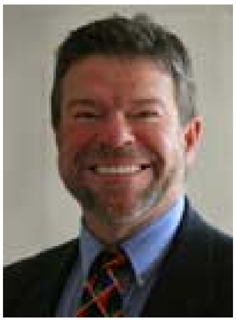
The Effects of Meandering in RFID Tag Design

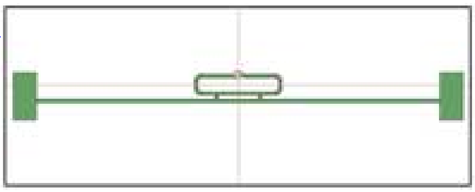
By Mark Forbes, Mentor Graphics Corporation



As is well known, maximum RF coupling occurs when impedances on each side of the coupling match. A perfect match occurs when the impedances are identical and the Complex Matching Factor (CMF) is 0dB. When the CMF is 0db, the imaginary terms of the complex conjugate cancel, and the resistance is equal. Although a perfect match can never be obtained in a physical world, the goal is to make it as close to ideal as possible.

For antennas, a resonant antenna can provide a much better match, and consequently, provide greater energy transfer. The half-wave dipole is a typical resonant antenna and commonly used.

RFID Technology



[1]

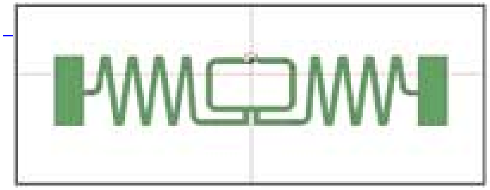
click to enlarge
Figure 1. Optimized RFID tag using a half-wave dipole antenna realized on a single-sided PCB.

For the purpose of this article, the RFID tag examined is an EPC Gen 2 tag operating at 915 MHz. These passive RFID tags use their antenna for two purposes: to collect energy from the RF signal transmitted by the RFID Reader to power the IC, and also to act as a reflector to communicate with the Reader using backscatter. Maximum backscatter amplitude occurs when the antenna impedance matches the Reader antenna impedance and the amplitude declines as the match (and consequently the CMF) becomes worse.

When sufficient RF energy is captured and rectified to power the IC, it begins transmitting its unique ID. The IC modulates the return signal by varying the impedance across the antenna, which causes changes in the amplitude of the reflected backscatter return signal, thus transmitting the ID information. In most systems, the RFID tag is said to be Forward Link Limited, meaning that as long as the RFID is gathering sufficient energy to power its IC (limited by separation of the tag and Reader), the backscatter signal will be of sufficient strength to be detected and demodulated by the Reader.

Matching Shortened Antennas Using PCB Meanders

An optimized far-field RFID tag antenna for EPC Gen 2 systems can be realized as the half-wave dipole described above. The design illustrated in Figure 1 shows an RFID tag with its associated half-wave antenna.

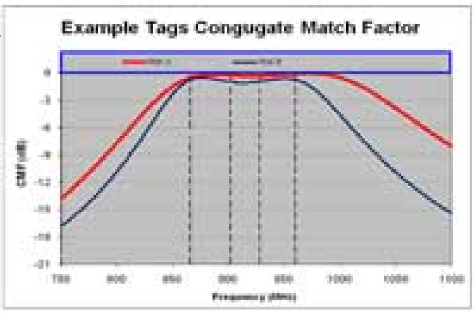


[2]

click to enlarge
Figure 2. Constraints limit this design to 60% the length shown in Figure 1.

In the real world, constraints often dictate that an RFID tag design must be designed such that there is insufficient space for a half-wave antenna. In that case, the antenna must be electrically lengthened by adding inductance into the antenna circuit. While this is common practice in antenna design, the fact that the RFID tag is housed on a tiny PCB allows the use of meandering, which uses the PCB traces to provide the requisite inductance. Figure 2 illustrates a design where the antenna has been electrically lengthened by meandering. All physical properties of the PCB are the same except it is 60% the length of the optimized design from Figure 1. The meanders on either side of the antenna provide the necessary inductance to force a complex conjugate match.

Figure 3 shows the CMF plot on the Mentor Graphics IE3D electromagnetic (EM) design and verification tool. The shortened antenna provides a good match, covering the entire range of RFID frequencies (866 MHz, 915 MHz, and 960 MHz) well above the 3db points. However, as with any electrically shortened antenna, the bandwidth begins to diminish. Physically shorter antennas show increasingly narrower bandwidths.



[3]

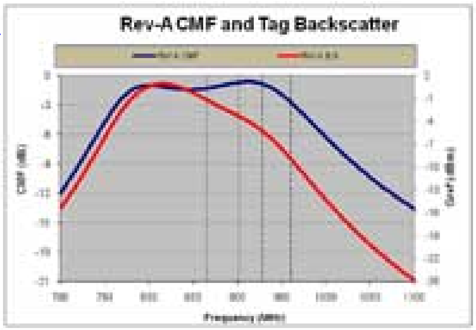
click to enlarge
Figure 3. Plot of CMF values using Mentor Graphics IE3D tool.

The figure also illustrates that in a Forward Link Limited system, CMF analysis indicates that the amplitude of the backscatter will be sufficient to be read, even with the shortened antenna.

Effects of External Influences

While CMF matching is a good indicator of tag communication efficiency, other factors can negatively affect the ability of the Reader to communicate with the tag. In fact, external influences can sometimes render the tag Reverse Link Limited, that is, although the tag is receiving sufficient energy to power the IC, the backscatter signal can no longer be successfully read by the Reader.

Once again, in the real world free space analysis that has been presented so far in this article can be affected by external influences, in particular proximity to an external dielectric. In short, when an RFID is placed on an actual object for practical use, the object will act as a dielectric and cause a shift in resonance. The amount of shift can be negligible or significant, and in many cases cannot be reliably predicted.

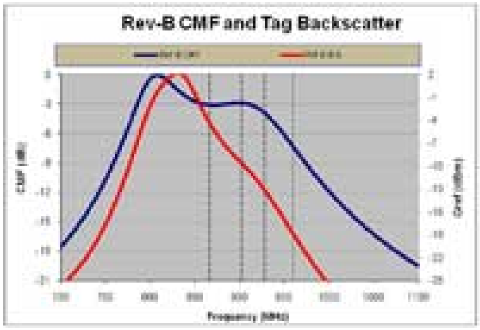


[4]

Figures 4 and 5 show plots of CMF vs. measured backscatter from the optimized tag and the 60% shortened tag. The affects of the external dielectric are quite clear, and result in a shift in the center point of the CMF resonance plot as well as the center of the backscatter frequency.

Further, the electrically shortened antenna exhibits greater narrowing of bandwidth that the free space model, along with distortion of the symmetry about the center frequency. The result is that the backscatter signal at the Reader’s frequency can be slightly or severely attenuated. This attenuation can result in the system becoming Reverse Link Limited and considerably shorten the maximum range of the RFID.

Antenna Gain



[5]

click to enlarge
Figure 5. IE3D plot of the 60% shortened tag design in the influence of an external dielectric. The blue line is the CMF plot and the red line is the simulated backscatter signal.

Antenna gain can also affect RFID tag performance. A dipole has a nominal gain of 2.0 dBi. Any shortened antenna will show a negative gain compared to a full-size dipole antenna. In depth analysis of the antenna gain on the system is beyond the scope of this article.

Conclusion

Most RFID tags are Forward Link Limited. For some systems however or for small tags the Return Link can become a limiting factor due to external dielectric influence in the real world. While optimizing the CMF as much as possible, using meanders for shortened antennas, other factors may cause less-than-optimal performance. In such instances measurement of the backscatter signal can reveal compromised system margins. This backscatter measurement can be obtained via simulation with tools such as the IE3D.

The design examples in this article can be summarized in three general statements:

1. CMF and Backscatter have independent and different frequency characteristics.

2. Backscatter is a system characteristic and not simple tag characteristic. It is affected by the Reader and can also be affected antenna gain.

3. Even if the CMF bandwidth is adequate over a required frequency band the impact of backscatter and tag gain may further impact system performance and must be considered.

A more in-depth discussion of RFID tag antenna systems is available by downloading a White Paper RFID Tag Design, Sub-Fractional Performance Effects at: http://www.mentor.com/electromagnetic-simulation/techpubs/rfid-tag-design-sub-fractional-performance-effects-61438.

Mark Forbes is Content Manager for Mentor Graphics Corporation with 31 years in electronic design, antenna design, product marketing, and documentation. Mark has patents in antenna design and digital communications, and is inventor of the Ventenna, a concealed antenna system. He has a BSEE from Bradley University in Peoria, Illinois.

Links:
[1] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/1101/Mentor_Fig1_lrg.jpg
[2] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/1101/Mentor_Fig2_lrg.jpg
[3] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/1101/Mentor_Fig3_lrg.jpg
[4] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/1101/Mentor_Fig4_lrg.jpg
[5] http://www.wirelessdesignmag.com/sites/wirelessdesignmag.com/files/legacyimages/1101/Mentor_Fig5_lrg.jpg