The Effects of a Metal Ground Plane on RFID Tag Antennas†

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Introduction

Although the popularity of RFID is growing, many problems still exist with widespread implementation using current technology. One critical problem is on-object degradations of antennas that are placed on conducting objects. In order for RFID to reach its full potential, much research is needed to design a system that minimizes the effects of nearby objects. Griffin [1] performed experiments placing thin tag antennas on many different types of materials, and Dobkin and Weigand [2] experimentally measured the effect on RFID tag read range in the presence of a ground plane. Raumonen et. al. simulated the impedance and gain as an antenna was moved away from a ground plane. This paper presents measured antenna impedance and patterns of a horizontally oriented folded dipole as it is moved toward a metal ground plane. The 915 MHz measurements on different antennas provide rules-of-thumb for RFID link design and suggest that changing antenna thicknesses may make tags more resistant to on-object degradations.

Simulations

To understand the expected outcome of the experiments, input impedance and pattern simulations of the antenna at various distances from the ground plane were created using Numerical Electromagnetics Code (NEC). The modeled tag antenna was a half wave, folded dipole designed for 915MHz. Figure 1 shows the real and imaginary parts of the antenna's input impedance versus the electromagnetic distance from an infinite, perfectly conducting ground plane.

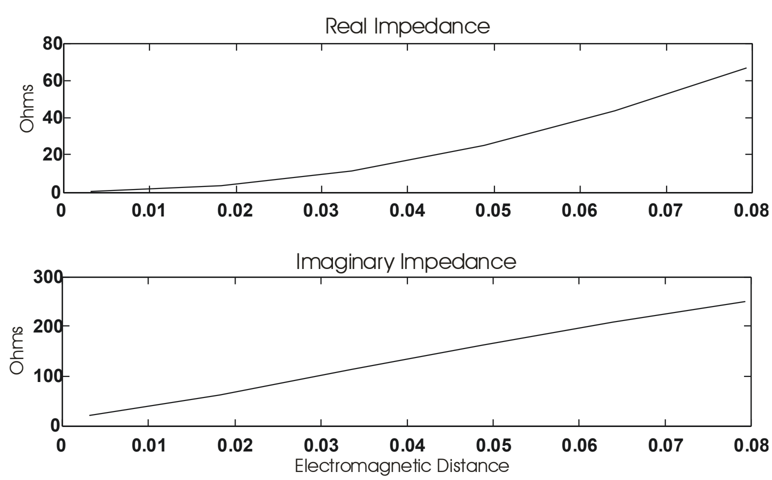


Fig. 1: The simulated real and imaginary impedance components of a half wave folded dipole versus distance from a perfectly conducting half-plane at 915 MHz.

†This work is sponsored by a grant from the Georgia Tech Foundation.

The simulated antenna pattern resembled the traditional figure-eight, free-space dipole pattern without the back-lobe. As the antenna moved toward the ground plane, the pattern became more directive, but the basic shape remained the same.

Experimental Methods

In order to test the simulations and gain a greater understanding of the effects of a ground plane, the impedance and gain patterns of three antennas were experimentally measured at 915Mhz. The baseline antenna was made of milled copper on an FR4 substrate with dimensions conforming to those specified by Griffin [1] and given in Figure 2. Another antenna with the same dimensions was created using a silver paste painted with a mask on a thin, flexible plastic substrate. Finally, the third antenna with a thinner trace width was created on a flexible plastic substrate using silver paste.

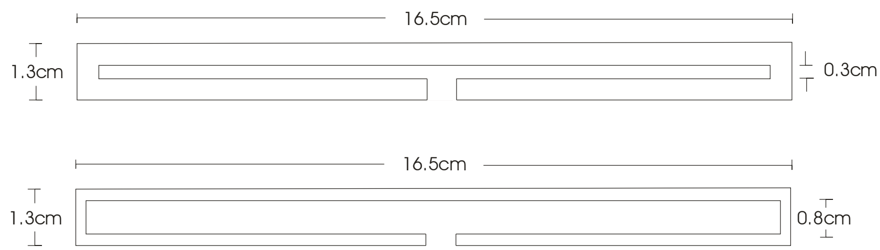


Figure 2: Dimensions of the thick (copper baseline and silver) and thin (silver) antenna.

Each antenna was placed on cardboard (assumed to be electromagnetically transparent) that was 0.6cm thick and then attached to an aluminum ground plane with dimensions 40 by 34 centimeters. The antenna was moved in 0.3cm increments from the plane by placing an additional piece of cardboard behind the antenna.

At each increment the input impedance was measured using an Agilent E5071B network analyzer. The network analyzer was calibrated to the ends of the transmission line that fed the balun and antenna. Thus, all reported impedances are the combined impedance of the balun and the antenna.

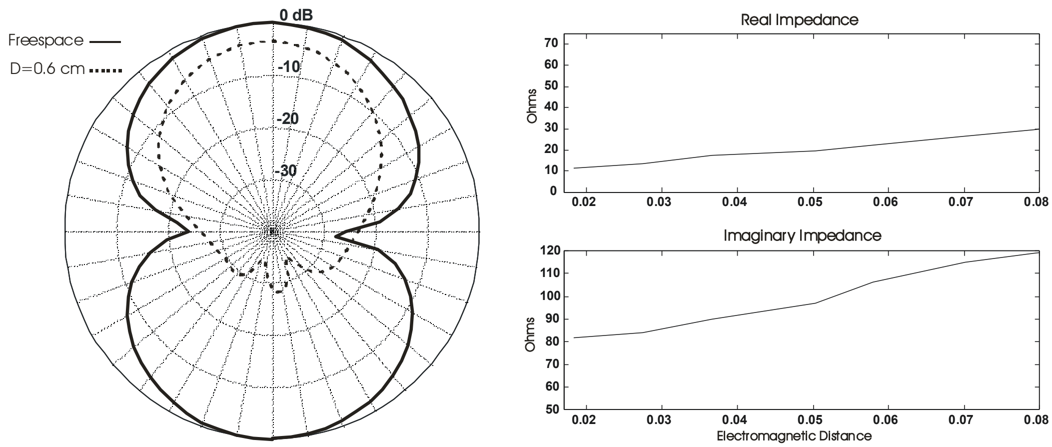
The antenna patterns were obtained using an outdoor antenna range. The tags were fed by a continuous wave signal generator outputting a 915MHz signal connected to the balun by a coaxial cable. Since the input impedance of the antenna was unlikely to match the 50 ohm impedance of the coaxial cable, the mismatch was mathematically calculated with Equation 1 where the measured impedance of the antenna was Z_L. The power lost due to mismatch was calibrated out of the reported gain values to separate observed changes in an antenna's radiation properties from an antenna's equivalent impedance.

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} \qquad \textbf{(1)}$$

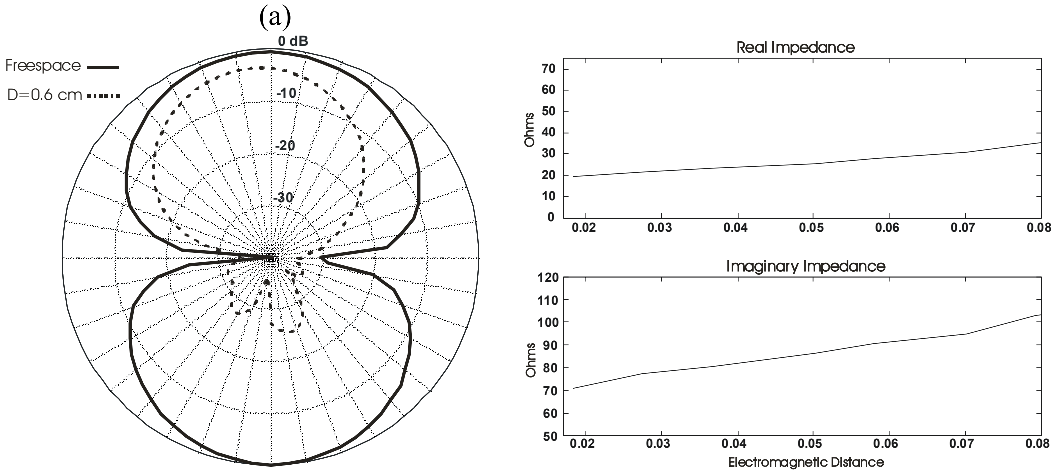
The signal was transmitted 8.3 meters to a horn antenna where it was filtered and measured using an Agilent E4407B spectrum analyzer in zero span mode. In addition to the measurements with the ground plane, a free space measurement was also taken.

Results

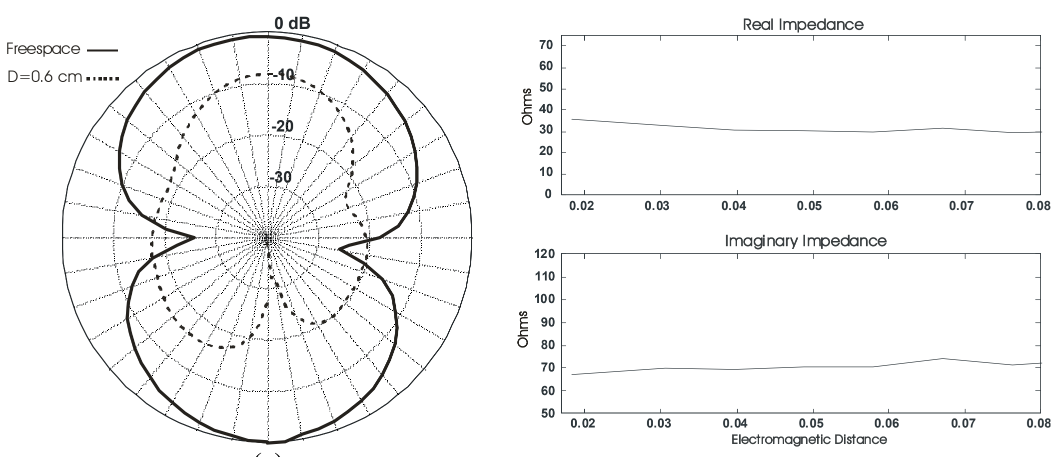
The left side of Figure 3 shows the antenna pattern for each of the antennas in free space, and the antennas 0.6cm away from the metal plane. The right side is the antenna's equivalent impedance as each antenna is moved from 0.6cm to 2.9cm away from the plane in increments of 0.3cm.



(a)



(b)



(c)

Fig. 3: Antenna pattern (normalized to free space) and impedance measurements of the copper (a), the thick silver paste (b), and thin silver paste (c) half-wave folded dipoles at 915 MHz.

Table 1: Impedance (Ohms) versus distance			
Distance (cm)	**Copper**	**Silver**	**Thin**
Freespace	71.0 + j112	48.4 + j87.7	39.6 + j60.5
0.6	11.2 + j81.7	19.6 + j70.8	35.6 + j67.1
0.9	13.4 + j84.1	21.3 + j77.3	32.7 + j69.9
1.3	17.4 + j89.9	23.3 + j80.2	30.8 + j69.3
1.6	19.7 + j97.2	25.6 + j86.2	30.4 + j70.4
2.0	22.3 + j106	27.8 + j90.5	30.0 + j70.7
2.3	26.3 + j115	30.6 + j94.8	31.4 + j74.3
2.6	29.4 + j118	35.1 + j103	29.6 + j71.3

Table 2: Gain penalty due to ground plane (dB)			
Distance (cm)	**Copper**	**Silver**	**Thin**
0.6	4.7	4.2	8.6
0.9	3.0	2.4	5.5
1.3	1.2	1.2	4.1
1.6	0.3	0.5	2.1
2.0	0.4	0.1	1.1
2.3	1.1	0.6	0.9
2.6	1.5	1.1	0.1
2.9	1.9	1.5	0.7

The antenna patterns above show that the antenna beamwidths drop when they are placed close to the metal. Even though the antennas become more directive in the presence of a ground plane, Table 2 shows that once inside two centimeters the effects of the ground plane on the radiation cause the antennas to lose 0.1 to 8.6 dB of gain when compared to free space.

The full-sized copper and silver antennas have similar performance when in free space and in the presence of the ground plane. The thin antenna has higher Ohmic losses and therefore, is approximately four decibels less efficient than the full sized antennas in free space; however, the impedance of the thin antenna is less affected by the ground plane than the thicker antennas. This characteristic might make the thinner antenna a good candidate for use close to a metal ground plane.

The impedance measurements are important for the design engineer to study for several reasons. First, the electrical loading of an RFID antenna must be designed for maximum power transfer. Otherwise, the tag cannot power-up for communications. A second reason relates to how efficiently an RFID tag backscatters power in the communication link. In a modulated backscatter scheme, information is encoded by switching between short and open circuit loads relative to the input impedance of the tag antenna; however, if the antenna has a very low impedance, it becomes impossible to short-circuit the antenna's load with a conventional RF semiconductor junction. The impedance graphs provided in Figure 3 allow the design engineer to relate antenna input impedance with tag-metal separation distances.

Conclusions

The impedance and gain patterns were studied when three different folded dipoles were moved very close to a metal ground plane. Although the impedances were smaller than free space, they were not too small to radiate, and the gain penalty for placing the object close to the ground plane was reasonable. This study gives the design engineer some direct measurements to help make decisions regarding folded dipole placement very close to a metal ground plane.

References:

[1] Joshua D. Griffin, Gregory Durgin, Andreas Haldi, and Bernard Kippelen, "Radio Link Budgets for 915MHz RFID Antennas Placed on Various Objects," *WCNG Wireless Symposium, Austin TX,* October 2005.

[2] D. M. Dobkin and S. M. Weigand, "Environmental Effects on RFID TagAntennas," in *IEEE International Microwave Symposium*, June 2005.

[3] P. Raumonen, L. Sydanheimo, L. Ukkonen, M. Keskilammi, M. Kivikoski, "Folded dipole antenna near metal plate," *Antennas and Propagation Society International Symposium*, 2003.