Antennas

Synthesis of Robust UHF RFID Antennas on Dielectric Substrates

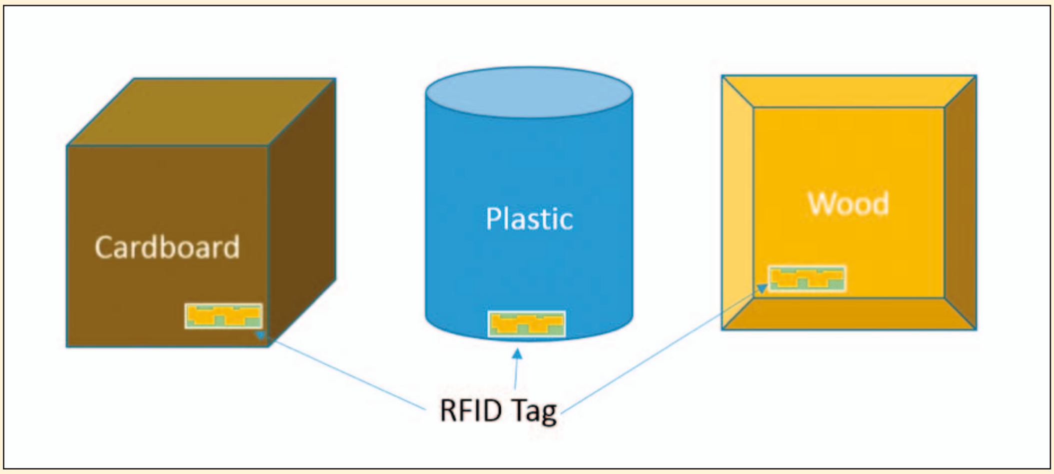

Figure 1: UHF RFID tag and environment

Figure 2: Setting dielectric values in band control

AntSyn, a new antenna synthesis tool within the NI AWR software portfolio, has been enhanced to rapidly explore the design space more efficiently, supporting the simultaneous optimization of RFID antennas on a wide variety of dielectric substrates as specified by the user. This article will discuss the methods used for optimization and describe two examples of RFID antennas created using this technology.

UHF RFID Tag Antenna Design Challenges

Ultra-high frequency (UHF) radio-frequency identification (RFID) tag antennas need to be inexpensive, efficient, and robust for the installation environment (immune to change in its electrical behavior due to its proximity to the mounting platform). Designing and optimizing such antennas by hand is a time-consuming and difficult process, and electromagnetic (EM) tools generally offer limited ability to explore the design space beyond modest tweaking of the antenna's geometry through parameterization. Furthermore, limited design space optimization is particularly restrictive when making the antenna environmentally robust.

Antenna synthesis has proven to be very effective at creating antennas for a wide variety of applications and has now been applied to this challenging problem. An important challenge in the design and integration of UHF RFID tag antennas in the real world is the difficulty of making them environmentally immune to the mounting platform, particularly if they will be installed over a dielectric, since the underlying dielectric properties are likely to be highly variable. A single tag design may need to be installed, for instance, on cardboard, drywall, plastic, fiberglass, wood, or other dielectrics [1], as illustrated in Figure 1. Placing a tag on different dielectrics will shift its resonant frequency. If it is sufficiently wideband, the tag will still have good performance as its resonant frequency shifts.

Reducing the antenna footprint is another challenge for designers. Tags of $\lambda/3$ or less can be used in many more situations and cost much less. Therefore, it is desirable that tags be as electrically small as possible, however, smaller antennas necessarily have smaller bandwidth than larger antennas [2]. While

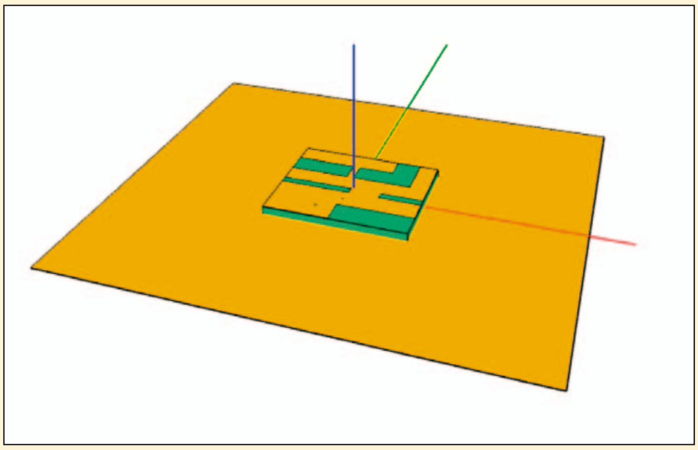

Figure 3: Example of original planar XYmesh antenna with dielectric on ground plane

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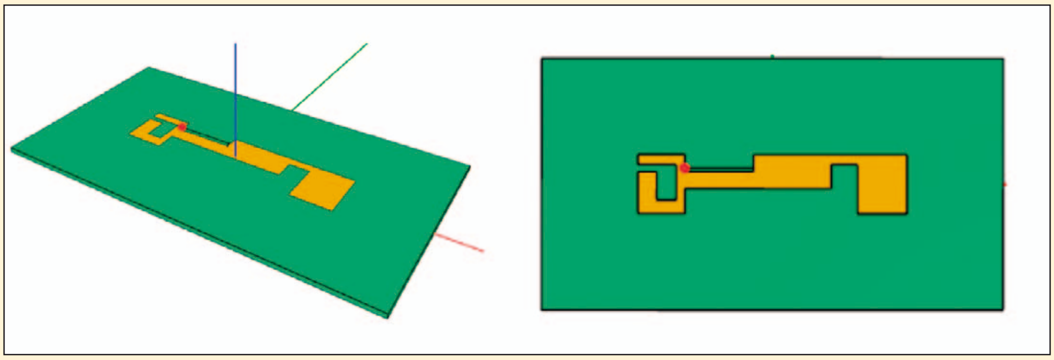

Figure 4: New antenna type with a single-layer antenna on a dielectric (green rectangle) that simulates its installation environment. The red dot indicates the chip position

Band 1:
Frequency: 902 - 928 MHz
Input Z: 16 + j148
Band Dielectric: Dielectric constant: 3 Loss tangent: 0.005

Band 2:
Frequency: 902 - 928 MHz
Input Z: 16 + j148
Band Dielectric: Dielectric constant: 6 Loss tangent: 0.005

Band 3:
Frequency: 902 - 928 MHz
Input Z: 16 + j148
Band Dielectric: Dielectric constant: 10 Loss tangent: 0.005

Band 4:
Frequency: 902 - 928 MHz
Input Z: 16 + j148
Band Dielectric: Dielectric constant: 13 Loss tangent: 0.005

Geo shape: Box - X:4 in, Y=1 in, Z=0.25 in

Figure 5: Specifications used to synthesize RFID antenna across four different substrates. The impedance used for each band was to provide a conjugate-match to a chip with 16 – j148 Ω impedance [4]

a very large tag antenna would easily be able to be wideband and thus very robust, it would only be able to be installed on relatively large objects and it would be higher in cost than a small tag. While tags of λ/3 or less can be used in many more situations and cost much less, when a tag is small compared to wavelength, bandwidth narrows and thus it is much more sensitive and difficult to design.

In addition, while antennas are usually designed to match a real (typically 50 Ω) standard line impedance, the RFID chips themselves are generally not 50 Ω devices and have reactive impedances. A typical value for a chip impedance might be 16 - j150 Ω [3]. To minimize reflection losses, it is desirable to design the antenna impedance to be a conjugate match of the RFID chip's complex impedance directly so a matching network will not be necessary. Direct antenna-to-chip matching will significantly decrease the cost and complexity, and improve the overall reliability. However, this non-standard impedance matching makes the design challenge even more complex.

Various approaches have been used in prior research to meet these challenges [3 - 6]. The most commonly used technique is making an antenna broadband to enable performance to be maintained over a set of substrates, which will shift the resonant frequency. In [4], a combination of equations and simulations are used to manually optimize existing commercial antennas to have good performance over a wide range of materials. Broadband performance is achieved in [5] by combining a small inductive coil with a planar dipole-type antenna, whereas [6] uses a complex design with multiple arrays of planar inverted-F antennas (PIFAs).

Another method is making the antenna easily tunable to the specific dielectric by manually trimming in preset locations [3]. All of these approaches have used standard human-in-the-loop engineering methods. This article discusses a new method of designing RFID antennas over a wide range of substrates using automated synthesis.

A New Design Approach

In this new design approach, AntSyn was used to create new RFID antennas on a variety of substrates. AntSyn uses evolutionary algorithms (EAs), a programmatic method that leverages EM simulations to efficiently explore the design space and automatically locate high-performance design options. Antenna synthesis with AntSyn is proving to be highly effective at generating antenna structures with excellent performance and has already been used to create many successful fielded antennas, including several that have been used on spacecraft [7].

AntSyn allows the user to enter RF and form-factor specifications, such as bands, patterns, efficiency, geometry constraints, and more. It has a library of design templates and uses full-wave 3D simulation [8, 9] to obtain performance information on candidate designs. Advanced optimization algorithms are used

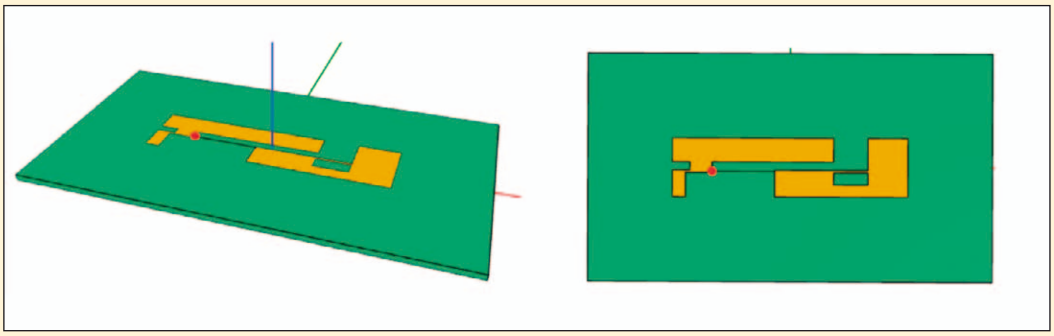

Figure 6: Design 1, where the red dot indicates chip location. The antenna's dimensions are 94.4 x 23.7 mm, while the substrate overall is 162.2 x 91.5 x 2 mm

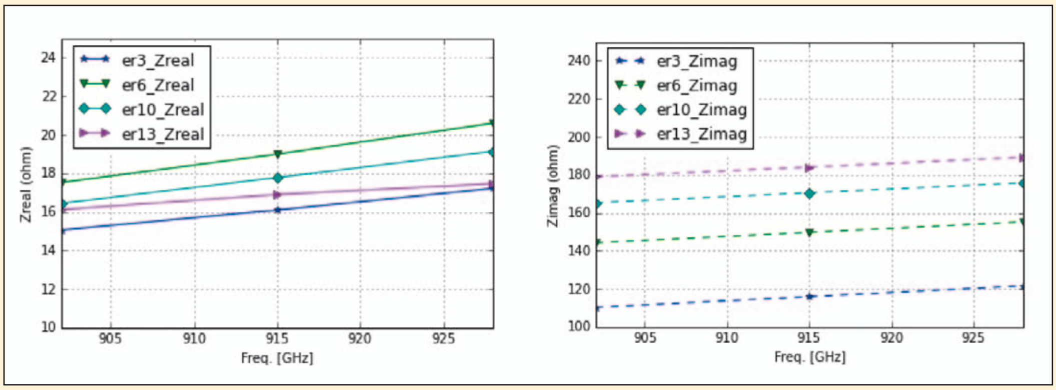

Figure 7: Design 1 input impedance for the frequency range optimized in AntSyn

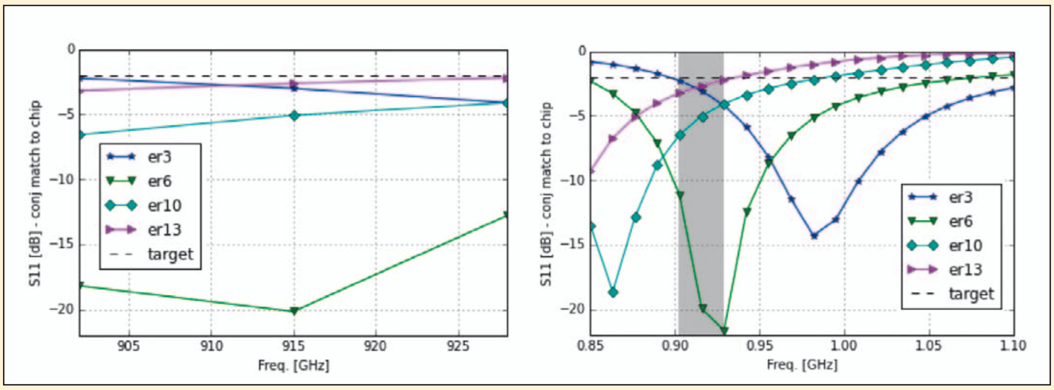

Figure 8: Design 1 return loss over AntSyn optimized frequency range and also a wider frequency sweep using input impedance from external full-wave 3D-simulation

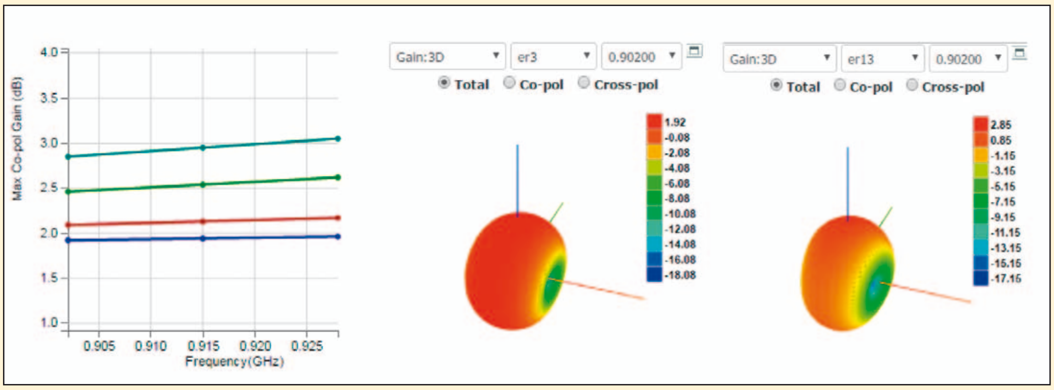

Figure 9: Design 1 maximum gain vs. frequency and radiation pattern for the ϵ_r = 3 and 13 cases

to select and create antennas that are optimized to meet the user's requirements.

A new capability has been added to AntSyn that enables a single antenna design to use a user-defined set of substrates during optimization. In AntSyn, the band control option enables the user to select many different performance criteria generally related to frequency bands, such as start and stop frequencies, pattern requirements, polarization, and cross-polarization levels. However, with the addition of this new feature, the user is now able to set capability, the dielectric constant as a parameter for each band, if desired (Figure 2).

This flexibility allows the user to essentially set up dielectric test cases for the antenna design. To do so, all criteria in each band is kept the same (impedance match, pattern), except for the dielectric. Each band is then given a different value for dielectric constant and loss tangent. AntSyn then directly optimizes performance for the antenna across the range of dielectrics.

A new type of antenna has been created to take advantage of this optimization capability specifically for RFID antennas. Based on a very generic type of antenna, the "planar-XYmesh" type shown in Figure 3, the new antenna type has been used for small, integrated antennas (see [10] for some examples). This type is typically a PIFA-style antenna with a ground layer.

For this effort, a new antenna type was added that is a single-layer design, but still on a dielectric substrate. In this antenna, the substrate is now used to simulate the surface on which the RFID antenna will be installed, instead of being a part of the antenna itself. When coupled with the band-dielectric control described above, it enables the optimization of RFID antennas across a range of installation environments.

This antenna is unique in how its geometric constraints have been implemented. The outer dimensions of all other antennas in the library are directly constrained by the user in the geometry control. For this new type, the antenna's dimensions are set by the geometry control, but an additional set of antenna-specific parameters are used to set how far the dielectric extends beyond the antenna and how thick the substrate is. An example of this new antenna is shown in Figure 4.

RFID Application Examples

Two RFID antenna designs are presented. For both designs, as run within AntSyn, the specifications listed in Figure 5 were used.

This set of specifications took only a few minutes to set up on the AntSyn web-based user interface and the run was executed using "medium quality," which means AntSyn was given a moderate computational budget for solving this problem. Edging, a WIPL-D EM solver-specific parameter, was used to increase the accuracy of the simulation at the expense of greater time required. A 2 mm substrate thickness was used, as in [4].

The resulting antenna design (Figure 6) had more than enough bandwidth to meet the target specification. However, the final design was scaled by

+1.9 percent to maximize the performance in the target band of 902 – 928 MHz. The final size was well within the desired size envelope, at 94.4 mm x 23.7 mm.

The resulting final input impedance of the antenna is shown in Figure 7 and the corresponding return loss (matching of conjugate antenna impedance to chip impedance) is given in Figure 8, including a wider frequency sweep using an external full-wave 3D simulator.

According to [4], a coupling of -2 dB appears to be acceptable. As can be seen in Figure 8, the synthesized antenna is able to meet this specification over the highlighted band of interest from 902 – 928 MHz. Radiation performance of the antenna is shown in Figure 9, illustrating good gain with an omnidirectional radiation pattern.

For the second design (Design 2), a higher impedance penalty was imposed, employing an advanced control in AntSyn that penalizes the impedance more harshly when it is out of spec. This added permutation to the spec in Design 2, as shown in Figure 10.

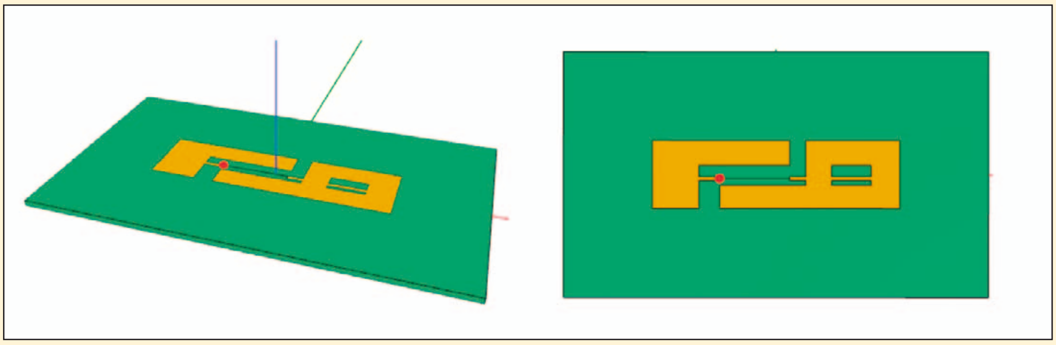

Figure 10: The antenna dimensions in Design 2 are 92.4 x 25.4 mm, while the substrate overall is 158.9 x 91.9 x 2 mm

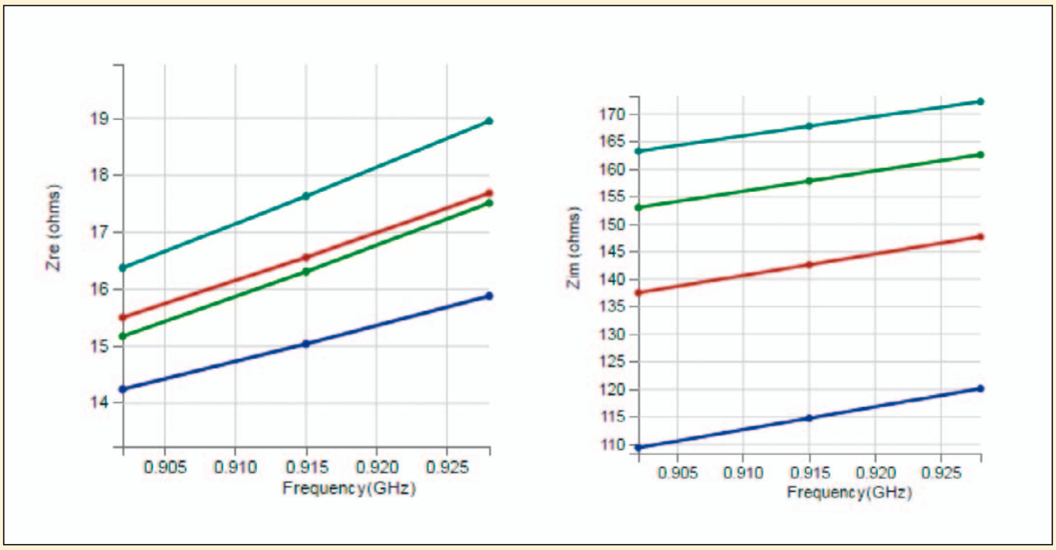

Figure 11: Design 2 input impedance as calculated by AntSyn

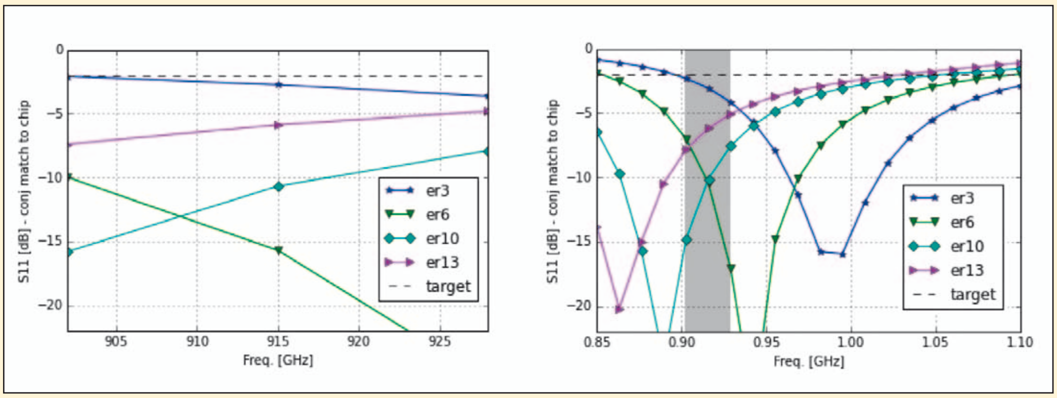

Figure 12: Design 2 return loss

The input impedance and return loss for this antenna are shown in Figures 11 and 12, respectively. Due to the increased focus on optimizing impedance, Design 2 has as good, if not better, performance than Design 1 across all dielectrics. Design 2 has a much wider matched frequency band across all dielectrics and no scaling was required. Finally, Figure 13 shows the radiation performance of Design 2, again showing good performance.

Conclusion

The examples illustrate that it is possible to automatically synthesize a new RFID antenna in AntSyn that will work on multiple substrates. The synthesis process can match the chip antenna impedance, work over multiple dielectrics, and do so with minimal human effort required. This new capability within AntSyn can be used for many applications in addition to RFID antenna design, such as to increase yield for antennas that are sensitive to dielectrics or for body-worn or body-internal antenna design.

Future work in this area will include adding multiple bands to accommodate worldwide UHF RFID frequencies, adding more dielectric variety, looking at how polarization can be added to the synthesis, and exploring the limits of how small the antenna can be when synthesized in this fashion.

Readers are encouraged to learn more by visiting awrcorp.com/antsyn or by reaching out to the authors through email.

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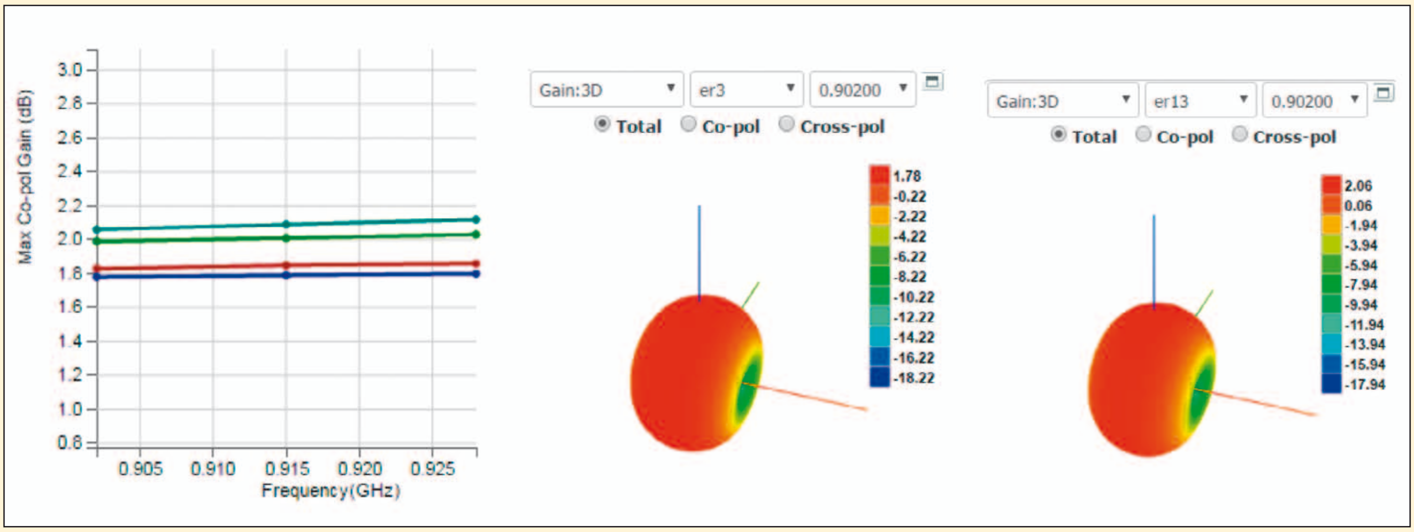

Figure 13: Design 2 maximum gain vs. frequency and radiation patterns for the ϵ_r = 3 and 13 cases

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