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EMC Laboratory RF Radiated Emission Report for Passive Radio Frequency Identification (RFID) Tags

RATIONALE

This document is created to support the AS5678 position that passive RFID tags do not interfere with any other electronic equipment on the airplane and as such does not cause any safety of flight issue.

INTRODUCTION

This paper:

- identifies test units,
- describes how the tests were conducted,
- identifies support equipment and instrumentation,
- includes test data, and
- provides results.

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1. SCOPE

This paper contains RF radiated emission and susceptibility data from passive Radio Frequency Identification (RFID) tags and readers operating at 13.56 MHz, 915 MHz, and 2.45 GHz. Laboratory test procedures incorporated the methods of RTCA DO-160D (test procedures for aviation electrical/electronic equipment) and DO-233 (test procedures for consumer portable electronic devices (PEDs)). Only one commercially available system was evaluated per established operating frequencies.

1.1 Purpose

The purpose of this paper is to record the RF radiated emissions and susceptibility from selected passive RFID systems operating at 13.56 MHz, 915 MHz, and 2.45 GHz. The emissions data (intentional and spurious) includes operation with both “good” and damaged tags. In addition, RF radiated susceptibility tests were performed to determine functionality and inadvertent operation.

These tests are limited in scope to the RF radiated emissions of PEDs tested in a controlled laboratory environment per the requirements of RTCA DO-160D, RTCA DO-233, and an airplane manufacturer's limit.

This paper:

- identifies test units,
- describes how the tests were conducted,
- identifies support equipment and instrumentation,
- includes test data, and
- provides results.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AS5678 Passive RFID Tags Intended for Aircraft Use

2.2 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160D "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 29, 1997

RTCA DO-233 "Portable Electronic Devices Carried on Board Aircraft," dated August 20, 1996

RTCA DO-294 SC202 Phase 1 Document, "Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft," October 19, 2004

2.3 Other References

Boeing Document D6-16050-4D, "Electromagnetic Interference Control Requirements," dated July 24, 2002

3. SUMMARY

3.1 Overview

RF radiated emission and susceptibility tests were performed in an EMC Laboratory to evaluate passive RFID tags. The following RF radiated scenarios were investigated:

1. Emissions from 150 kHz to 6 GHz
2. Emissions at the operating frequency range
3. Emissions from damage tags
4. Emissions from multiple tags
5. Susceptibility of tags to HIRF (damage assessment)
6. Susceptibility at operating frequency (inadvertent activation)

All measurements were made per the procedure of DO-160D for RF radiated emissions and susceptibility with the exception of the RFID tags being 1 meter off of the ground plane (similar to DO-233). Data plots were recorded with emission limits of avionic equipment as a comparison. RF radiated emission limits of RTCA and an aircraft manufacturer were used. The RFID tags were oriented to allow recording of maximum RF energy at a distance of 1 meter from the receiving antenna. Commercially available RFID passive systems were obtained for the test.

3.2 Results

3.2.1 RFID Passive System – 13.56 MHz

The RFID handheld reader had to be within inches of the RFID tag for system operation. There was no known way to differentiate between the RFID transmitted signal and the RFID tag's reflected signal. Therefore, the evaluation of RF radiated emissions was system-based and not tag-only.

Fundamental frequency emission level was approximately 25 dB above the DO-160D RF radiated emission limit and 35 dB above an airplane manufacturer's HF notch limit.

Spurious emissions were below an airplane manufacturer's and DO-160D Category H limits except in the VHF notch which were above the limit by 3 dB. It appeared that these emissions were from the RFID reader and not the RFID tag.

A laboratory test signal was used in an attempt to activate the tag. The test signal was transmitted at 13.56 MHz, CW, while the VHF band was monitored. No emissions were seen in the VHF band, and was concluded that the tag did not activate.

Damaged tags were not evaluated.

3.2.2 RFID Passive System – 915 MHz

The RFID system included a laptop with controlling software, reader, an antenna module with both transmitting and receiving antennas, and tags. The tags could be read anywhere within the screen room. The wireless technology incorporated was frequency hopping between 902 and 928 MHz.

Fundamental frequency emission level was approximately 52 dB above the DO-160D RF radiated emission limit for Categories L/M/H.

Spurious emissions were below the DO-160D Category L/M/H limit.

Separation of the RFID transmitted signal and the RFID tag reflected signal was accomplished by tapping into the RFID antenna module transmit and receive antennas. This was done by using directional couplers outside the screen room. Data showed that the reflected energy from 1 tag is approximately 40 dB down from the RFID transmitted signal. Note: It was not verified if the received energy was totally from the tag or if leakage existed within the RFID antenna module. However, the data from multiple tag testing suggested that the RFID antenna module isolation was sufficient to differentiate between the transmitted and reflected signals.

Multiple tags were evaluated. It was established that the RF emission level increased by approximately 2 dB for every doubling of the number of tags per the given physical layout.

A copper sheet cut to the same size as a tag reflected more energy (2 to 10 dB) than a tag.

Spurious emissions were not seen from damaged tags. Either the RF profile remained as normal or the tag completely failed and produced no emissions. Various sections of the tag's antenna were either shorted or opened. In addition, a HIRF failed tag was used.

Tags were evaluated for survivability to HIRF (200 V/m). Only 1 tag out of 10 failed. The failure was complete and the tag's chip was burned.

GSM 900 mobile phones and 2-way pagers operate in either the same or adjacent frequencies with this RFID system. A compatibility test was done with the mobile phones at various power levels. (Note: 2-way pagers were not obtained for the test.) The mobile phones did reduce the effectiveness of the RFID system to operate. At 2 watts, the RFID system lost about half of its efficiency.

A test was done to simulate onboard aircraft com/nav transmitters to determine if the tags could inadvertently activate. Category R of DO-160D RF radiated susceptibility levels were used across the associated frequency bands of VHF, ATC, TCAS, DME, SATCOM, and Radio Altimeter. The tag was monitored for any energy in the 900 to 930 MHz band. No inadvertent activation was seen.

3.2.3 RFID Passive System – 2.45 GHz

A 2.45 GHz RFID system was evaluated. The system was not compatible with other IEEE 802.11b systems as the RFID system is also spread spectrum. Only limited testing was done.

Fundamental frequency emission level was approximately 51 dB above the DO-160D RF radiated emission limit for Categories L/M/H.

Spurious emissions were below the DO-160D Category L/M/H limit except at 2 to 7 MHz by 20 dB over the limit.

4. MAIN COMPONENTS OF THE RFID SYSTEMS

13.56 MHz Passive System

- Hand Held Reader
- Tags

915 MHz Passive System

- Antenna Module
- Reader
- Tags

2.45 GHz Passive System

- Scanner/Reader
- Planar Antenna
- Tags

NOTE: The goal was that only the RFID tags were the units under test; however, in most of the systems the reader could not be physically isolated from the tag.

4.1 Test Setup

The test method of RTCA Document DO-233, "Portable Electronic Devices Carried On Board Aircraft," dated August 20, 1996 was followed:

- PED placed on a non-conducting ground plane,
- Ground plane elevated off the floor by 80 cm (height of 1 meter was used)

The RF radiated emission limits of an aircraft manufacturer's electromagnetic interference control requirements were plotted on the figures. The limit chosen is the most stringent and is used when there are ten or more of the same LRU installed in the aircraft. This limit is equivalent to the RF radiated emission limit of RTCA DO-160D Category H, with the exception of starting at 150 kHz (DO-160 starts at 2 MHz) and an HF notch (10 dB). Orientation of the RFID tag was situated to record maximum emissions. The basic setups are shown below in the following three sets of figures. The 13.56 MHz system (Figure 1) occupied an area of approximately 12 inches in diameter. A person had to be in the screen room to operate the system. The system consisted of a tag and a hand-held reader.

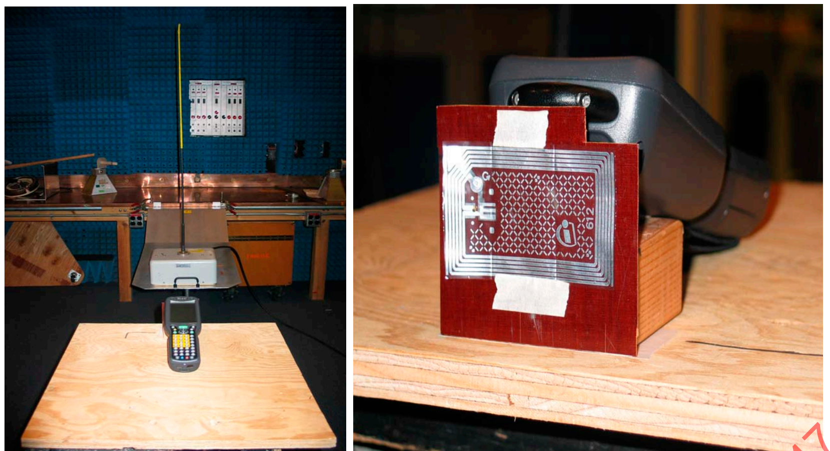

FIGURE 1 - TEST SETUP – 13.56 MHZ SYSTEM

The 915 MHz system (Figure 2) consisted of a tag, antennas (transmit and receive in same unit), reader, and a laptop computer. A person outside the screen room operated the system. Inside the screen room were the tag and antennas. Outside the screen room was the reader and laptop.

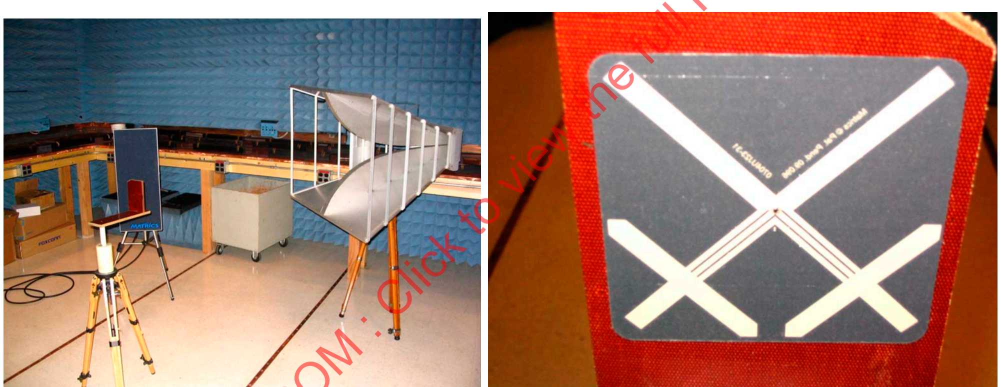

FIGURE 2 - TEST SETUP – 915 MHZ SYSTEM

The 2.45 GHz system (Figure 3) occupied an area of approximately 1 to 2 meters in diameter. A person had to be in the screen room to operate the system. The system consisted of a tag and a body-held reader. (The reader was physically structured similar to a metal detector like the kind seen on beaches by people searching for coins or other metal objects.)

FIGURE 3 - TEST SETUP – 2.45 GHZ SYSTEM

5. RF RADIATED EMISSION AND SUSCEPTIBILITY DATA AND RESULTS

5.1 Passive 13.56 MHz System – RF Radiated Emissions

150 kHz to 6 GHz

Figures 4A through 4D show the RF radiated emission profile from both the RFID tag and reader together. The reader had to be within inches of the tag in order for the system to operate. Therefore, the reader emissions and tag reflected emissions comprise the profile in the figures. No significant difference was seen between vertical and horizontal polarities. Test setup photos are contained in Figures 5 and 6. A summary of the RF radiated emission profiles are as follows:

Fundamental Level @ 13.56 MHz: 61 dBuV/m (above an airplane manufacturer's HF notch limit by 35 dB, and above DO-160D Cat L/M/H by 25 dB)

Spurious Emission Levels below an airplane manufacturer's limit and RTCA Cat H limits except at 100 to 150 MHz: 28 dBuV/m (above Cat H by maximum of 3 dB, but below Cat M)

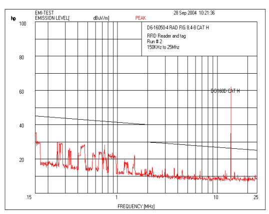

FIGURE 4A - 150 kHz TO 25 MHz

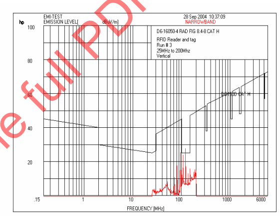

FIGURE 4B - 25 TO 200 MHz

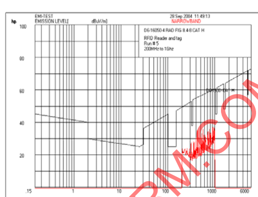

FIGURE 4C - 200 TO 1000 MHz

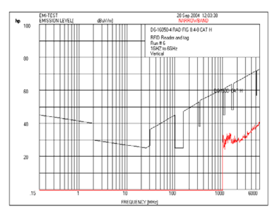

FIGURE 4D - 1 TO 6 GHz

FIGURE 4 - RFID 13.56 MHz PASSIVE SYSTEM – RF RADIATED EMISSIONS – 150 kHz TO 6 GHz

FIGURE 5A - TEST SETUP 150 kHz TO 25 MHz

FIGURE 5B - READER

FIGURE 5C - READER WITH FEDEX TAG

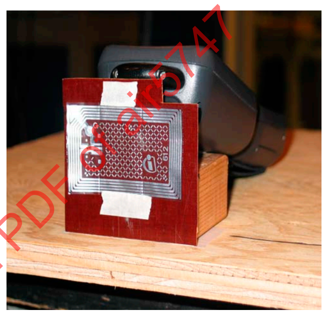

FIGURE 5D - READER WITH 612 TAG

FIGURE 5 - RFID 13.56 MHz PASSIVE SYSTEM – PHOTOGRAPHS OF TEST SETUP (1 OF 2)

FIGURE 6A - 641 TAG

FIGURE 6B - INSTRUMENTATION OUTSIDE OF SCREEN ROOM

FIGURE 6C - LABORATORY MADE TEST ANTENNA FOR TRANSMITTING AT 13.56 MHz

FIGURE 6D - INADVERTENT ACTIVATION TEST SETUP

FIGURE 6 - RFID 13.56 MHz PASSIVE SYSTEM – PHOTOGRAPHS OF TEST SETUP (2 OF 2)

Operating Frequency

Figure 7A is a close-up of the operating frequency emission profile. In an attempt to distinguish between the reader transmitted emissions and the tag reflected emissions, the tag was removed from the room and the emissions from the reader only were recorded. Figure 7B shows no significant difference from when the tag was in the room with reader. Figure 7C is the emission profile of the reader in a standby mode – on with a screen display, but not transmitting.

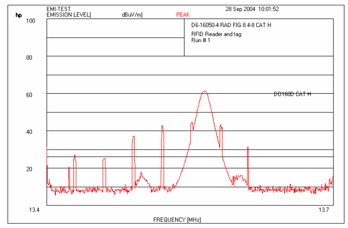

FIGURE 7A - FUNDAMENTAL (OR OPERATING) FREQUENCY

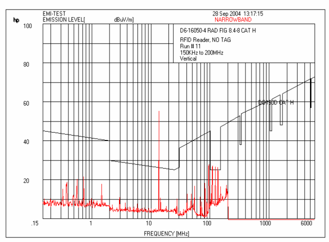

FIGURE 7B - READER ONLY – TRANSMITTING (TAG REMOVED FROM SETUP)

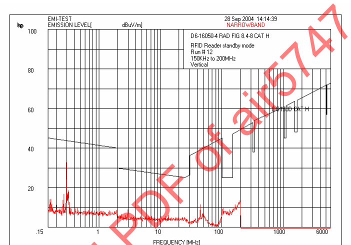

FIGURE 7C - READER ON BUT NOT TRANSMITTING (STANDBY MODE)

FIGURE 7 - RFID 13.56 MHz PASSIVE SYSTEM – RF RADIATED EMISSIONS – FUNDAMENTAL AND VARIATIONS ON CONFIGURATION

Multiple Tags

Test not performed.

Damaged Tags

Test not performed.

5.2 Passive 13.56 MHz System – RF Radiated Susceptibility

HIRF (Damage Assessment)

Test not performed.

Inadvertent Activation

A 13.56 MHz laboratory test signal (CW) was used in an attempt to activate the tag. There were no indications of a reflected signal as indicated by monitoring the 100 to 150 MHz frequency band. See Figure 8.

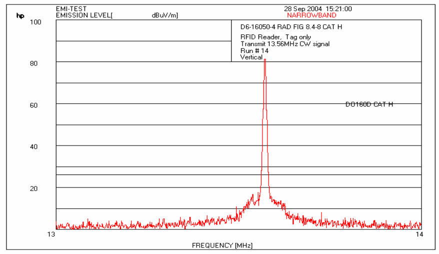

FIGURE 8A - LABORATORY TEST SIGNAL AT 13.56 MHz

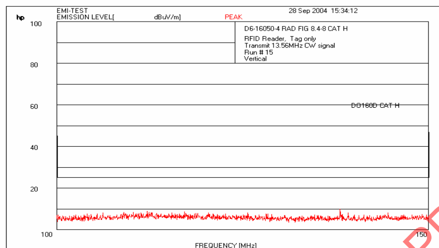

FIGURE 8B - 100 TO 150 MHz

FIGURE 8 - RFID 13.56 MHz PASSIVE SYSTEM – RF RADIATED EMISSIONS – EVALUATION OF INADVERTENT ACTIVATION

5.3 Passive 915 MHz System – RF Radiated Emissions

<u>150 kHz to 6 GHz</u>

Figures 9A through 9C show the RF radiated emission profile from both the RFID tag and system antennas. The RFID system antennas module was place one meter from the tag. Both transmit and receive antennas are contained within this module. See Figures 10 and 11 for test setup photos.

Fundamental Level: 112 dBuV/m (above DO-160D Cat L/M/H by 52 dB, vertical polarity, maximum level in band of operation)

Spurious Emissions: below an airplane manufacturer's and RTCA Cat H limits

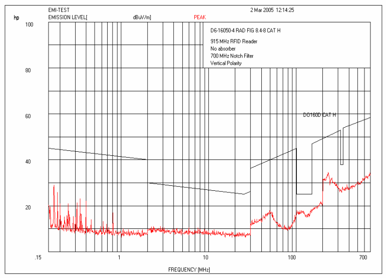

FIGURE 9A - 150 KHz TO 700 MHz
VERTICAL POLARITY

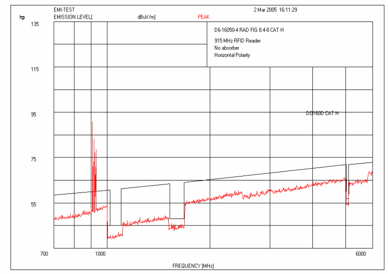

FIGURE 9B - 700 MHz TO 6 GHz
HORIZONTAL POLARITY

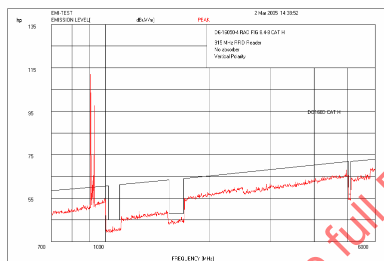

FIGURE 9C - 700 MHz TO 6 GHz VERTICAL POLARITY

FIGURE 9 - RFID 915 MHz PASSIVE SYSTEM – RF RADIATED EMISSIONS – 150 kHz TO 6 GHz

FIGURE 10A - TEST SETUP WITH HORN ANTENNA

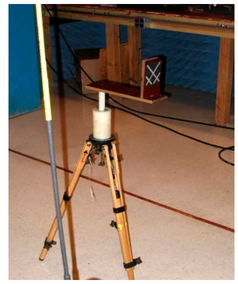

FIGURE 10B - TAG ON STAND

FIGURE 10C - BACK OF RFID ANTENNA MODULE (TOP COAX TX, BOTTOM COAX Rx)

FIGURE 10D - FRONT OF RFID ANTENNA MODULE

FIGURE 10 - RFID 915 MHz PASSIVE SYSTEM – TEST SETUP AND COMPONENTS

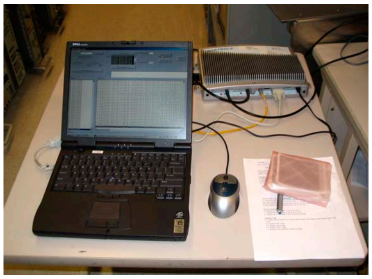

FIGURE 11A - LAPTOP COMPUTER AND RFID READER

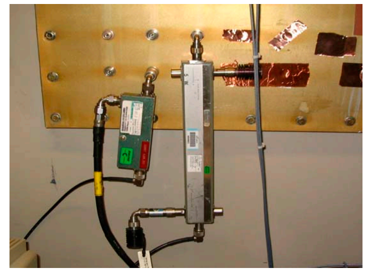

FIGURE 11B - SCREEN ROOM ACCESS PANEL WITH DIRECTIONAL COUPLERS

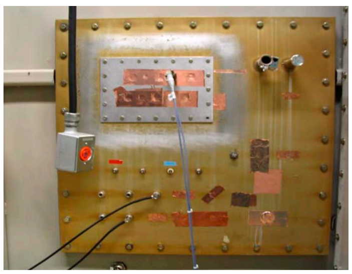

FIGURE 11C - SCREEN ROOM ACCESS PANEL WITHOUT DIRECTIONAL COUPLERS

FIGURE 11D - LABORATORY TEST INSTRUMENTATION

FIGURE 11 - RFID 915 MHz PASSIVE SYSTEM COMPONENTS

Operating Frequency

Figure 12 shows close-ups of the operating frequency emission profile. Note that this system is frequency hopping in the 902 to 928 MHz band. Data using both polarities of the laboratory receive antenna were recorded. The test setup configuration was with the tag one meter from the laboratory receive antenna (to spectrum analyzer) and 1 meter from the RFID antenna (to RFID reader). Both antennas were approximately 2 meters from each other.

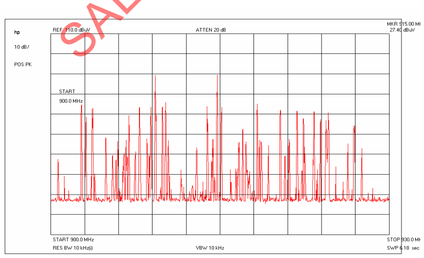

FIGURE 12A - VERTICAL POLARITY

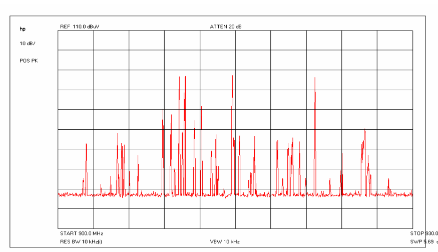

FIGURE 12B - HORIZONTAL POLARITY

FIGURE 12 - RFID 915 MHz PASSIVE SYSTEM - RF RADIATED EMISSIONS – 900 TO 930 MHz

Figures 13A through 13C show the various tag positions: (1) face of the tag (paper side) facing towards the antenna, (2) rear of the tag (antenna) facing towards the antenna, and (3) no tag. There were no significant differences in emission profile from front to rear of the tag – as expected. The power spectral density of the antenna appeared to be greater when no tag was present. This was reasonable as the system was in a search mode.

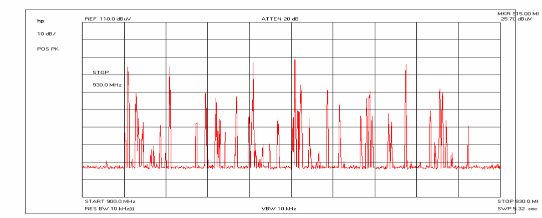

FIGURE 13A - TAG FRONT FACING TOWARDS ANTENNA

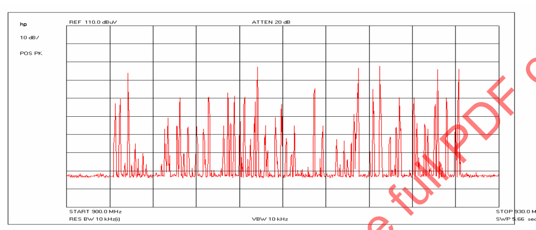

FIGURE 13B - TAG REAR FACING TOWARDS ANTENNA

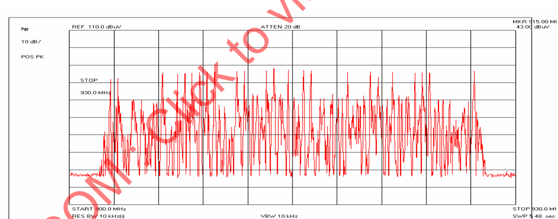

FIGURE 13C - NO TAG

FIGURE 13 - RFID 915 MHz PASSIVE SYSTEM - RF RADIATED EMISSIONS – TAG ORIENTATION

An attempt to isolate the transmitted signal from the reflected signal was made by using absorber material between the RFID transmitting antenna and the laboratory test receiving antenna. See Figure 14. This was not successful. It was decided to use the RFID systems transmitting and receiving antennas to monitor the levels. It was not known what the isolation values were within the RFID antenna module.

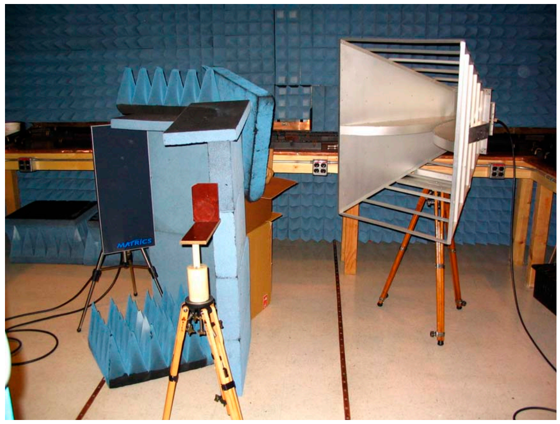

FIGURE 14 - RFID 915 GHz PASSIVE SYSTEM – SETUP WITH ABSORBER

Multiple Tags

Using a directional coupler to tap into the transmit and receive antennas of the RFID antenna module, the emission profiles from multiple tags were obtained. See Figure 16. The following figure (#15) shows the levels of the receive antenna in relation to the transmit antenna for various scenarios:

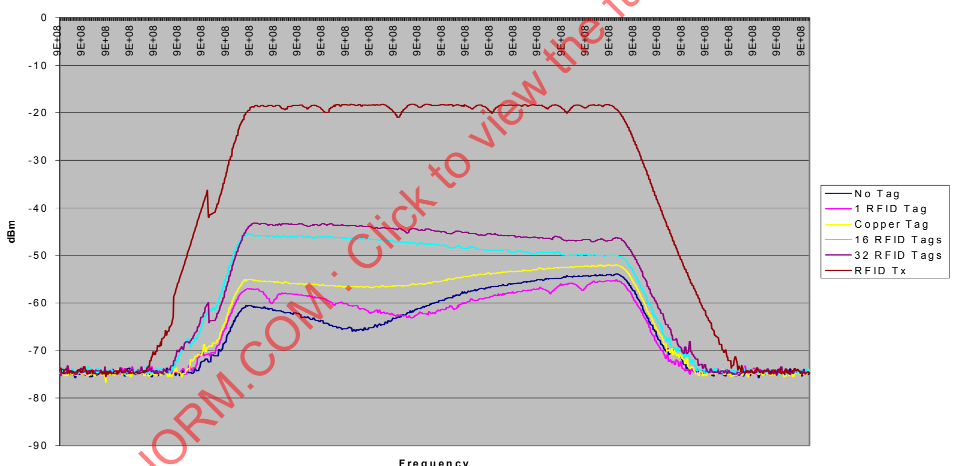

FIGURE 15 - LEVEL OF RECEIVE ANTENNA IN RELATION TO TRANSMIT ANTENNA

Using the maximum levels from the above curves:

Transmit RFID Level	-18 dBm
1 Tag Level	-56 dBm or 38 dB below transmit level
No Tag Level	-54 dBm or 2 dB above 1 tag level
Copper Sheet Level	-52 dBm or 4 dB above 1 tag level
16 Tag Level	-46 dBm or 10 dB above 1 tag level
32 Tag Level	-44 dBm or 12 dB above 1 tag level

Based upon the limited data above, it appears that the multiple effect factor is 2 dB for each doubling of the number of tags. However, an upper boundary was not established. RTCA DO-294 established several methods of calculating a multiple effect value. The most conservative and simplest is MEF = 10 log (# of T-PEDs). This equation is independent of frequency and results in 3 dB per every doubling of the number of T-PEDs. Based upon this, the MEF measured here seems reasonable for this physical layout.

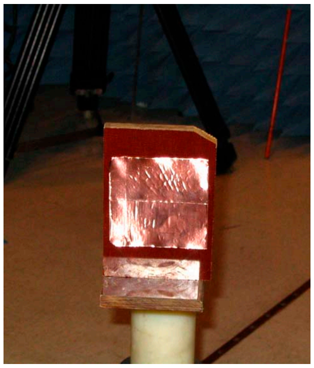

FIGURE 16A - COPPER SHEET WITH SAME DIMENSIONS AS A TAG

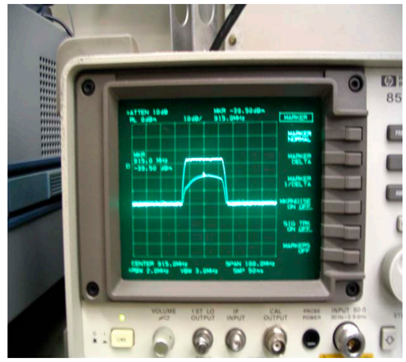

FIGURE 16B - SPECTRUM ANALYZER PHOTO WITH Tx AND Rx LEVELS FROM RFID ANTENNAS

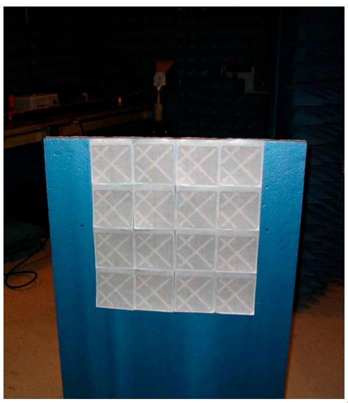

FIGURE 16C - 16 TAGS

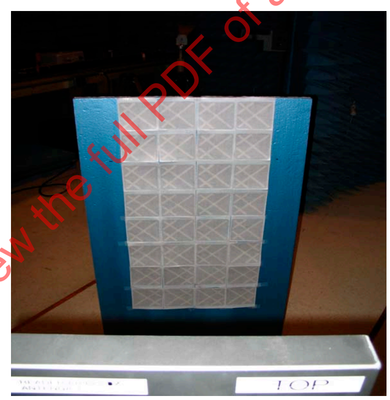

FIGURE 16D - 32 TAGS

FIGURE 16 - RFID 915 MHz PASSIVE SYSTEM – PHOTOGRAPHS OF MULTIPLE TAGS TESTING

Damaged Tags

Many variations of opening and shorting the tag's antenna were evaluated. The tag either operated normally with a normal RF emission profile or the tag did not operate at all and with no emissions. Figures 17A and 17B show the emission profile from the composite of all damage tags. Figures 18 and 19 along with Table 1, identifies the damaged tag's configuration.

TABLE 1 - CIRCUIT VARIATIONS

Open Circuit Variations	Shorted Circuit Variations
a & i opened	#1
a, i, d, & h opened	#2
a, b, & c opened	#3
a, b, c, d, e, f, h, & i opened	#4
b & c opened	#5
j, k, & l opened	#6
k & n opened	
l, j, & o opened	
j, o, h, & i opened	
chip removed	

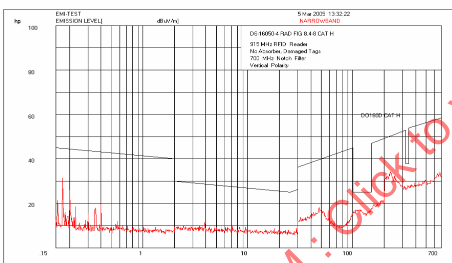

FIGURE 17A - 150 kHz TO 700 MHz

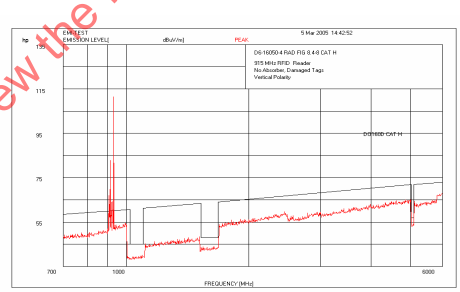

FIGURE 17B. 700 MHz TO 6 GHz

FIGURE 17 - RFID 915 MHz PASSIVE SYSTEM – RF RADIATED EMISSIONS – DAMAGED TAGS

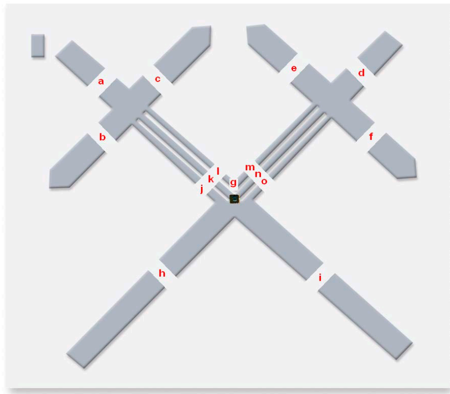

FIGURE 18A - DAMAGED TAG – LOCATIONS OF OPENED CIRCUITS

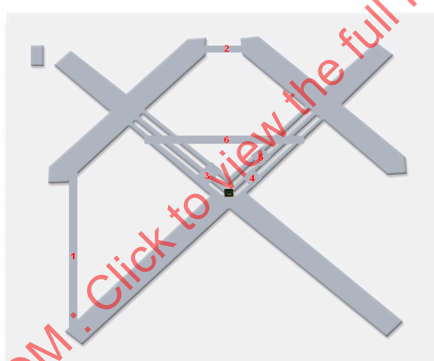

FIGURE 18B - DAMAGED TAG – LOCATIONS OF SHORTED CIRCUITS

FIGURE 18 - DAMAGED TAG LOCATIONS

FIGURE 19A - DAMAGED TAGS - OPENED

FIGURE 19B - DAMAGED TAGS - SHORTED

FIGURE 19C - ALL DAMAGED TAGS

FIGURE 19 - LAYOUT OF DAMAGED TAGS

In addition to the above damaged tag variations, one tag was damaged during the HIRF testing. This tag had a burned mark on the chip. See Figure 20C. A total of 17 damaged tags representing opens, shorts, and HIRF damage were adhered to a Styrofoam board. No spurious emissions were noted during the scan from 150 kHz to 6 GHz. The tags were also monitored for functionality. 10 of 17 communicated successfully with the reader.

5.4 Passive 915 MHz System – RF Radiated Susceptibility

HIRF (Damage Assessment)

Ten tags without the RFID antenna module were subjected to HIRF per DO-160D. The level was 100 V/m from 100 to 200 MHz (lab problems maintaining 200 V/m so level was reduced to 100 V/m for this lower frequency range) and 200 V/m from 200 MHz to 6 GHz. Both CW and AM (square wave) modulations were used along with vertical and horizontal antenna polarities. Dwell time was 1 second per step. (2 MHz from 100 to 200 MHz, 5 MHz steps 200 to 400 MHz, 10 MHz steps 400 to 1000 MHz, 15 MHz steps 1 to 1.7 GHz, 10 MHz steps 1.7 to 2.6 GHz, and 25 MHz steps 2.6 to 6 GHz.) During antenna changes, each tag was checked for functionality. Only one tag failed. This was during the 400 MHz to 1 GHz scan, 200 V/m, and vertical polarity. See Figure 20.

One tag was evaluated for HIRF using the laboratory horn antenna, 300 V/m SW and CW, from 900 to 930 MHz. After the test, functionality was checked and the tag was found ok (visually and operationally).