UHF Isolator for RFID

Gregory D. Durgin

***Abstract*— An *isolator* in RF engineering is an thin spacer placed between an antenna and an electromagnetically lossy object to improve radiation characteristics. Isolators are commonly used in RFID to overcome losses when RFID tags are placed on metallic objects. This set of notes provides an overview of UHF (Ultra-high-frequency) and microwave isolator operation.**

In UHF RFID, on-object degradations result from field boundary conditions similar to the on-metal HF RFID case [1]. Consider the normal-incident electromagnetic wave on a dielectric substance in Figure 1(a). The field boundary conditions dictate that the reflection coefficient at the air-dielectric interface becomes

$$\Gamma = \frac{\sqrt{\mu_r} - \sqrt{\epsilon_r}}{\sqrt{\mu_r} + \sqrt{\epsilon_r}} \tag{1}$$

For the majority of dielectric materials, relative permittivity is greater than unity ($\epsilon_r > 1$) and relative permeability is nearly its free space value ($\mu_r \approx 1$). Under this scenario, the reflection coefficient in Equation (1) will *always* be negative, implying a reflecting electric field that will partially or completely cancel the electric field due to the incoming wave. It should be noted that the opposite is true of the magnetic field, which will constructively reinforce along the reflection surface as illustrated in Figure 1(b).

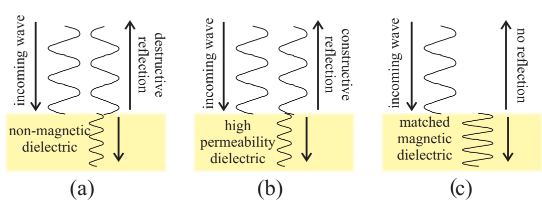

Fig. 1. Three categories of interface: (a) non-magnetic, where electric field cancelation occurs (similar to a conductive interface), (b) magnetic ($\mu_r > \epsilon_r$), where electric field reinforcement occurs, and (c) matched ($\mu_r \approx \epsilon_r$), where no reflection occurs.

This electric field behavior has serious implications for UHF RFID antennas. Thin peel-and-stick RFID tag antennas are trapped in the two-dimensional plane of their object surface. These antennas must use their metallic traces to accumulate enough electric field along the surface of the object to provide a power-up or communicative voltage to its RFIC. With significant cancelation of tangential electric fields, this becomes nearly impossible. In terms of far-field antenna properties, the on-object degradation most significantly manifests itself as a precipitous drop in the RFID antenna's radiation impedance, making impossible to couple power into a typical RFIC. Figure 2 illustrates this drop in real and imaginary radiation impedance as a half-wave dipole is brought closer and closer to a metallic surface.

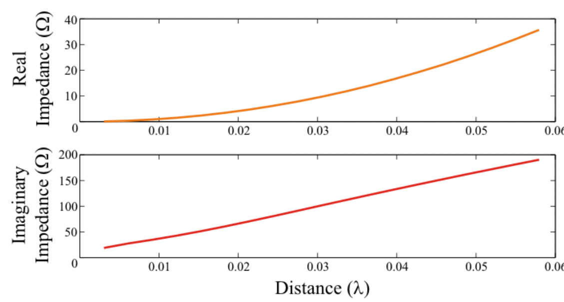

Fig. 2. Illustration of how real-valued radiation impedance drops for an ideal half-wave dipole as it draws closer to a conductive metal surface [2].

There are a number of techniques used by antenna engineering to circumvent this problem solutions, with Table 3 summarizing some of the most common types and their relative trade-offs. The only truly broadband solutions for antenna isolation involve using engineered RFID substrates where the dielectric has significant relative permeability, $\mu_r > 1$. In fact, if $\mu_r > \epsilon_r$, we can see from Figure 1 that there would actually be a *constructive* electric field reflection coefficient at the material interface where the RFID tag antenna is placed. This would dramatically increase the efficiency of the antenna at *all* frequencies.

References

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Fig. 3. A summary of techniques used to isolate UHF RFID antennas from dielectric and conductive objects. Table is meant to show *qualitative* differences in techniques.

	Planar-F Antenna	PCB Patch Antenna	Printed Dipole Folding	Super Permittivity Spacer	Magnetic Spacer	Absorptive Spacer	Surface-Coupled Antenna	Artificial Magnetic Conductor
low cost	poor	poor	excellent	good	good	good	good	terrible
on-metal improvement	excellent	excellent	poor	poor	fair	good	good	excellent
on-dielectric improvement	fair	excellent	terrible	good	good	fair	poor	excellent
thinness	terrible	fair	excellent	good	good	excellent	excellent	poor
industry acceptance	good	good	good	poor	poor	poor	poor	fair
RFIC integration	poor	poor	excellent	excellent	excellent	excellent	fair	poor
high bandwidth	fair	poor	poor	terrible	excellent	good	fair	poor
omni radiation	excellent	excellent	excellent	good	good	fair	good	good
small footprint	excellent	fair	poor	fair	good	fair	good	fair
printability	terrible	terrible	excellent	excellent	excellent	excellent	fair	terrible
radiation efficiency	excellent	excellent	excellent	excellent	good	good	good	excellent
flexibility	terrible	terrible	excellent	excellent	excellent	excellent	excellent	terrible

○ **terrible** ◢ **poor** ◐ **fair** ◔ **good** ● **excellent**

Planar-F Antenna	The general shape of this antenna – 90° bent metal flange attached and tuned in a compact space – still requires some vertical protrusion above a surface and does not lend itself to the peel-and-stick functionality of RFID.
PCB Patch Antenna	Patch antennas on printed circuit board (PCB) function well on materials, but are too costly and inflexible for most RFID applications. Thinness is difficult to achieve for 1 GHz systems and lower [3].
Printed Dipole Folding	Folded dipole antennas on a 2D plastic surface is a common way in RFID to make a thin tag antenna with increased radiation impedance. The free-space radiation impedance of this antenna increases for each fold incorporated in the dipole. Thus, by starting with a large value in free space, the folded dipole's radiation impedance drops to a value that can still couple some received power into the RFIC [4].
Super-Permittivity Spacer	Use of a high-permittivity dielectric substrate of a few millimeters or less allows resonant antennas, such as a patch, to radiate on objects; this solution tends to be extraordinarily narrowband [3].
Magnetic Spacer	A magnetic spacer (a dielectric substrate with high permeability) would allow constructive field reinforcement on its surface across a broad band [1], [5].
Absorptive Spacer	An absorptive spacer is a low-conductivity substrate between object and antenna that tries to accept and attenuate an incoming wave. Often relying on a matched interface, illustrated in Figure 1(c), this is also the principle behind low-observability materials in radar. Ideally, this partially suppresses field cancelation along the surface, unless the spacer is *too* conductive.
Surface-Coupled Antenna	In some circumstances, it is possible to ground the antenna against a metal object with an electrical connection. This is obviously not practical for general RFID tag use.
Artificial Magnetic Conductor	PCBs with tessellated conductive elements and metallic vias create resonant structures that mimic a substance with magnetic current (similar to high permeability). Such PCBs allow antennas to radiate directly on their surface at the resonant frequency [6].

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