HF Isolator for RFID

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***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 HF (high-frequency) isolator operation using magnetic circuit theory.**

Relying entirely on inductive coupling of magnetic near-fields, the high frequency (HF) RFID tag collects the magnetic flux circulating around a square or circular loop reader antenna. The flux that makes it *through* the RFID tag's coils excites a voltage around the coil path, which powers-up the terminals of the tag's RFIC. As the magnetic field sketch in Figure 1 illustrates, it becomes extremely difficult to get magnetic flux through the RFID tag coil when it rests on a metallic object. One way to construct the total magnetic field solution of an RFID reader antenna operating in the presence of a flat metal surface is to use the method of images. Thus, in Figure 1 (left), the total magnetic field above the conductive surface is the sum of the free-space fields due to the RFID reader antenna and its virtual, mirror-image current on the other side of the material interface. The net effect is that surface fields are forced to travel parallel to the metal plane.

The on-metal degradation of HF RFID tags (those operating from 3-30 MHz) can best be explained using magnetic flux circuits. In a flux circuit, magnetic flux takes the place of electrical current in a conventional circuit; instead of voltage sources, the magnetic circuit is excited by *magneto-motive force*, $\mathcal{V}$ – a loop or coil of current that effectively energizes the magnetic flux. Because magnetic flux is neither created nor destroyed, it follows a Kirchhoff current law just like electrical current. The net magnetic flux into any node within the flux circuit must be zero. Likewise, magneto-motive force satisfies the same conservation properties as its counterpart, voltage, in electric circuits. When summed around any arbitrary loop, the quantity we define as total magneto-motive force must equal zero in the magnetic circuit – just like Kirchhoff's voltage law.

To complete the analogy, we need a physical quantity in a magnetic circuit to serve as the analogy to resistance; then we can apply Ohm's law and calculate how magnetic flux might distribute itself in an inhomogeneous collection of materials. This resistive term is called *reluctance*, $\mathcal{R}$, in a flux circuit and quantifies how easily magnetic flux is conducted through an object. Reluctance is inversely proportional to material permeability and has the same relationship to geometry as resistance. For simple objects with prismatic structure – a cross-sectional area A and a length L – the reluctance takes on the following approximate form:

$$\mathcal{R} = \frac{L}{\mu A} \tag{1}$$

Note the similarity in the definition of Equation (1) to the formula for resistance in an electrical circuit, where permeability, μ, is simply replaced by conductivity, σ, for a structure with identical geometry. In most flux circuits, Equation (1) serves as rough guideline, since the overall reluctance is difficult to calculate for an irregular, non-prismatic object.

With the flux circuit analogy in mind, consider what happens when an RFID tag approaches a metallic surface in Figure 1. Almost all of the magnetic flux circumvents the tag's coil aperture because the fields would have to travel through an area of extremely high reluctance, $\mathcal{R}_{\text{tag}}$: through the very narrow opening between the metallic surface and the coil traces of a tag. One way to improve the flux coupling is to place a magnetic isolator pad underneath the RF tag. Such a pad is usually a polymer impregnated with iron oxide or tiny iron particles that yield a high permeability in the HF bands. The additional spacer, coupled with the larger μ-value, dramatically lower the reluctance through the tag. Now a significant amount of magnetic flux will travel through the RFID tag coils instead of entirely through the return paths, $\mathcal{R}_{\text{around}}$.

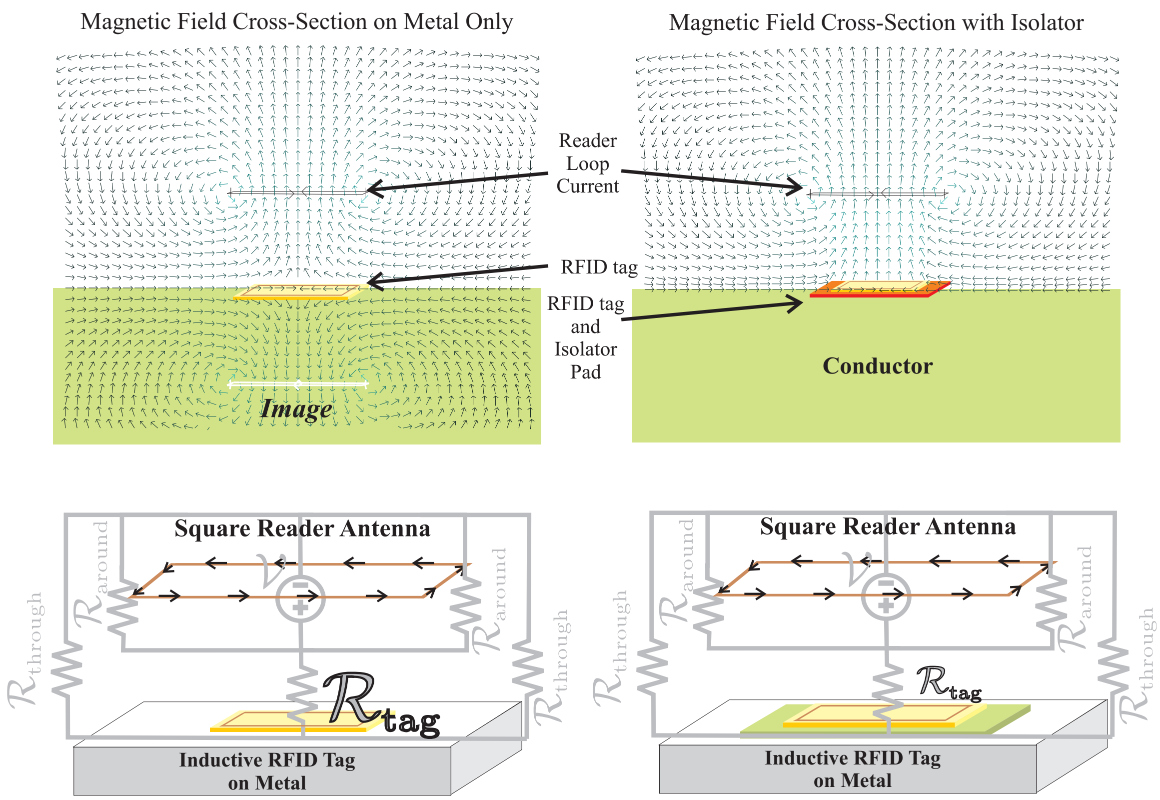

Fig. 1. Example of on-metal HF RFID tags excited by a square loop with equivalent magnetic flux circuits. The left case demonstrates how a simple tag struggles to collect enough magnetic flux through its tag coils to operate. The right case demonstrates how a high-permeability isolator allows additional flux through the tag.