Gain Measurement of Antennas using RFID

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***Abstract*— This paper presents a method for contactless gain measurements of 50 Ohm antennas. The method is based on connecting a special passive RFID chip assembly, matched to 50 Ohm in the wide band, to the antenna and measuring the read sensitivity of the resulting tag in the tag characterization system. The gain of the antenna is then calculated from previous calibrated measurement done with reference antenna of known gain, such as dipole. We illustrate the method with experimental measurements on several antennas. The main advantage of this method is that it does not require any external cables and can be used for characterization of small antennas inside modern mobile wireless devices.**

Keywords-antennas; RFID; measurements

I. INTRODUCTION

Antenna gain measurements constitute a well established technical field [1-3]. However, almost all current antenna measurement techniques require coaxial cable to be connected to the antenna to be tested which affects the measurement results and makes it difficult to measure antenna and pattern of small antennas integrated into handheld or mobile devices.

Existing methods for contactless antenna measurements include optical modulation [4-6], using fixed impedance loads [7], and special small battery operated RF transceivers [8-10]. Gains of RFID tag antennas have been measured before in-situ [11-12] (as well as using cables [13]) but in those contactless measurements the tag antenna was an integral part of the tag (matched to complex IC impedance) and could not be replaced with an arbitrary 50 Ohm antenna.

Here, we propose a method to measure the realized gain pattern of any antenna using passive RFID tag characterization setup. Such setups can already be found in many companies which develop RFID and wireless products. They typically consist of an anechoic chamber and RFID reader with variable output power and frequency. Such specialized readers are readily available from test equipment companies (such as Voyantic), can be constructed from National Instruments PXI RF hardware [14], or even made simply and inexpensively using a standard RFID reader and a bank of controllable attenuators. The main advantage of the proposed method is that it allows one to measure contactlessly and accurately in the wide frequency range the gain of various antennas (RFID, Wi-Fi, GPS, WAN, Bluetooth, etc.) integrated inside compact mobile wireless devices without using external cables which can severely affect measurement results for small low gain antennas.

II. METHOD

The proposed method is based on creating a special passive RFID chip assembly matched to 50 Ohm, connecting it to the 50 Ohm antenna under test, and measuring the sensitivity of the resulting tag in the tag characterization system such as shown in Fig. 1.

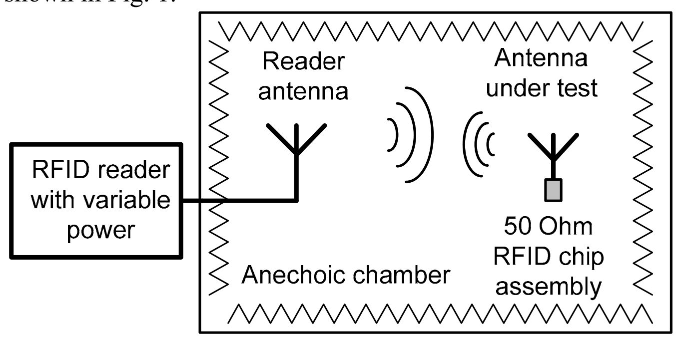

Figure 1. Proposed method for measuring antenna gain.

The read sensitivity P of the tag formed by the antenna under test and the matched chip assembly is the minimum incident power needed to read the tag ID and is given by:

$$P_{tag} = \frac{P_{chip}}{G \tau \, p} \quad (1)$$

where P_{chip} is the chip sensitivity, G is the gain of the tag antenna in the direction of the reader antenna, τ is the impedance matching coefficient, and p is the polarization efficiency. The product $G\tau$ is the realized gain of the tag antenna which includes the effect of impedance mismatch for a particular load (chip assembly).

First, a measurement of tag sensitivity P_{ref} is done using a reference antenna of known realized gain $(G\tau)_{ref}$ connected to matched chip assembly. Then, the same measurement is repeated with antenna under test (AUT). Assuming matched polarizations, the realized gain of the AUT antenna can then be found as:

$$(G\tau)_{AUT} = (G\tau)_{ref} \frac{P_{ref}}{P_{AUT}} \quad . \quad (2)$$

III. PRACTICAL IMPLEMENTATION

A. RFID IC assembly

The RFID chip assembly was built using Impinj Gen2 Monza 2 IC in TSSOP package mounted on 60 mil FR4 board (25 mm x 25 mm) with SMA connector and matched to 50 Ohm in wide frequency band. To further improve VSWR and isolation, we used an external 6 dB attenuator. The IC assembly is shown in Fig. 2. The passive matching network is shown in Fig. 3. The values of the discrete matching components were: L1=L2=18 nH, L3=27 nH, C1=C2=100 pF.

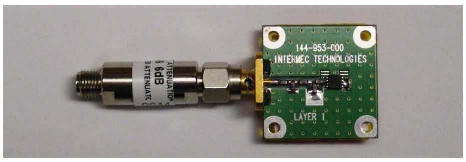

Figure 2. RFID IC assembly (board and 6 dB attenuator) matched to 50 Ohm.

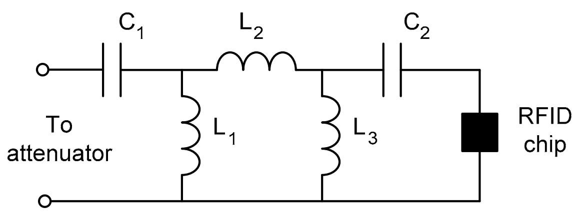

Figure 3. Passive matching network on board of RFID IC assembly.

The minimum power to activate RFID chip assembly (read chip ID) was measured with RFID reader test equipment (described in section C) and is shown in Fig. 4. These results are in agreement with Impinj Monza 2 IC sensitivity measurements and specifications [15]. The return loss of the IC assembly was also measured with network analyzer at different power levels. As shown in Fig. 5, it was better than 15 dB across 800-1000 MHz band..

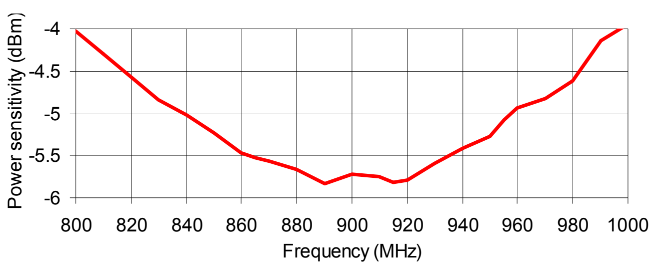

Figure 4. Minimum power to activate RFID IC assembly.

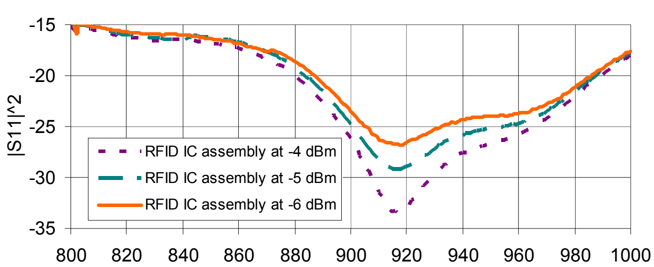

Figure 5. Return loss of RFID IC assembly (measured with network analyzer at -5 dBm output power) and of reference dipole.

B. Reference antenna

For reference, we built a wideband bowtie dipole antenna (dimensions 120 mm x 20 mm) which is shown in Fig. 6 connected to RFID IC assembly. This antenna was modeled and simulated with Ansoft HFSS (the geometry screenshot is shown in Fig. 7). The simulated gain and the return loss are given in Fig. 8 and 9 and compared with network analyzer data. The antenna had VSWR<2 in 850-1000 MHz band.

Figure 6. Reference dipole antenna connected to 50 Ohm RFID IC assembly.

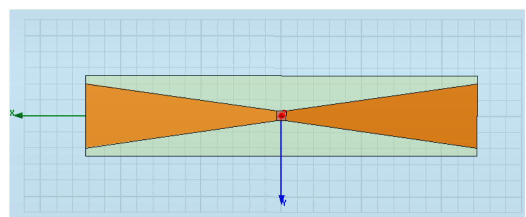

Figure 7. Reference dipole antenna geometry in HFSS.

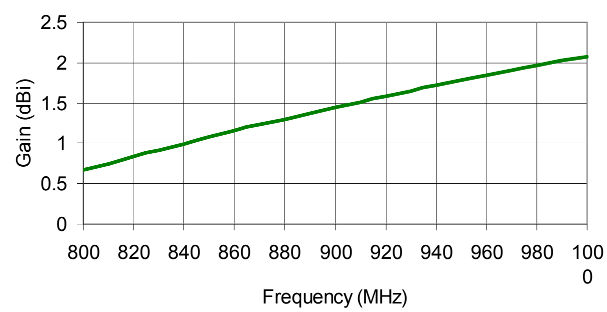

Figure 8. Gain of the reference dipole antenna (from HFSS simulation).

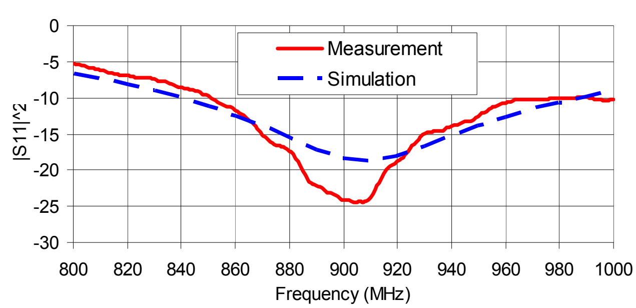

Figure 9. Return loss of the reference dipole (measurement and simulation).

C. *Measurement equipment*

Our test measurement equipment was based on Intermec Gen2 RFID reader with variable frequency, power, controllable Gen2 protocol settings, and modified RF front end (to allow wideband characterization). Antennas under test were connected to RFID IC assembly and placed on a foam stand at fixed distance (2 ft) from the 6 dBi wideband (800-1000 MHz) linearly polarized log-periodic reader antenna (Sinclair SRL441U) inside a compact anechoic chamber, as shown in Fig. 10. The reader output power was changed in 0.1 dB steps using a bank of programmable attenuators. The minimum transmitted power $P_{\min}$ needed to read the tag with 90% success rate (9 out of 10 queries) was measured.

Figure 10. Gain measurement based on passive RFID characterization setup.

The tag read sensitivity was calculated as

$$P_{tag} = P_{min}\, G_{reader} \left(\frac{\lambda}{4\pi d} \right)^{2}, \qquad (3)$$

where G_{reader} is the gain of the reader antenna, λ is the wavelength, and d is the distance to the tag (this distance was frequency-dependent in our case because the phase center of log-periodic reader antenna shifted with frequency).

D. *Antennas under test*

To illustrate the method, we present the results for two commercial circularly polarized ceramic patch antennas: small (24 x 24 x 4 mm) and large (80 x 80 x 6 mm). The antennas connected to IC assembly are shown in Fig. 11 and Fig. 12.

Figure 11. Small ceramic patch antenna connected to RFID IC assembly.

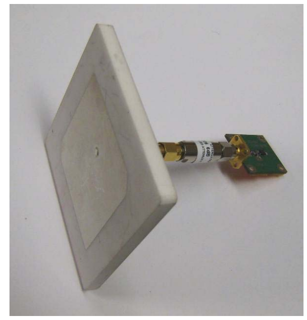

Figure 12. Large ceramic patch antenna connected to RFID IC assembly.

E. *Measurement results*

Fig. 13 shows the return loss of the reference dipole, large, and small patch antennas. Large patch antenna is tuned to US ISM band 902-928 MHz while small patch antenna operates in European band (865-870 MHz). Fig. 14 shows the measured minimum power to activate the tag formed with IC assembly connected to each of our three antennas (reference dipole and two patches) in boresight direction. Patch antennas were measured in both horizontal and vertical orientations.

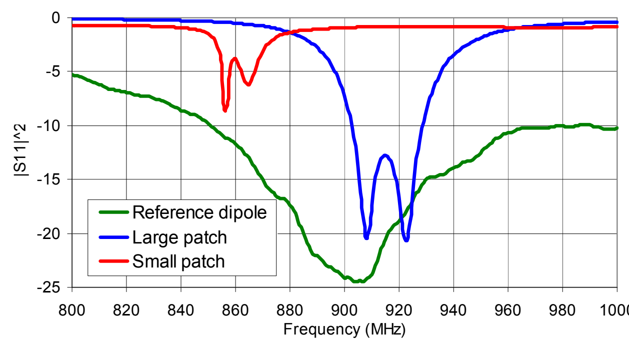

Figure 13. Return loss of the reference dipole and two patch antennas.

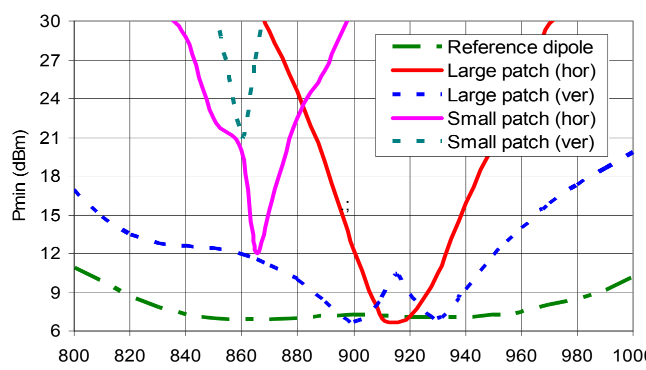

Figure 14. Minimum transmitted power to read the tag formed with chip assembly and each of the three antennas (reference dipole and two patches).

Fig. 15 shows the gains of the patch antennas calculated from measured tag sensitivity (Eq. 2). From that plot, axial ratios can also easily be found. These results agree with both ceramic patch antenna specifications. For reference, the realized gain of the reference dipole (calculated as a product of simulated gain and the impedance matching coefficient obtained form the measured return loss) is also plotted.

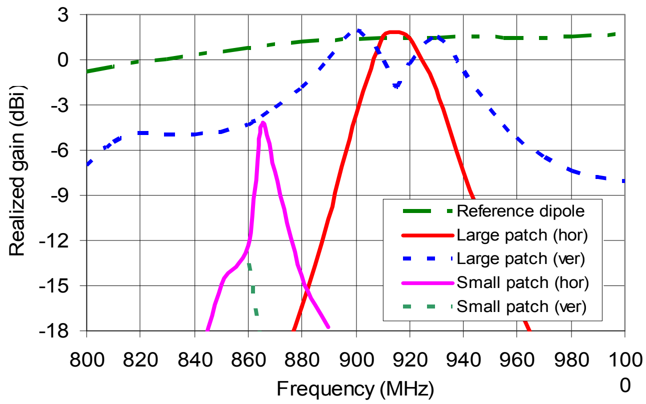

Figure 15. Realized gain of the two ceramic patch antennas (measured using our method) and reference dipole (simulated with HFSS).

IV. Discussion

The RFID IC assembly used in experiments was built on relatively large (25 x 25 mm) board with SMA connector. However, because the only components required (besides attenuator) are passive RFID IC and a few discrete matching components, it can potentially be miniaturized to a very small size (less than 10 x 10 mm), especially if one uses latest RFID IC in small package (such as Impinj Monza 4 in uDFN or NXP UCODE G2iL in SOT886) and miniature RF connector (such as Hirose or MMCX). Such assembly will never need batteries and can be completely sealed and EM shielded. Such miniaturization and lifetime would not be possible for small active RF transceivers used in contactless antenna characterization [8-10]. The attenuator value (6 dB) which we chose for the matched RFID IC assembly was a tradeoff between improving the VSWR of the assembly and its sensitivity, necessary to measure the gains of low gain antennas, such as small ceramic patch. A higher value attenuator could be used if better sensitivity RFID IC is used.

One can also measure a general antenna gain by replacing the RFID reader antenna with antenna under test and characterizing the reference tag of known sensitivity. Using the 50 Ohm matched IC assembly one can easily construct such reference tag from any desired 50 Ohm antenna. In this paper, we chose to build our own reference antenna and use its simulated gain as a reference. One can also use a commercial reference antenna and characterize it experimentally.

In perspective, our measurement method can be considered to be a part of general RFID tag antenna-based sensing [16-17], where the change of the tag antenna gain can be detected by the reader if the reference tag characteristics (such as sensitivity) are known or pre-measured.

V. Conclusions

In this paper, we described a method for measurement of the realized gain pattern of any antenna using RFID and provided experimental results for two antennas. The method is based on connecting a 50 Ohm matched IC assembly to the antenna and measuring the sensitivity of the resulting tag. The gain of the antenna is then calculated using calibrated measurement with a known reference antenna.

The presented method allows one to measure a general antenna gain simply and quickly without any modification to existing RFID tag characterization setup. It can be used to measure the gain patterns of internal antennas in mobile devices without using any external cables. The absence of cables gives better accuracy when characterizing small low-gain antennas and also allows one to easily rotate the device under test during antenna pattern measurements.

Acknowledgements

The authors would like to thank their Intermec colleague Sander Lam for making the matched chip assembly.

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