Harmonic Scattering from Passive UHF RFID Tags

Pavel V. Nikitin and K. V. S. Rao
Intermec Technologies Corporation
6001 36th Ave W, Everett, WA 98203
www.intermec.com
Email: {pavel.nikitin, kvs.rao}@intermec.com

Abstract

This paper discusses harmonic scattering from passive UHF RFID tags. We describe the problem and the basic theory; explain our measurement setup, and present experimental results for three different commercial Gen2 tags.

Introduction

Currently, there exists a strong interest from aircraft and airline industries in tagging airplane parts and cabin items using RFID tags. RF emissions from electronic devices (including various tags) which can interfere with aircraft systems and components have always been a concern for FAA and have been extensively studied and regulated [1-2]. Recent FAA RFID policy [3] relieved passive UHF tags on aircraft from complying with EMC/EMI requirements for active devices [4]. However, the level of harmonic backscattering from passive RFID tags remains the subject of interest, especially for environments where "pollution" of RF spectrum by spurious backscatter emissions is undesirable.

A typical RFID tag consists of an antenna directly connected to an integrated circuit with nonlinear RF front end. A common front-end architecture is diode-based voltage multiplier [5] that makes an RFID tag to appear as an antenna loaded with a nonlinear load. Unlike antenna terminated with constant impedance load or ideal modulator switch, such system has a nonlinear transfer function and can backscatter harmonics and intermodulation products when interrogated with the modulated or unmodulated reader signal [6]:

$$V_{out} = \alpha_0 + \alpha_1 V_{in} + \alpha_2 V_{in}^2 + \alpha_3 V_{in}^3 + \ldots , \qquad (1)$$

where V_{in} is the input signal, V_{out} is the output signal, and α_n are harmonic coefficients. Nonlinear harmonic generation has been extensively studied in antennas [7] and circuits [8] literature. This phenomenon also found a good use in harmonic radars [9]. In passive RFID, it was used in active antennas [10], location estimation [11], and tag radiation pattern measurement [6].

In this paper, we present an experimental characterization of harmonic scattering from three popular commercial passive UHF RFID Gen2 tags available on the market today (AD-222, AD-223, and AD-224). Due to our equipment limitation (highest operating frequency is 2.7 GHz), we concentrate on the analysis of first three harmonics whose powers are denoted as P_1, P_2, and P_3. The harmonic frequencies are 880 MHz, 1760 MHz, and 2640 MHz.

Measurement Setup

We employed in our measurements a compact broadband GTEM cell shown in Fig. 1. Such cells are often used for radiation and susceptibility testing and allow one to create a controlled uniform field at desired location, excluding from consideration frequency dependent responses of transmitting antenna and anechoic chamber material. An RF signal applied to port 1 generates an electric field inside the cell which can be expressed in terms of input voltage V_{in} (or power P_{in} , both rms), input impedance Z, and cell height h at specific cross-section (the distance between the center conductor and the ground wall) as [12]:

$$E = \frac{V_{in}}{h} = \frac{\sqrt{P_{in} Z}}{h} \quad . \tag{2}$$

A specific TEM cell used in measurements was TESCOM TC5060 (S11<-15 dB in 0.4-3 GHz band). In the tests, an RFID tag was placed inside the cell (where h=22 cm). Field backscattered from the tag was detected with the sensing probe antenna connected to the port 2 as shown in Fig. 1. The antenna was simple half-wavelength dipole (no balun) printed on FR4 and located 10 cm away from tag.

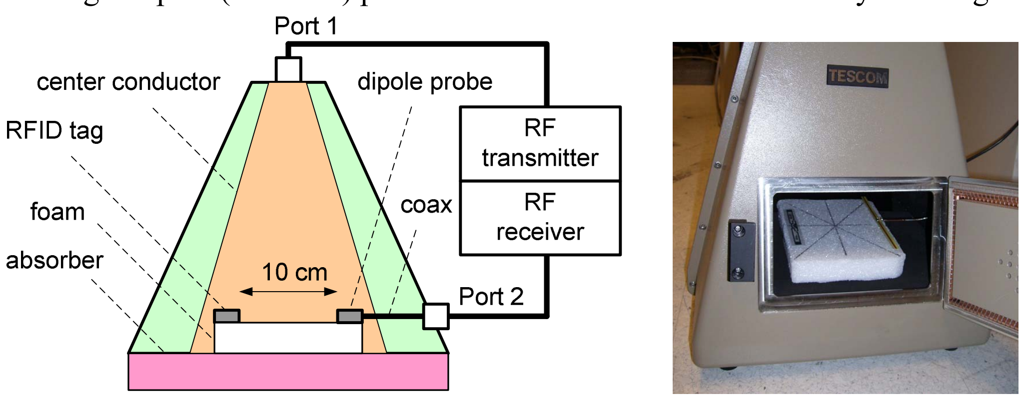

Figure 1. Measurement setup with TEM cell: diagram and photograph.

Figure 2. Tags used in measurements, left to right: AD-222 (Impinj Monza 2 IC), AD-223 (Impinj Monza 3 IC), and AD-224 (NXP G2XM IC).

The tags used in tests were from AD-22x family by Avery Dennison [13] and are shown in Figure 2. They had different RFID ICs but similar dipole-like antennas. In Fig. 1, RF transmitter / RF receiver combo connected to ports 1 and 2 represents one of three equipment configurations used in measurements: a) RF network analyzer used for S-measurements of ports 1 and 2 (Agilent E5071C); b) RFID tag tester used for determining the minimum power needed to activate (read) tags in TEM cell (NI PXI RFID tester described in [14]); c) RF signal generator and spectrum analyzer used for creating and measuring harmonics (NI PXI-5671 and NI PXI-5660 operating in 300 KHz-2.7 GHz band and running appropriate LabVIEW applications for RF CW generation and spectrum analysis).

Measurement Results

Figure 3 shows that the main resonances of probe (S22) are 880 MHz and 2640 MHz. Measured path loss S21 (-14 dB at 880 MHz, -32 dB at 1760 MHz, and -30 dB at 2640 MHz) shows how the power received by the probe varies with frequency (field strength inside cell remains constant during S21 measurement).

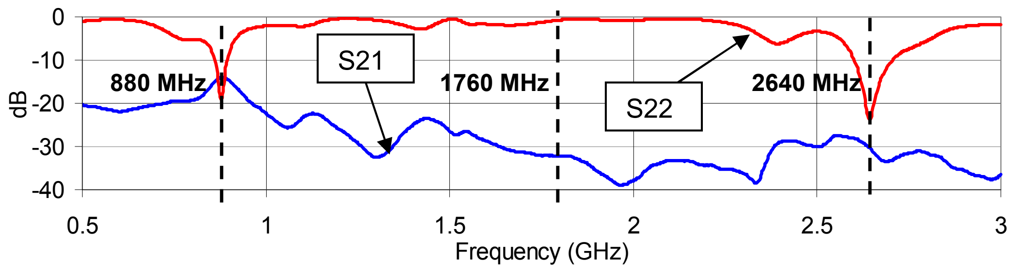

Figure 3. Probe return loss (S22) and path loss (S21) of TEM cell.

Figure 4 shows that minimum power sensitivity thresholds in TEM cell at 880 MHz are 6 dbm, 1 dBm, and 3 dBm for AD-222, AD-223, and AD-224 accordingly. For all tags, 3rd harmonic power increases with input power.

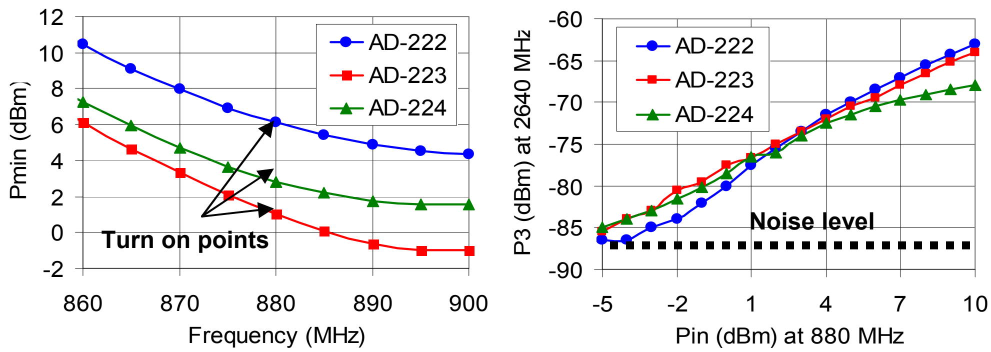

Figure 4. Minimum power needed to activate tags in TEM cell (left) and the power of third harmonic as a function of input power at 880 MHz (right).

Table 1 shows that harmonics are present even in the absence of tag (due to transmitter spectrum). The 1st harmonic from the tag destructively interferes with the cell field, lowering P_1 by 2 dB. No significant 2nd harmonics due to tags were observed. The 3rd harmonic distortion can be calculated as $HD_3 = (P_3 / P_1) \cdot (S21_1 / S21_3)$ and gives -41 dB for AD-222. 3rd harmonic field (V/m) at probe location can also be easily found as $E_3 = (1/h) \cdot \sqrt{(P_3 Z / S21_3)}$.

Harmonic power	Transmitter OFF	No tag	AD-222	AD-223	AD-224
P_1 (dBm)	-91	-4	-6	-6	-6
P_2 (dBm)	-90	-72	-72	-72	-72
P_3 (dBm)	-87	-86	-63	-64	-68

Table 1: Measured powers of harmonics for 10 dBm 880 MHz input signal.

Discussion and Conclusions

An RFID tag consists of an antenna and a chip and is usually designed to operate in a specific frequency band where inductive impedance of the antenna is close to complex conjugate of capacitive impedance of the chip. This causes the tag to act as a resonance system with filtering properties. Most tags have dipole-like antennas which can resonate at odd harmonics and scatter those as well, while scattering of even harmonics is suppressed, as we observed in measurements. All tag backscatter emissions can potentially be mitigated by adding a dedicated bandpass filter to the tag antenna.

We conclude that current passive UHF RFID tags can generate and scatter harmonics and intermodulation products whose powers depends on specific tag details (chip and antenna), as well as power and spectral content of interrogation signal. Harmonic scattering from RFID tags can be characterized in controlled EM environment such as TEM cell as shown in this paper.

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