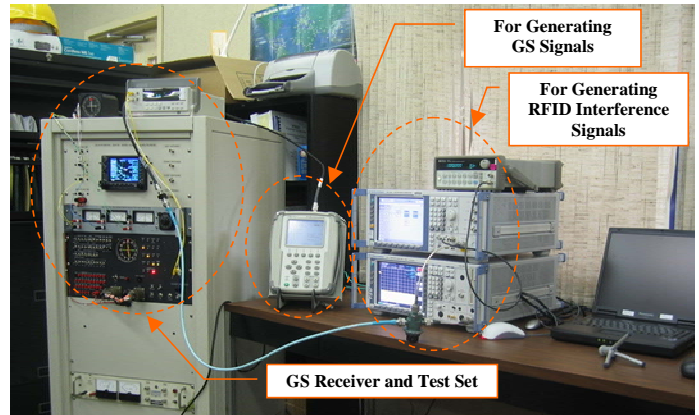


Figure 5. Laboratory receiver interference test setup.

V. 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 interference signal characteristics. These factors and all their possible values in combination can result in an impractically large test.

In this paper, the thresholds were determined for only two GS signal levels and two interference criteria combinations, resulting in four sets of tests. Within each test set, the RFID burst interval was the test variable. Varying the burst interval was accomplished by varying the trigger interval to the VSG, which in turn produced an interference signal burst with each trigger signal.

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 as can be seen in the results presented later in the paper.

A. GS Signal Level

GS signal strength was known to have a significant impact on the receiver interference threshold. Two GS signal levels were chosen: 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 [5], the GS signal level selected was computed from the 400 microvolts per meter ($\mu\text{V}/\text{m}$) field strength specified at the GS airspace's *outer limit of coverage* (OLC) in an International Civil Aviation Organization (ICAO) document [7]. The 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. This level, denoted as $\text{GS}_{\text{ICAO/OLC}}$, was chosen as one of the two GS test signal levels.

In addition, many GS receiver models can be much more sensitive than required 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. The receiver sensitivity was determined to be -95.5 dBm by slowly increasing the GS signal until the receiver showed a valid GS signal flag. The test GS signal was set 3 dB higher, or -92.5 dBm, and is denoted as " $\text{GS}_{3\text{dB} > \text{Sensitivity}}$ ".

Both $\text{GS}_{\text{ICAO/OLC}}$ and $\text{GS}_{3\text{dB} > \text{Sensitivity}}$ 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.

B. 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 7.5 μA deflection used in DO-199 is nearly imperceptible on the CDI. 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 "one dot" deflection on the CDI and is considered reasonable for aircraft at 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. Additional information on performance standards for GS equipment can be found in RTCA/DO-192 [8].

In addition to the CDI, a digital voltmeter and an analog meter on the receiver test set were also used in monitoring the 25 μA course deviation error criteria during tests.

C. 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 interference power was slowly increased or decreased to determine the thresholds for creating and recovering from the interference conditions.

The RFID burst rate was the independent variable in each test group. 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. In addition, the 8.7 Hz corresponded to a 115 msec burst interval, representing nearly continuous burst transmissions. 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 0.1 Hz or 0.2 Hz burst rate increment was chosen depending on whether significant change was observed.

It was not necessary to conduct frequency sweeps of the interference signal. The signal's 1 dB bandwidth (where signal was reduced by 1 dB from the peak) was 75 kHz. This was significantly wider than the highly sensitive 90 Hz and 150 Hz GS receiver's sidebands [5].

D. Interference Threshold Results

The following acronyms are used to denote the interference thresholds in the charts presented in this section:

T_{Flag} : Threshold to cause flag condition,

T_{noFlag} : Threshold below which the system recovers from flag interference,

$T_{25\mu A}$: Threshold for 25 μA course deviation error.

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.

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

Fig. 6 shows the T_{Flag} , T_{noFlag} , and $T_{25\mu A}$ for GS signal level at the edge of airspace coverage ($GS_{ICAO/OLC}$). Similarly, Fig. 7 shows the T_{Flag} , T_{noFlag} , and $T_{25\mu A}$ interference threshold for the GS signal level near the receiver’s sensitivity ($GS_{3dB > Sensitivity}$).

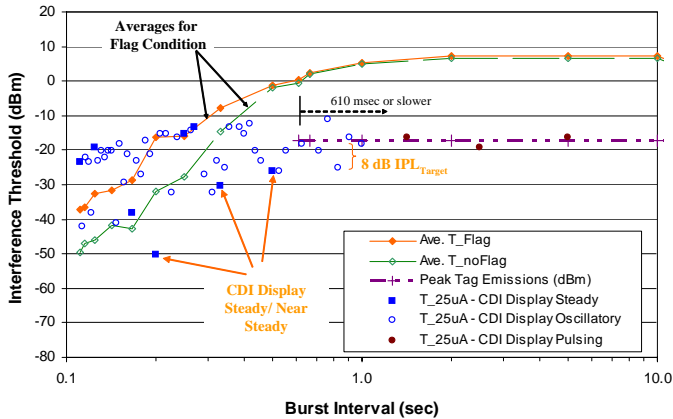


Figure 6. Interference thresholds for flag condition and for 25 μA course deviation error. GS signal at ICAO/OLC level.

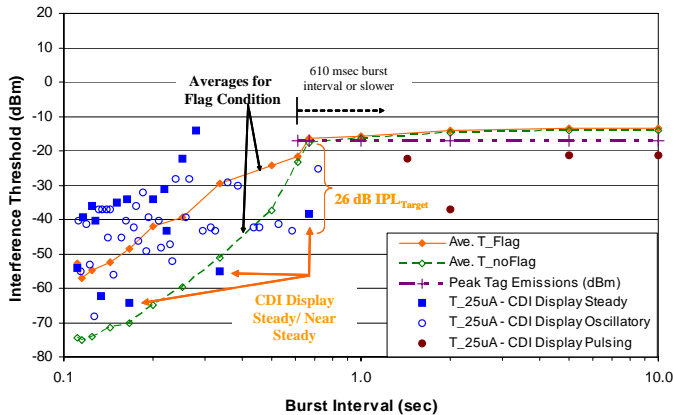


Figure 7. Interference thresholds for flag condition and for 25 μA course deviation error. GS signal at 3 dB above receiver sensitivity.

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 Eq. (1), are computed and illustrated in Fig. 6 and Fig. 7. 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 Fig. 6 and Fig. 7.

E. Data Summary, Analysis and Observations

With the GS signal at the ICAO/OLC level, Fig. 6 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 I summarizes the IPL_{Target} results after Eq. (1) is applied. 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 I. IPL_{TARGET} TO AVOID POTENTIAL INTERFERENCE

GS Signal Level at:	Flag Interference	Course Deviation Interference
ICAO/OLC	None	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).
- Five separate measurements over time show that flag condition thresholds can vary by as much as 22 dB for a few burst rates.
- 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 ($610 \text{ msec} \div 2$). From the Fig. 7 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). Similar approximation for four tags results in -65 dBm interference threshold, and 48 dB IPL_{Target} . It is noted that 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.

For multiple tags, the effects are much more significant from the increased burst rate than from the increased peak interference power. Using data for one tag as the baseline, two and four tags contributing equally would only increase the peak interference power by 3 and 6 dB, respectively, if the bursts align. In contrast, the increased burst rate would raise the IPL_{Target} by 12 dB and 22 dB for two and four tags (from the previous paragraph). Therefore, the effects of the increased burst rate must be considered if multiple tags are used.

F. Aircraft Interference Path Loss Comparison

The IPL_{Target} results should be compared against actual aircraft minimum IPL to determine if interference should be a concern. An aircraft minimum IPL is defined as the minimum propagation loss between tag locations and the receiver's antenna port. Measuring IPL typically includes transmitting from locations of interest, and the coupled powers are measured at the GS receiver's antenna cable. The IPL value is determined by normalizing the receive power against the transmit power.

Table II provides the minimum passenger cabin and cargo bay IPL data for several large and small aircraft models [5][9][10]. In a few cases where data were available for multiple similar aircraft model, the results are listed in Table II as a range rather than the individual values. Since the data came from different sources, small inconsistencies with respect to transmit antenna gain normalization should be expected. Omni-directional antennas were used in all cases.

The lowest IPL value for large aircraft is 46 dB, providing at least a 20 dB safety margin over the 26 dB IPL_{Target} . For small aircraft, the minimum value in the table is 34 dB, providing at least an 8 dB safety margin. Interference to the GS receiver is therefore not expected from a single tag in the passenger cabins or cargo bays of the aircraft listed.

TABLE II. MEASURED GS BAND AIRCRAFT MINIMUM IPL (DB)

Large Aircraft - Cargo Bay		Small Aircraft	
Boeing 747	59	Cirrus SR-22	39
Airbus A320	70	Cessna 172R	34
Large Aircraft -Pass. Cabin		LearJet 35A	36
Boeing 747	49 - 53	Sabreliner 65	45
Boeing 757	58 - 59	Citation II	39
Boeing 737	59 - 61	Baron B-58	42
Boeing 727	68	Piper Saratoga	44
Airbus A320	56-64	Gulfstream GII	50
Bomb. CRJ	52	King Air 200	38
EMB-120	46		

G. Application to Other Glideslope Receivers

Comparing the tested receiver model against published specifications for nine other GS receivers from various vendors, the GNS 530 is more sensitive than all but one model. The measured sensitivity for the GNS 530 is roughly -95.5 dBm. Other GS models have sensitivity specification ranging from -99 dBm to -87 dBm. Thus, it can be interpreted that the threshold results for the GNS 530 model are more conservative than for most other receivers.

VI. CONCLUSIONS

An approach to show compatibility of an RFID tag with an aircraft GS receiver was demonstrated. The tag chosen was previously shown to have high peak spurious emissions far exceeding the GS band RTCA/DO-160 limits for aircraft equipment. The approach included capturing and simulating the spurious emissions using a vector signal generator, and receiver interference thresholds were determined 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 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 at least 8 dB for general aviation aircraft.

The thresholds to cause and to recover from flag conditions were different for a 0.5 second burst interval or faster. 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 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.

VII. REFERENCES

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