

# Design and Simulation of an ISM Band Antenna on PCB Technology

ISM radio bands have traditionally been reserved internationally for the use of radio frequencies (RF) for industrial, scientific, and medical (ISM) purposes. In recent years, the fastest-growing uses of these bands have been for short-range, low-power, communications systems. Cordless phones, Bluetooth devices, near field communication devices, and wireless computer networks all now use ISM.

This application note describes the co-simulation of an electrically small ISM band antenna with the matching network built

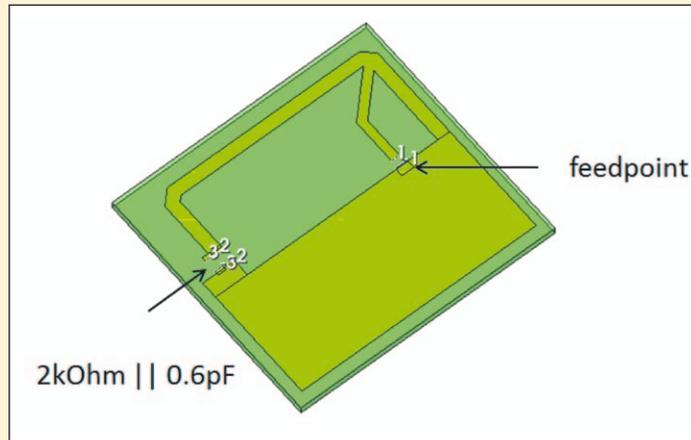


Figure 1. ISM band antenna layout.

from surface mounted devices (SMDs). NI AWR Design Environment™ software, inclusive of Microwave Office, AXIEM and Analyst™ modules, was used to design the ISM band antenna and to simulate the effect of finite PCB size and possible PCB cutouts.

## AXIEM Simulation

The challenge was to design a small omnidirectional antenna for a handheld device that is insensitive to its environment. This was achieved by shortening the radiator with a capacitive

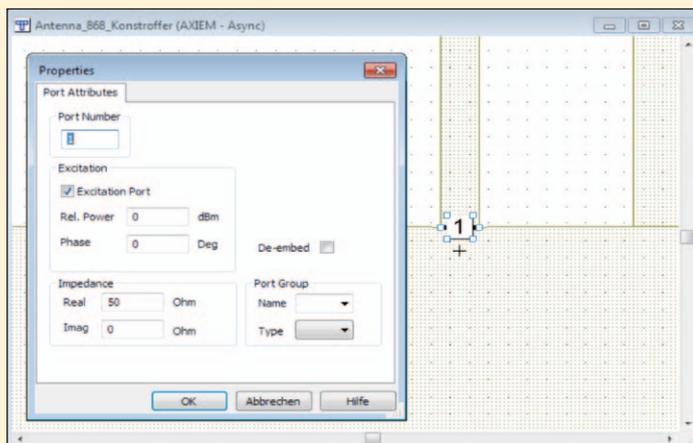


Figure 2. The feed port was modeled as a zero-gap series port (“internal port” in AXIEM).

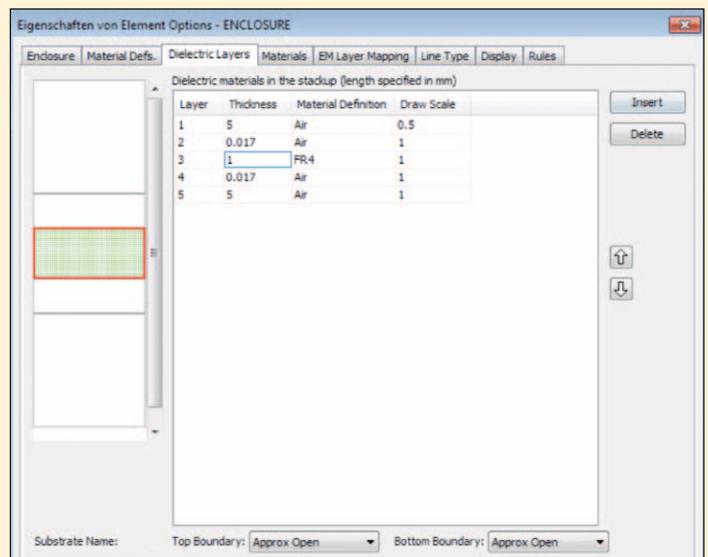


Figure 4. The PCB is modeled with infinite extension in the xy plane.

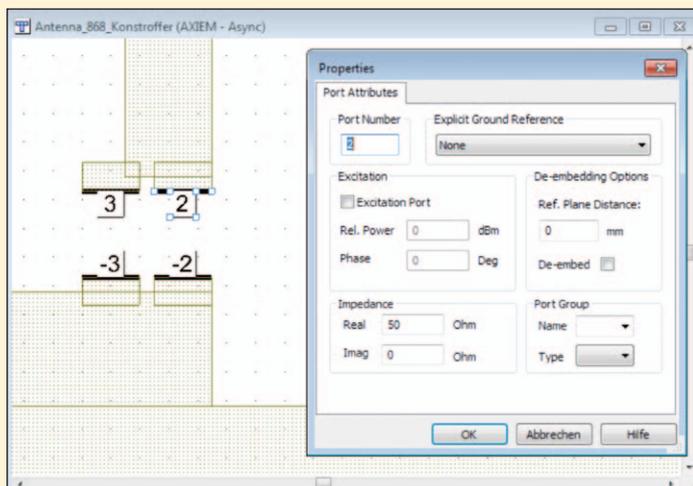


Figure 3. For the two SMD elements, explicit (+) and (-) pins were placed on the pads, creating a differential port for each of the SMD elements.

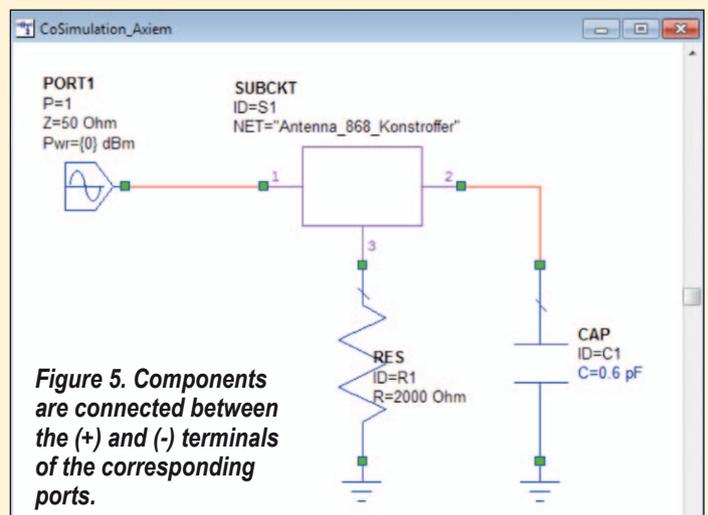


Figure 5. Components are connected between the (+) and (-) terminals of the corresponding ports.

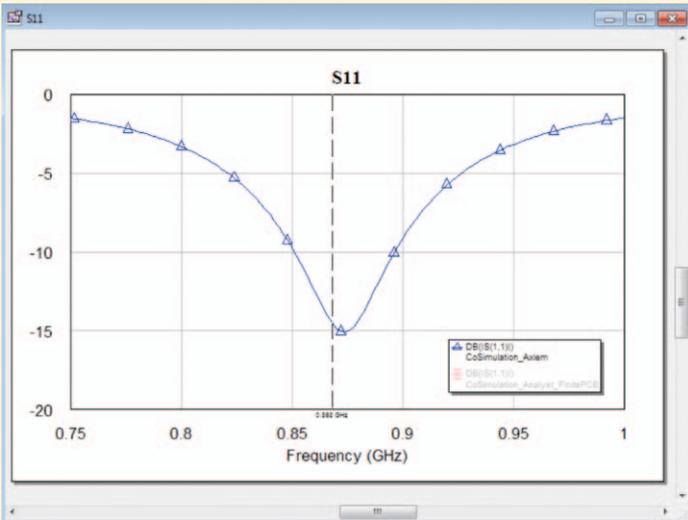


Figure 6. The simulation results showing good return loss at the target ISM band.

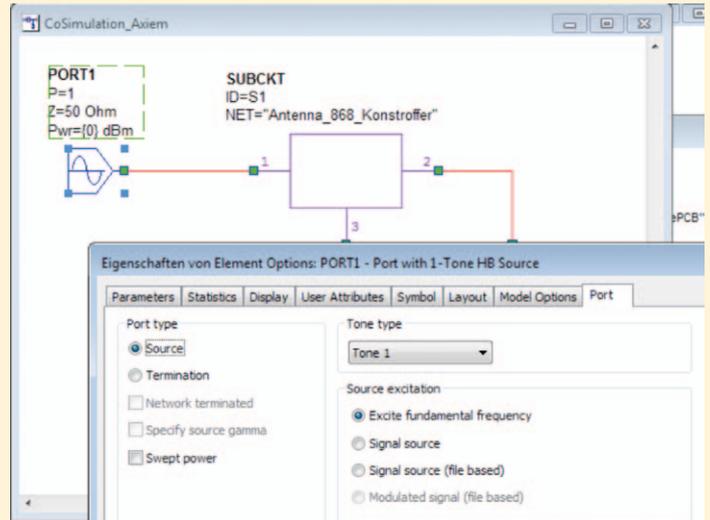


Figure 7. Schematic was set up for nonlinear simulation to generate voltage/current data for co-simulated antenna patterns.

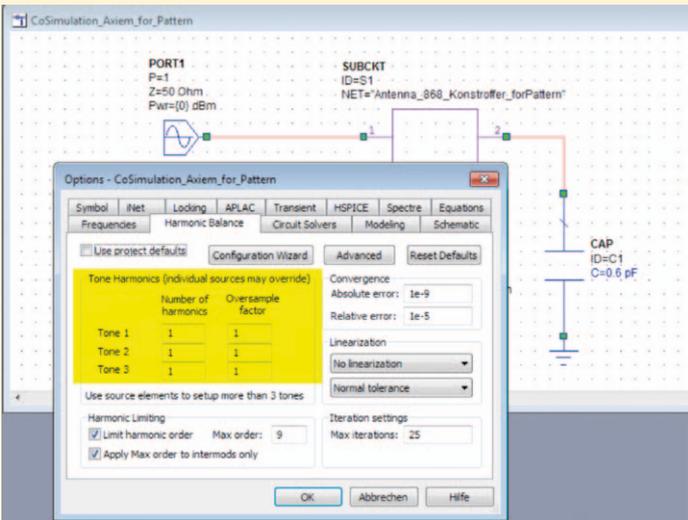


Figure 8. To avoid harmonic balance warnings, the number of harmonics was set to one in harmonic balance analysis.

top load and placing a resistor in parallel to that top load. The resistor caused a lower gain, but that gain became relatively stable over different environments such as different placement of the device in the user's hand. For the antenna input, an internal

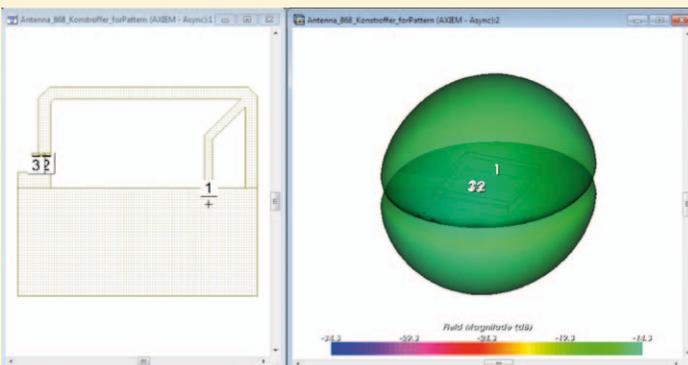


Figure 10. 3D antenna pattern.

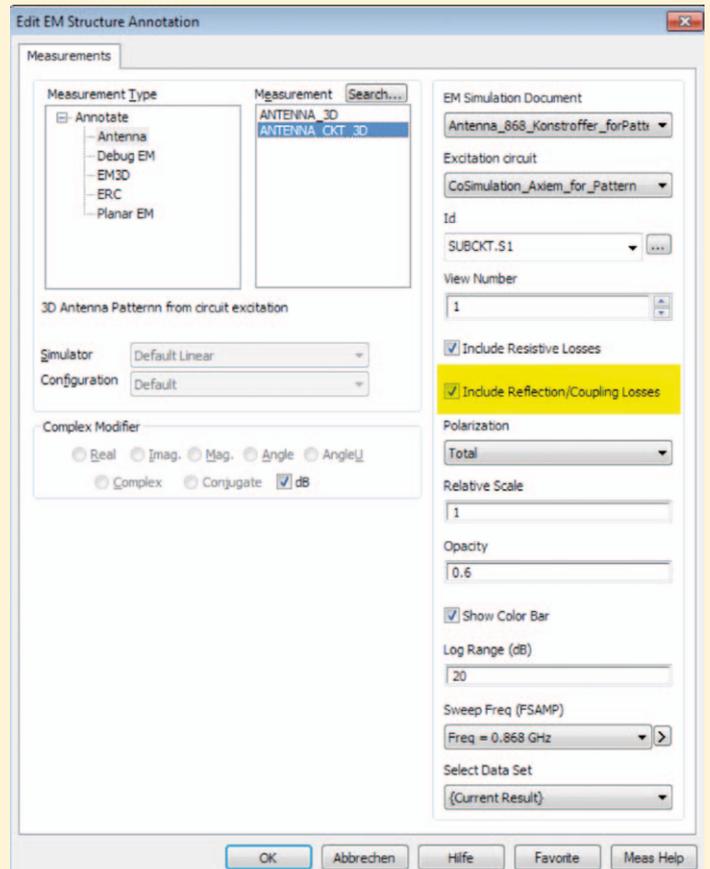


Figure 9. It is important to include the resistive and mismatch losses so that the antenna pattern represents the true radiated power.

series port was added between the feed line and ground metal (Figure 1). This port internally created an infinitesimal gap with the (+) terminal on one side of the gap and the (-) terminal on the other. It was equivalent to using explicit (+) and (-) pins over a gap, with the gap size shrinking to zero (Figure 2). For the two SMD elements, explicit (+) and (-) pins were placed on the pads. This created a differential port for each of the

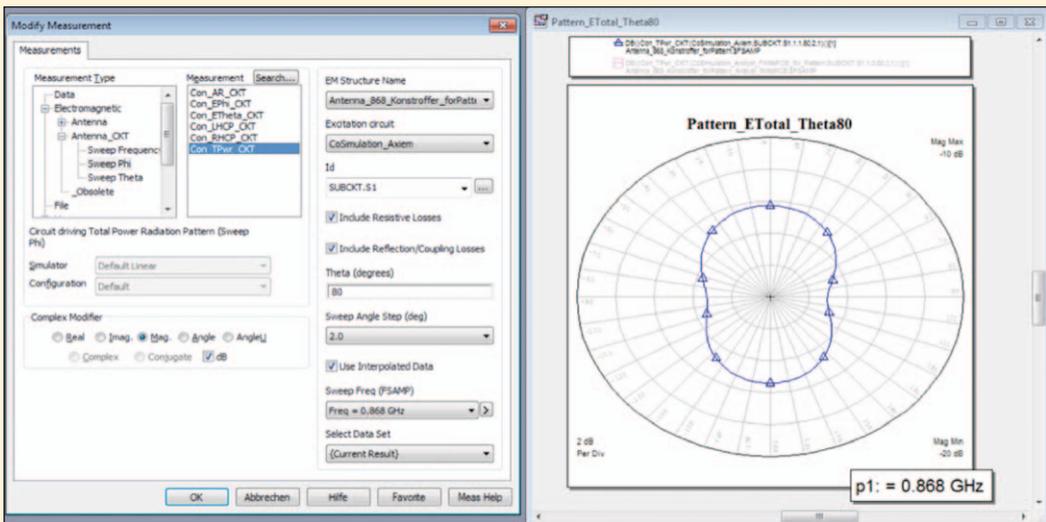


Figure 11. Result for the gain (total over all polarizations) at theta=80.

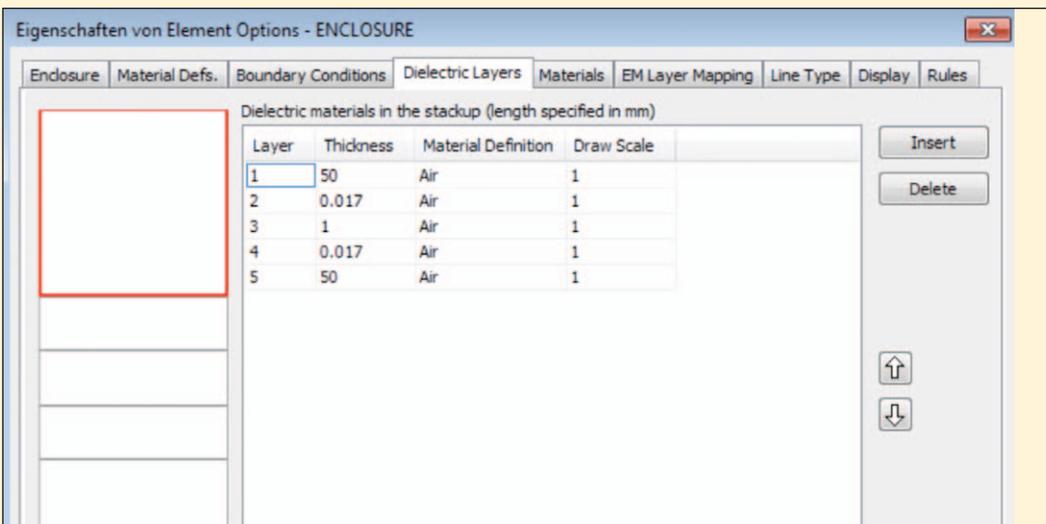


Figure 12. In the Analyst 3D model, the background is air everywhere, and FR4 is selectively inserted by drawing a PCB rectangle.

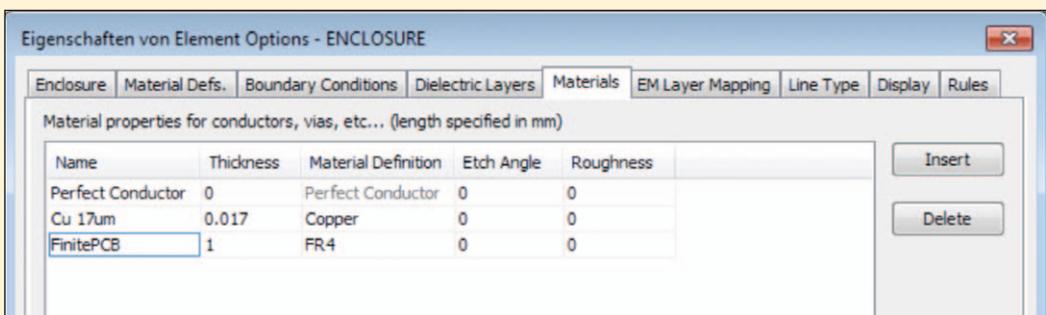


Figure 13. A material definition was created with 1 mm thickness FR4.

SMD elements (Figure 3). There was no infinite ground in this model, so the negative terminal of the ports needed to be explicitly defined. Like all dielectric layers in AXIEM, the FR4 diel-

etric for the PCB was modeled with infinite size in the xy plane (Figure 4). More discussion on this to follow.

Next, this EM structure was simulated and 3-port S-para-

meter results were extracted. To get the combined result for the antenna with matching network, it was necessary to connect the SMD elements at ports 2 and 3. The schematic shown in Figure

5 might look strange with the SMD connected to ground on one side, but that notation only means that these components are connected between the (+) and (-) terminals of the corresponding ports. The return loss of the antenna with the SMDs connected was then simulated.

It can be seen in Figure 6 that the antenna was matched, but what about the radiation pattern? That's where it got a bit tricky: that radiation pattern changed when the SMD was connected, so EM-circuit co-simulation was needed to get the correct radiation pattern. The next section shows how this was easily done within Microwave Office circuit design software.

### Microwave Office Co-Simulation

The 2D and 3D antenna patterns were calculated with special antenna annotations that referenced the EM structure under circuit stimulus. This technology requires the use of a nonlinear signal port in order to evaluate voltages and currents at all EM document ports. This information is in turn used to compose the total far field pattern. The required voltage and current data is why the schematic was set up for nonlinear simulation (Figure 7).

The designer was interested in the 868 MHz fundamental frequency only. To avoid warnings from harmonic balance about missing EM results at  $n \cdot 868$  MHz harmonic frequency, the number of harmonics was set to one in the co-simulation project settings (Figure 8).

Once this step was complete, the annotation to visualize the co-simulated 3D antenna pattern was created. For simplicity, a copy of the EM structure was used that was configured for single frequency 868 MHz (so that EM results for that exact frequency were obtained), as well as a schematic that simulated that exact frequency. One very important setting is to enable the "Include Reflection/Coupling Losses" checkbox here

(Figure 9), so that the antenna pattern with the proper loads at the SMD terminals is included.

After simulating the schematic and EM structure, the 3D antenna pattern can be visualized as shown in Figure 10.

The drop in radiation in the PCB plane isn't real – this is an artifact from the Method-of-Moments (MoM) simulation method used by AXIEM, which simulates with substrates of infinite size. These infinite substrates cause a drop in simulated gain at the horizon ( $\theta=90^\circ$ ). The true pattern shape was continuous at the horizon, with no such drop.

The antenna peak gain was approximately -14 dBi with a very nice omnidirectional antenna shape. Besides the 3D pattern that gave a good overview of the radiation characteristics, the “classical” antenna parameters in 2D polar format were also plotted. Figure 11 shows the result for the gain (total over all polarizations) at  $\theta=80^\circ$ , or  $10^\circ$  above the PCB plane. A reasonable question is how much the finite PCB size influences the results obtained with an infinite PCB model.

**Analyst Simulation**

The PCB edge was relatively near the antenna where the relative permittivity changed from 4.5 (FR4) to 1.0 (air). It was expected that the measured antenna resonance frequency would be slightly above the resonance that was simulated with AXIEM (infinite dielectrics), because the antenna in reality would see slightly lower effective permittivity.

With the Analyst 3D FEM solver, the finite PCB size could be included in the simulation. Analyst solves a more general problem, so that it takes more time and usually more memory. While the designer wanted to avoid heavy 3D simulations for planar antennas and could have used the AXIEM solution, which is much faster with adequate underlying assumptions, he went ahead and used Analyst for the PCB antenna comparison.

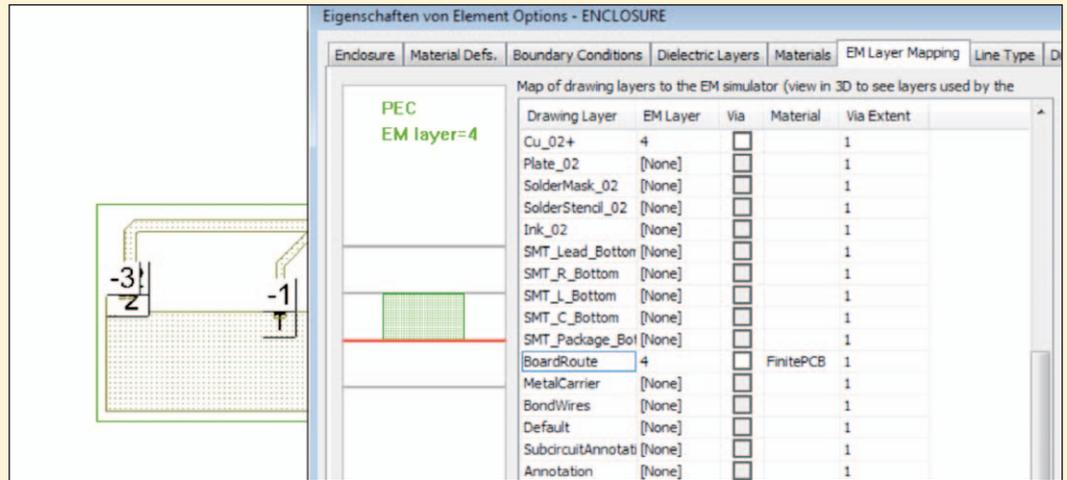


Figure 14. The material definition was mapped in the PCB location and assigned to drawing layer “BoardRoute.”

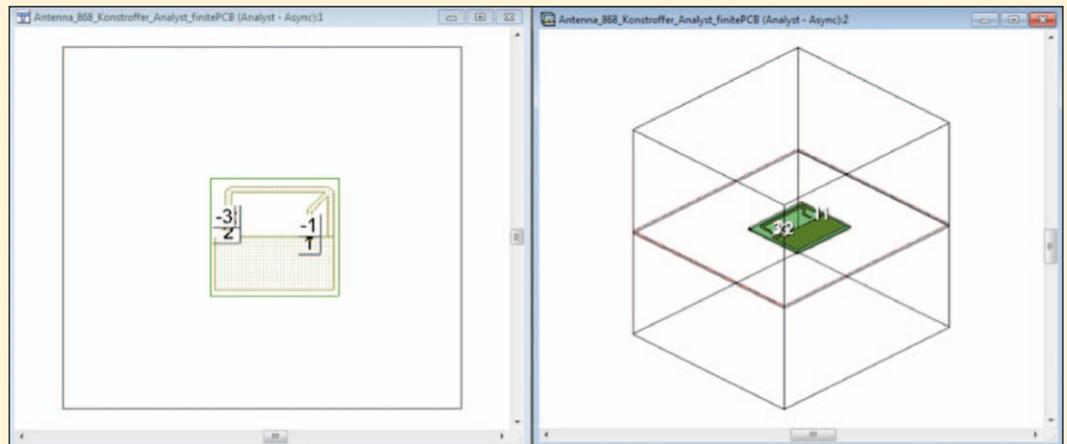


Figure 15. A finite size FR4 dielectric for the PCB in the Analyst 3D model.

The EM stackup was modified for the finite substrate calculation: the infinite FR4 dielectric was changed to air and FR4 was only selectively inserted by drawing a PCB rectangle that was properly mapped, as shown in Figure 12. A material definition named “FinitePCB” was created with 1 mm thickness and material FR4 (Figure 13). It was then mapped in the PCB location and assigned to the drawing layer “BoardRoute” (Figure 14).

The resulting finite PCB model is shown in Figure 15. The simulation boundaries (sidewalls as well as top/bottom) were placed at a minimum distance of ~ 1/4 wavelength.

To calculate antenna patterns in Analyst 3D FEM, it is imperative to set the boundaries to Per-

fectly Matched Layer (PML). PML increases the problem size, and thus the memory consumption and simulation time, but it is by all means better for antennas because it more accurately represents free space radiation.

Because Analyst doesn't support the internal port that was used for AXIEM, it must be changed to a differential port with separate (+) and (-) pins (Figure 16). After making that change, the EM model was simulated. The schematic for connecting the SMD was similar to the AXIEM schematic shown earlier in this application note in Figure 5. After running the simulation, the S11 results for AXIEM (infinite PCB) and Analyst (finite PCB) were compared, as shown in Figure 17.

The result was as expected: with the finite PCB size, the effective dielectric constant was slightly smaller and the antenna resonance went up. However, the effect wasn't too bad and was easily compensated for by tweaking the series capacitor value. This tweak was pure circuit simulation, so it wasn't necessary to repeat the time-consuming EM simulation.

What about the antenna pattern? Earlier it was noted that the drop in the gain at the horizon isn't real, but is actually caused by the AXIEM infinite substrate. Figure 18 shows what the designer obtained from the finite pattern simulation in Analyst and how the patterns compared. Left is the infinite substrate (AXIEM) and right is the finite substrate (Analyst). The plots were done

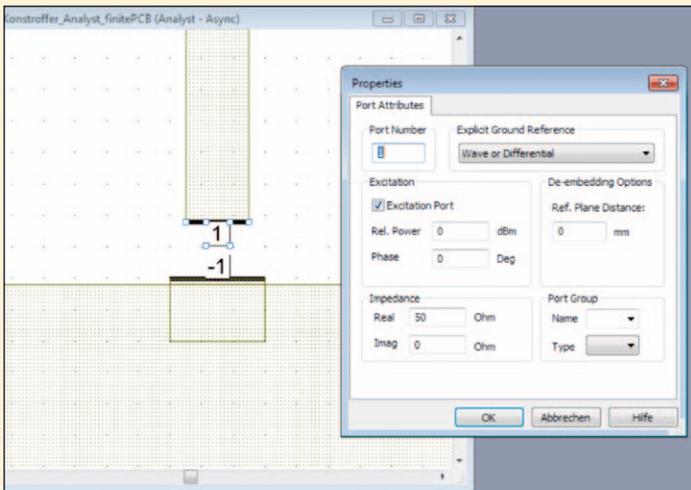


Figure 16. Analyst doesn't support the internal port used in AXIEM, so it must be changed to a differential port with separate (+) and (-) pins.

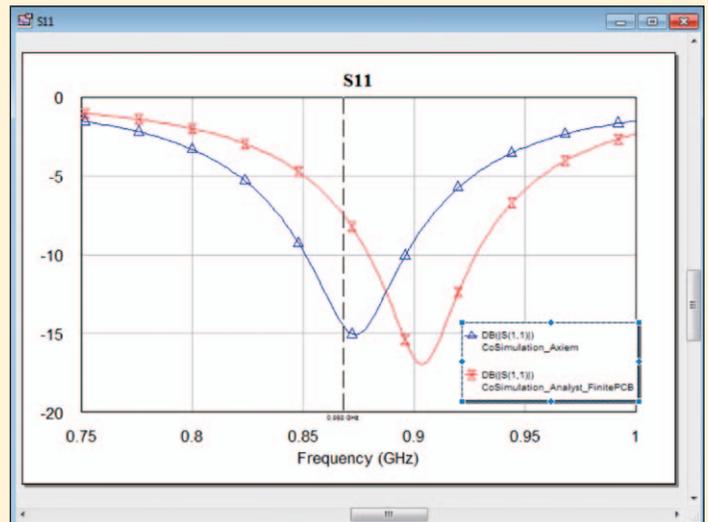


Figure 17. S11 results for AXIEM (infinite PCB) and Analyst (finite PCB) are compared.

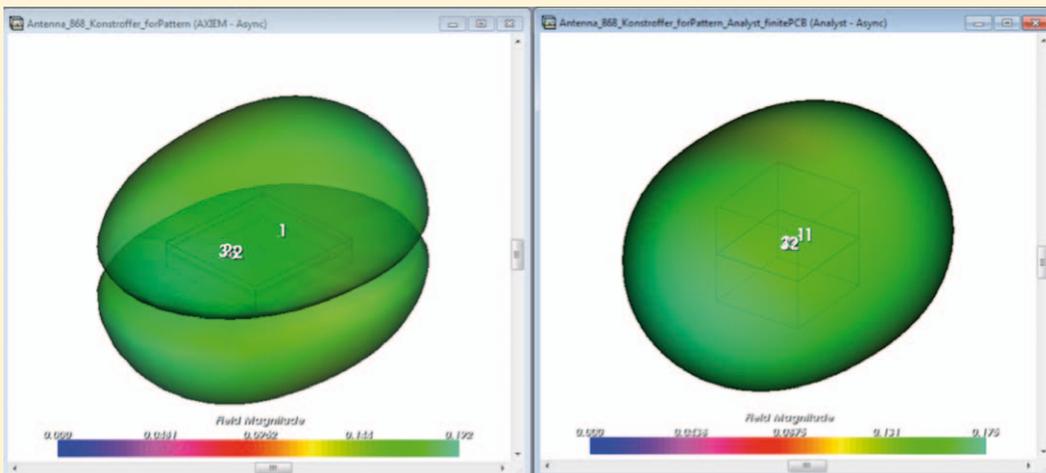


Figure 18. Comparison of the infinite substrate model in AXIEM (left) and the finite substrate model in Analyst (right).

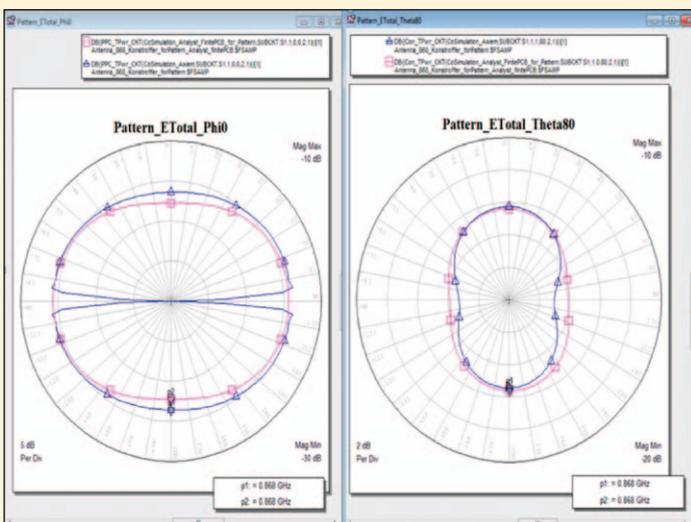


Figure 19. Comparison of the AXIEM (blue) and Analyst (magenta) 2D antenna patterns.

AXIEM or Analyst EM simulators can be obtained from a co-simulation with a driving schematic. This co-simulation takes into account losses in the circuit components, as well as the radiation efficiency of the antenna itself. Likewise, the radiation pattern is influenced by the discrete components and correctly taken into account in the pattern calculation. Comparison of the 3D Analyst model of a finite-sized PCB and the AXIEM model of an infinite PCB reveals that the influence of the finite PCB size has insignificant influence on the radiation pattern of the antenna. It does have a slight impact on the resonant frequency, but that is easily corrected by fine-tuning the matching components. This justifies the use of the much faster AXIEM for the analysis of planar antennas. ◀

**Note of thanks:**

AWR Group, NI would like to thank Dr. Ing. Volker Mühlhaus, Dr. Mühlhaus Consulting & Software GmbH, for his contributions to this application note. [www.muehlhaus.com](http://www.muehlhaus.com)

The 868 MHz antenna design in this example was created by consultant Lutz Konstroffer ([www.rfconsult.com](http://www.rfconsult.com)) and is used with permission.

with linear scale (not dB) for better comparison.

Finally, the designer compared the 2D patterns. The antenna pattern and gain calculated by AXIEM with the infinite substrate was similar to the Analyst 3D FEM results, except for data at the horizon (Figure 19). Knowing that this drop at the horizon isn't real for this antenna type, it was simply ignored and the analysis confirmed that AXIEM could reliably be used for efficient and fast design of the PCB antennas.

**Conclusion**

Radiation properties of PCB antennas modeled either with