

RFID Transponders' RF Emissions in Aircraft Communication and Navigation Radio Bands

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Abstract— Radiated emission data in aircraft communication and navigation bands are presented for several active radio frequency identification (RFID) tags. The individual tags are different in design, operation and transmitting frequencies. The process for measuring the tags' emissions in a reverberation chamber is discussed. Measurement issues dealing with tag interrogation, low level measurement in the presence of strong transmissions, and tags' low duty factors are discussed. The results show strong emissions, far exceeding aircraft emission limits and can be of potential interference risks.

Keywords- Emissions; RFID; aircraft; navigation; communication.

I. INTRODUCTION

Radio frequency identification (RFID) usage experienced an explosive growth in recent years. The U.S. Department of Defense's (DoD's) and major retailers' mandated use in many automatic identification and tracking applications jumpstarted the public interest and awareness of the technology's potential. Initial applications include area monitoring, spot-level locating, cargo security, data storage and logging among many others.

RFID generally can be categorized into passive and active transponders, or tags. Passive tags utilize the power received from the interrogator to power the tags for data transmission. These tags can be produced at very low cost. However, their range is limited due to their low reflected power from the tags. Passive tags are considered less of an interference concern for aircraft since they do not transmit without an interrogator, whose electromagnetic fields power the tags.

Active tags, on the other hand, are powered with internal batteries. As a result, range is better than for passive tags in most cases. Without the batteries, an active tag cannot respond to an interrogation as a passive device could. Active tags can be of higher interference risks since many can transmit on their own without an interrogator.

The actual interference risks depend on several factors, including the tags' intentional and unintentional emission levels, the propagation path loss factor, and the victim system's susceptibility threshold to the emissions type. This paper focuses on the emission measurements of active tags and their interference potential on aircraft sensitive radio receivers. Specifically, this study measures the unintentional emissions from several popular RFID tags used for cargo tracking. Personnel tags are not considered.

The tags considered in this study came from several major active tag vendors specializing in cargo tracking technology, including Savi Technology, Identec Solutions, Sovereign Tracking Systems LLC, WhereNet and RF Code. Spurious emissions were measured in five measurement bands that cover many important aircraft radio bands. The aircraft bands include Localizer (LOC), Glideslope (GS), Very-High-Frequency Omnidirectional Range (VOR), Very-High-Frequency Voice Communication (VHF-Com), Global Positioning Systems (GPS), Traffic Collision Avoidance System (TCAS), Air Traffic Control Radar Beacon System (ATCRBS), Distance Measuring Equipment (DME) and Microwave Landing Systems (MLS).

The primary objective of this paper is to present a process for measuring spurious emissions from RFID tags and to assess the potential interference risks to aircraft radio receivers. The measurements are restricted to unintentional (spurious) emission in and near the aircraft radio spectrum. Intentional transmissions from the tags are typically known, or are easily determined, and are excluded from the measurements.

For a complete interference assessment, other factors such interference path loss and receiver interference thresholds should also be considered. These factors were addressed previously in other efforts. Reference [1] documented the measurement of interference path loss for cargo bays on a Boeing 747 and an Airbus A320 aircraft. Reference [2] provided a summary of passenger cabin path loss data for many commercial transport aircraft. Reference [3] reported the path loss measurements for general aviation aircraft. These path

loss data represent the propagation loss between the tag locations and the victim receiver's antenna port.

Aircraft radio receiver interference thresholds for continuous interference signal transmission were addressed in [4]. The effort in [5] analytically determines thresholds for intermittent interference signals similar to RFID emissions. The effort in [6] reports the laboratory effort to determine the GS system interference threshold to an RFID interference signal. The tag chosen in that report was a result of a high emission level determined from this study.

II. APPROACH

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

$$Emission + IPL \geq Threshold, \quad (1)$$

Emission is the maximum emission level in dBm,

IPL is the interference path loss,

Threshold is victim system's interference threshold to the specific interference signal, in dBm.

There is an interference risk if (1) is satisfied. This paper specifically addresses the measurement of *Emission*. Aircraft system emission limits in RTCA/DO-160E [7] provide an initial comparison baseline. Emissions levels that exceeded DO-160E limits can be considered risky, and further analysis using *IPL* and *Threshold* is warranted.

The reverberation chamber method is used due to the excellent measurement speed, accuracy and repeatability. This method was used in previous studies [2], and showed good results compared with the semi-anechoic method. The results are specified in total radiated power [8]. This method differed from the approach used in RTCA/DO-199 [9], where radiated power was estimated from the electric field measured at a distance from the device-under-test.

The aircraft radio bands were grouped into five measurement bands, designated as Band 1 to Band 5, to reduce the total number of measurements and the test time. Aircraft bands that overlapped, or were near one another were grouped together, and emissions were measured across the entire combined band simultaneously. It is assumed that high emissions anywhere in a measurement band potentially affect all systems grouped in that band. No effort is made to distinguish whether the emissions are on any specific radio band or channel. Table I shows the relationship between the measurement and aircraft radio bands.

Each tag model is tested individually. In all cases, there is no option to change the tags' operating frequency and data rates. However, the blink rate of the beacon tags may be changed. Emission characteristics are expected to be the same, regardless of the method to blink the tags.

TABLE I. EMISSION MEASUREMENT BAND DESIGNATIONS AND CORRESPONDING AIRCRAFT RADIO BANDS.

Measurement Bands	Measurement Freq. Range (MHz)	Aircraft Systems Covered	Spectrum (MHz)
Band 1	105 – 140	LOC	108.1 – 111.95
		VOR	108 – 117.95
		VHF-Com	118 – 138
Band 2	325 – 340	GS	328.6 – 335.4
Band 3	960 – 1250	TCAS	1090
		ATCRBS	1030
		DME	962 - 1213
		GPS L2	1227.60
		GPS L5	1176.45
Band 4	1565 – 1585	GPS L1	1575.42 ± 2
Band 5	5020 - 5100	MLS	5031 – 5090.7

III. RFID ACTIVE TAG EMISSIONS MEASUREMENTS

This section addresses the tag characteristics and triggering methods, harmonics consideration, the test method, the measurement issues and results.

A. Tag Selection and Characteristics

The ten tags considered in this study are shown in Fig. 1. It was not the intention to compare the tags. Rather, they were selected to cover a wide operating frequency range and to include a variety of modes of operation and form factors.



Figure 1. RFID tags considered (not to scale).

Typically, RFID tags have three modes-of-operation: Beacon, Interrogated and Motion. These modes determine how and when the tags “blink”. A “blink” may consist of one or multiple bursts of transmissions. Many tags may operate in multiple modes concurrently, such as beacon and motion modes, or beacon and interrogated modes.

In Beacon mode the RFID tags automatically transmit at a programmable regular interval. This mode allows for continuous monitoring of the conditions and locations of the cargo while the tag is at a fixed location or in motion.

It was observed that many tags can beacon reliably as fast as every two seconds. While the tags may be programmed to beacon at a faster rate; the transmission interval may not be reliable.

In Motion mode the tags blink whenever encountering abrupt motions such as vibrations, bumps or physical movement. A motion tag can blink as fast as every 1-2 seconds if experiencing motions continuously. On an aircraft the motion tags may blink in a coordinated manner corresponding to the aircraft's abrupt motions. These motions are typically observed during take-off and landing or may be caused by rough weather.

In Interrogated mode a tag would blink whenever it received an interrogating signal. The interrogating signal may be addressable to a specific tag, or non-addressable commanding all the tags within the coverage area to respond. The interrogating signals usually come from the reader for wide range coverage. However, there are implementations in which a separate interrogator with shorter range is positioned near a choke point. As a tag enters the coverage of area of an interrogator, it transmits the stored information as well as the identification of the interrogator. A separate reader receives and interprets the signal from the tags, and to interface with the network. There may be more than one interrogator positioned at one or more choke points such as doors. In addition, the interrogator frequency may be different from the tag transmitting frequency.

A few basic tag operating parameters are shown in Table II for the tags used. Table II also documents the typical blink rates, and the fastest blink rates used in the test. It is desirable to blink the tags at the fastest speed possible to minimize measurement time.

TABLE II. TAG OPERATING CHARACTERISTICS

Manu-facturer.	Transmit Frequency (MHz)	Burst Duration (msec)	Xmit Power (mW)	Typical Blink Interval-	Fastest Blink Interval For Test
Savi	433.92	5	0.6 & 0.025	Interrogated and/or 10 secs Beacon	2 secs Beacon
Identec	868 & 915	20	0.75 0.75	Interrogated	Interrogated
RF Code	303.8	113	5	1sec (Motion) 12.5sec Beacon Spider: 7 sec Beacon	1 sec (Motion) 2 sec (Beacon)
WhereNet	2400 – 2483.5	1.4	2	Trigger 6 sec Beacon	5 sec beacon
Sovereign Tracking	417.8 & 433.72	290	0.1	1.5 seconds maximum	1.5 sec Motion

B. Harmonic Considerations

For high sensitivity measurements, harmonics and high unwanted signals outside of the measurement bands should be blocked before reaching the measurement

systems. This requires using filters tuned specifically for the measurement. Without filters the measurement signals may overload the pre-amplifier or the front-end of the spectrum analyzer, leading to intermodulation products as well as skewed measurements. However, certain high harmonics and spurious emissions were extremely difficult to reject due to their close proximity to the measurement bands. In those cases the measurements were performed with reduced amplification, resulting in reduced sensitivity.

In selecting filters it was important to compare the aircraft radio bands of interest to the tags' fundamental and harmonic frequencies. The comparisons show that none of the fundamentals or harmonics (up to 5th) fall within the aircraft radio bands listed. However, the fourth harmonic of the RF Code tag (1215.2 MHz) and third harmonic of the 417.8 MHz tag (1253.4 MHz) came very close to the DME (962 – 1213 MHz) band. These were difficult to filter out in the measurement.

It was determined during the testing that many tags also have strong spurious emissions outside of the measurement bands, and that filtering the fundamental and harmonic frequencies alone may not be sufficient. Many of those emissions were at frequencies close to the measurement bands and were difficult to filter. Signal amplification was reduced to avoid overloading the pre-amplifier, effectively reducing measurement sensitivity. This issue is illustrated later in the paper.

C. Reverberation Chamber Measurement Method

Performing antenna port conducted power measurement is the most direct to measure emissions from the antenna port of the device. However, most RFID tags do not have an antenna port accessible from the outside. In addition, conducted power measurement fails to account for radiated emissions from components other than through the antenna port. A radiated emission test chamber is usually required for a more complete measurement.

Reverberation chambers were used in this study for their excellent repeatability, field uniformity, aspect independence, and measurement speed. The results were in the form of total radiated power, rather than in field strength as in anechoic or semi-anechoic chamber test methods. The measurement and data analysis processes used were similar to those previously documented in [2], but with modifications to accommodate the RFID types of signals.

RFID testing was different in that the signals were very short in duration and have low duty factors. In combination with the wide measurement bandwidth and instrument speeds, the high number of samples required for the reverberation test method can result in very long test time. As a result, measuring multiple tags concurrently was adopted to reduce test time.

Two different reverberation chambers were used. The larger chamber had the lowest usable frequency of

approximately 100 MHz and was used for Band 1 and Band 2 measurements. The smaller chamber, with 350 MHz lowest usable frequency, was used for the higher frequency Band 3 to Band 5 for improved sensitivity. The smaller chamber had lower absorption loss, leading to higher signal strength at the receive antenna. This resulted in better measurement sensitivity. Simple chamber setups are illustrated in the next section.

The test chambers were first calibrated by transmitting a known power level out of the transmit antenna while a spectrum analyzer recorded the peak power from the receive antenna. A chamber calibration factor was computed to relate the transmit power and the peak receive power. During the testing with the tags transmitting, a similar peak receive power measurement was made. The chamber calibration factor was applied to the new measurement to determine the tags' spurious emissions. The mechanical stirrers rotated continuously during both the calibration and the tests. Log periodic antennas were used for Band 1 and Band 2 in the larger chamber. Dual-ridge horn antennas were used for Band 3 to Band 5 in the smaller test chamber.

Due to the chambers' high quality factor, Q , the method was suitable if the chamber's time constants were shorter than 0.4 times the signal pulse width. This requirement ensured that once a pulsed signal was turned on, the field environment in the chamber had sufficient time to reach (near) steady-state before the pulse was turned off. Using the method for measuring chamber Q and time constants described in [10], the worst case chamber time constant was about 0.6 microsecond at 100 MHz for an empty chamber. Applying the $0.4 \cdot (\text{pulse width})$ criteria, it was determined that the chamber could accommodate all the RFID pulse-widths under consideration.

D. Tag Interrogation Method

Different methods were used to blink the tags for the testing. For motion activated tags, a special assembly was fabricated to shake the tags. The shaker assembly was driven by a power supply located outside the chamber. The motor for the shaker assembly and the power supply cable were shielded to minimize unintended emissions. Fig. 2 and Fig. 3 illustrate the chamber setup and the shaker assembly developed for the testing.

For interrogated tags, the test setup included an interrogator for communicating with the tags as shown in Fig. 4. The interrogator hardware was linked to its antenna inside the test chamber through a filter network to minimize undesirable noise. An interrogator may come in various formats, including a PC card (run on a laptop computer) or a separate fixed unit. The interrogator may also be built into the same housing with a RFID reader. Figure 5 shows the layout of setup of the tags and the interrogating antenna. The two transmit and receive dual-ridge horn antennas can also be seen in the figure.

For tags in Beacon mode, no special steps were needed. The tags were programmed to beacon at their fastest rates possible. The chamber setup was similar to Fig. 2 and Fig.3, but without the interrogator antenna or the tag shaker assembly. Fig. 6 shows the testing of the beacon tags in the larger chamber. The log-periodic transmit antenna receive antenna and a stirrer can be seen in the background.

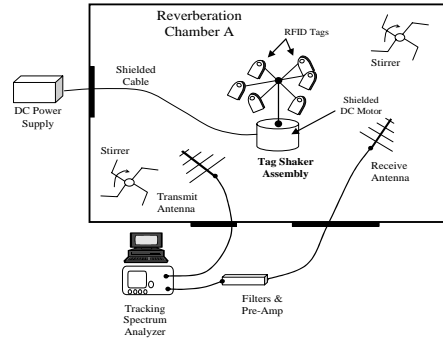


Figure 2. Setup for testing motion tags.

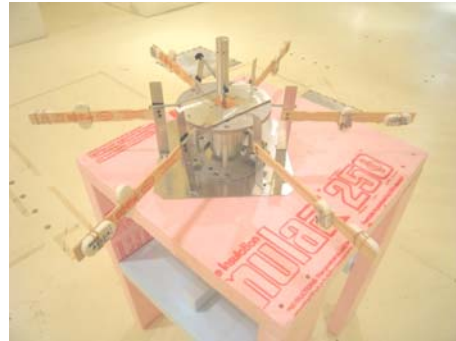


Figure 3. Motion tags mounted on the shaker assembly.

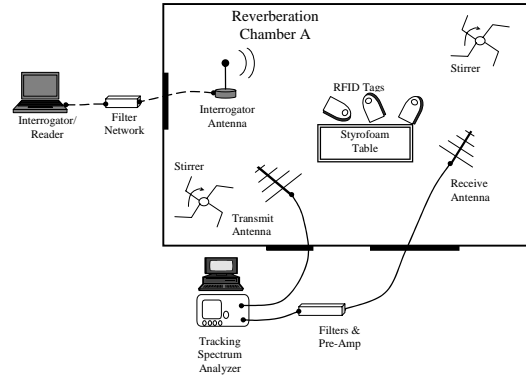


Figure 4. Setup for testing interrogated tags.

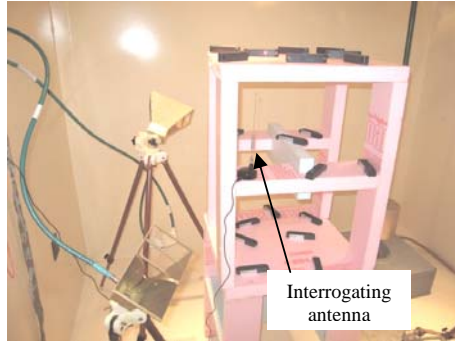


Figure 5. Testing interrogated tags.



Figure 6. Testing beacon tags.

E. Measurement Issues

1) Low duty signal

Typical RFID emissions have a very low duty cycle. The longest signal had a 0.06 percent duty cycle at its maximum blink rate. Low duty signals created a challenge for the measurement and could take a very long time to fill the measurement bands.

One measurement approach was to sweep at a rate sufficiently low so that the sweep time to complete one sample (there are 601 samples per trace) was longer than the blink period of the tags. This approach ensured at least one tag transmission during the time it took for the frequency to sweep across one frequency bin (of the 601 frequency bins per trace). A quick calculation showed that it would take in excess of four days per tag per measurement band for 100 samples per stirrer revolution. This approach and several others were tried and abandoned in favor of a more speedy approach, but possibly not as rigorous.

The final approach adopted was to have the spectrum analyzer trace display on maximum hold, while watching the envelop results for convergence. The envelop data were recorded at regular intervals, approximately every 15-30 minutes, and the results were plotted and compared against earlier traces. Over a period of time, which varied with different tags, the peak emission envelops converged. The test was considered complete once the last several measurement traces were nearly identical.

Experimentations using slow sweeps versus fast sweeps also did not show significant differences in a few test cases. However, fast sweeps reduced the test time significantly. In many cases, the measurements converged within as short as 1 hour or less, especially for signals with longer duty factors.

Using this approach, the results were shown to be very repeatable, and the measurements could easily be repeated for verification purposes. More attention from the test conductor was required, however.

In addition to selecting the fast sweep rate, testing many tags at the same time reduced test time significantly. Testing 20 tags concurrently increased the burst transmission rate by factor of 20. However, there was a small possibility of having multiple tags transmit at the same time, resulting in cumulative effects at the receive antenna. The cumulative effects were previously defined as multiple equipment factor, or MEF. It is noted that MEF was not an issue in testing interrogated tags. These tags were interrogated sequentially, and only one tag could blink at any given time.

MEF was also not a major concern in testing beacon tags and motion tags. The tag transmissions were very short relative to the blink period, and the chance of both signals transmitted at the same time was small. The probability of having three or more tags blink at the same time was even more remote. At the worst case, two tags contributing equally at the receive antenna would result in a 3 dB MEF. This small error was considered acceptable for the benefit of much reduced test time. However, it was highly unlikely that any two tags would blink at the same time while contributing equally at the receive antenna. Thus the MEF was expected to be lower than 3 dB.

2) Pre-measurement Scan

It was desirable to conduct the measurement with the maximum sensitivity possible due to the sensitivity of aircraft radio receivers. This could be accomplished using high gain signal amplifications in addition to low resolution bandwidth settings on the spectrum analyzer. The use of broadband high gain amplifications requires that the setup be checked to ensure that the amplifiers were not driven into saturation with strong signals that may be outside of the measurement bandwidth.

A pre-scan over the bandwidth of the components and of the set-up were performed to identify any high emissions that could affect the measurements. Once the high emissions were identified, it was preferred that they be filtered out for the best measurement sensitivity. However, using filters were not an option if the emissions were close to the measurement bands. In such cases, input to the amplifier was attenuated to ensure overloading the amplifier was not an issue. The measurement sensitivity was reduced as a result.

Fig. 7 illustrates the presence and the strength of the intentional and spurious signals that were outside of the measurement bands, as measured using a reverberation

chamber. The data were not calibrated; however, the chamber's responses to calibration signals were shown for comparison.

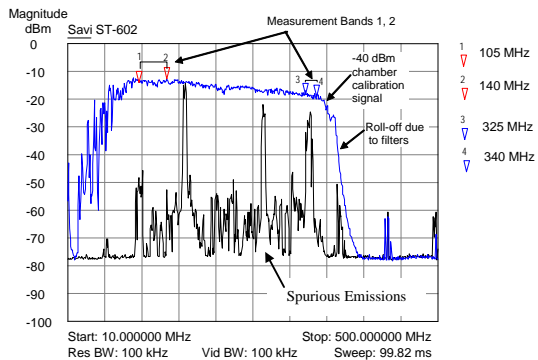


Figure 7. Illustration of strong spurious emissions near measurement bands. Data not calibrated.

F. Measurement Results

The measured peak total radiated power value for each measurement band is plotted for the tags in Fig. 8. They are compared against the minimum RTCA/DO-160E (Section 21) Category L and M limits specified for the measurement bands.

The Category L is specified for aircraft equipment and wiring located in areas far from apertures of the aircraft (such as windows) and from radio receiver's antennas. Category M is defined for equipment and wiring located in areas where apertures are electromagnetically significant and not in direct view of radio receiver's antenna. Category M is suitable for areas such as in the passenger cabin or in the cockpit of a transport aircraft. The field limits were converted to Effective Isotropic Radiated Power (EIRP) for the comparison.

The results indicate that in at least five cases, involving three tags, the peak emissions exceeded the RTCA/DO-160E Category L limits in Band 2 and Band 3. In one instant, the emissions exceeded the limit by 35 dB in the Band 2 (covering GS band). These cases warrant additional studies to determine the true interference thresholds for the specific interference signals if they are to be used during flights. The efforts in [5] and [6] develop the process for that threshold determination.

IV. SUMMARY AND CONCLUSIONS

Emission measurements were conducted on multiple active RFID devices. The measurements were performed at various aircraft radio bands. The results show that many tags' peak total radiated power exceeded

RTCA/DO-160E Categories L and M EIRP emission limits. One of the RFID tags exceeded RTCA/DO-160E Categories L and M limits by as much as 35 dB in the GS band. These tags warrant further analysis to determine aircraft compatibility. Consideration for the tags low duty factor on receiver interference thresholds should be made in determining interference risk.

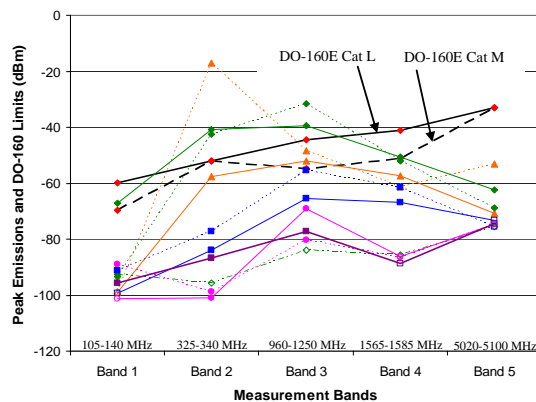


Figure 8. RFID tag emissions and comparison with RTCA/DO-160E Section 21 emission limits. (tag models omitted).

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