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Design and Simulation of a 2.4 GHz/5.6 GHz WLAN Antenna on PCB Technology

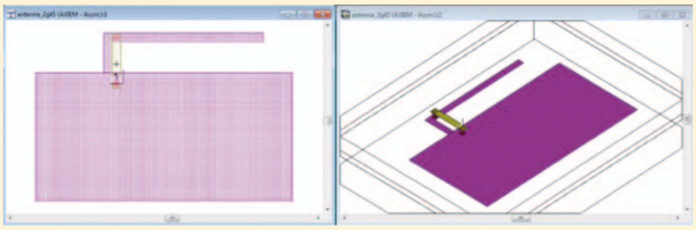


Figure 1. A planar PCB antenna using PCB conductor layers to form an inverted-F shape.

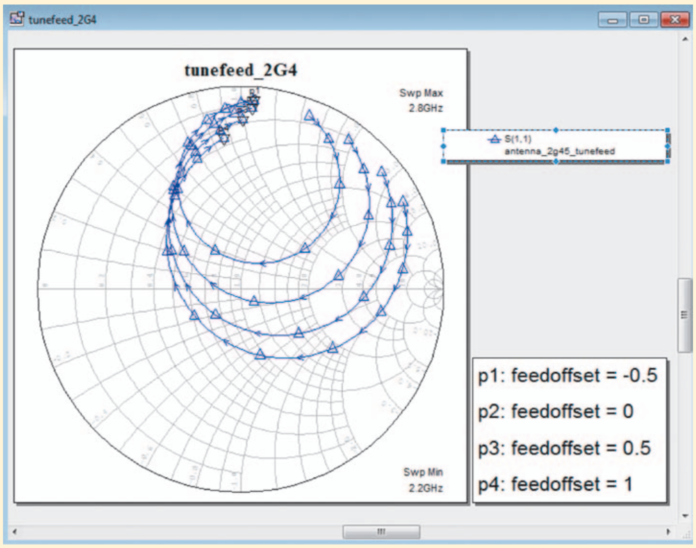


Figure 2. Plot of the antenna input impedance when the tap position was moved.

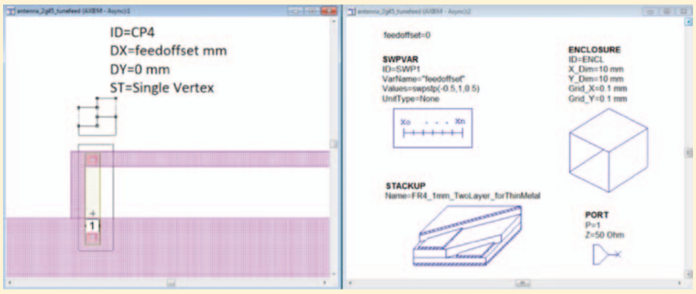


Figure 3. Setting up a parametric modifier of type control point and sweeping with variables in the EM schematic.

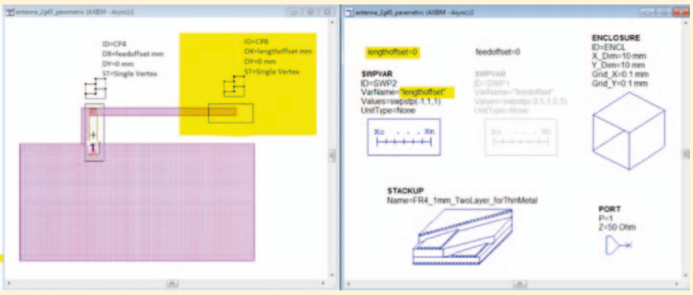


Figure 4. Sweeping using parametric modifier to find the optimal radiator length.

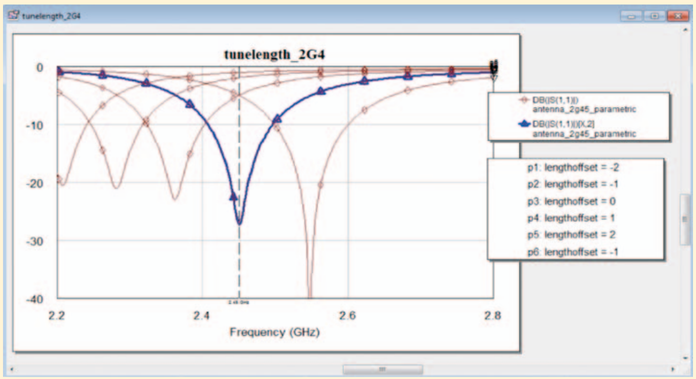


Figure 5. The matching changed only slightly for the small change in antenna length

This application note describes the design and simulation of a simple printed circuit board (PCB) antenna for 2.4 GHz and 5.6 GHz using NI AWR Design Environment™, inclusive of Microwave Office circuit design software and AXIEM 3D EM planar simulator.

- The first example is a 2.45 GHz single band antenna
- The second example is a dual band version for 2.4 GHz and 5.6 GHz
- The third example investigates sensitivity to PCB material tolerances

Inverted-F Antenna for 2.4 GHz

Planar inverted-F antenna (PIFA) shapes, which have become popular in mobile phones, typically have a metal bracket as the radiating element at some distance above the PCB. This application is a truly planar PCB antenna with no extra bracket—instead the PCB conductor layers were used to form an inverted-F shape (Figure 1). The basic idea is similar to the PIFA with a radiator of 1/4 wavelength and one end connected to the PCB ground plane. The radiator was tapped at some distance from the ground connection to connect the feed. The tap position changed

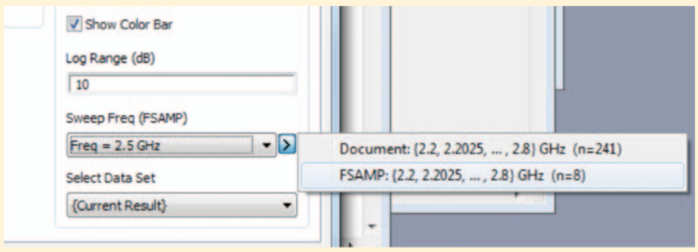


Figure 6. There were 241 frequencies for S-parameters obtained from 8 discrete EM analysis frequencies.

Software

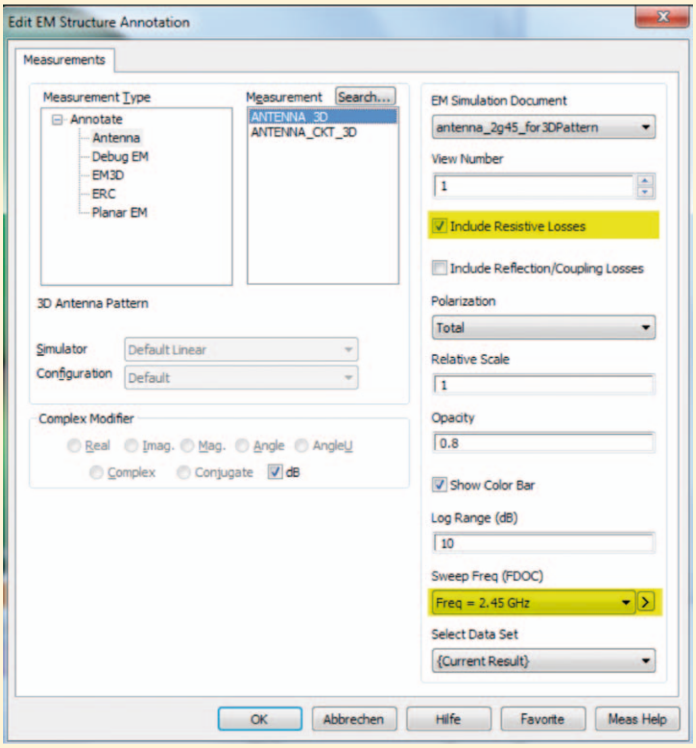


Figure 7. Settings needed to plot the antenna gain (dBi) with losses in the antenna included.

the resulting input impedance and so did the distance between the radiator and the ground plane.

The plot in Figure 2 shows the antenna input impedance when the tap position was moved. This parametric sweep was done by adding a parametric modifier of type control point and sweeping that control point with a variable in the EM schematic. It can be seen that in this case the nominal value (feedoffset=0 mm) gave the closest match to 50 Ohm.

After determining the tap position for the feed, the antenna frequency was fine tuned by adjusting the radiator length. There are multiple ways to define that length by parameters. Here, a parametric modifier of type control point has again been used (Figures 3 and 4). This sweep reveals that the antenna length must be tweaked by -1 mm to reach the 2.45 GHz target frequency. The matching changed only slightly for this small change in length, so it was not necessary to re-tune the tap position again (Figure 5). Next, the antenna was tuned for good matching at 2.45 GHz, but what about the antenna gain? So far, the adaptive frequency sweep for EM simulations has been used, which automatically chose the EM analysis frequencies as needed, with only the start and stop frequency defined by the user. The adaptive frequency sweep provided nicely interpolated S-parameters, but currents and antenna patterns were only available for the discrete frequencies that had actually been EM simulated. In Microwave Office software these are called FSAMP frequencies.

Figure 6 shows that there were 241 frequencies for S-parameters obtained from eight discrete EM analysis frequencies. Antenna patterns were only available for those eight frequencies, which had been chosen automatically by the software. The nearest frequency to the 2.45 GHz target was the 2.5 GHz frequency point.

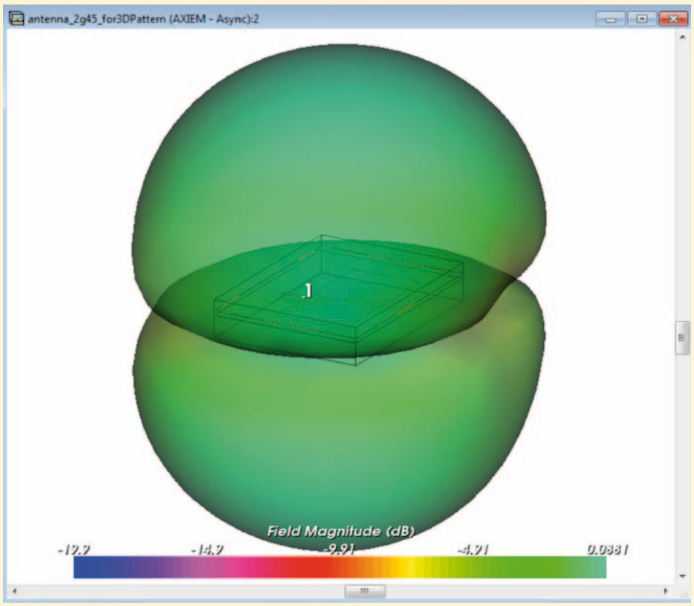


Figure 8. The resulting pattern from setting the antenna annotation parameters for a 3D far-field pattern.

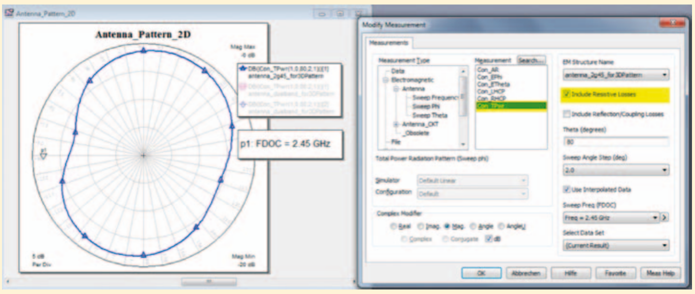


Figure 9. The result for the gain (total over all polarizations) at theta=80°.

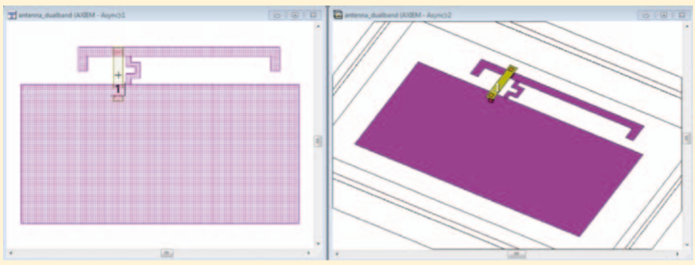


Figure 10. The layout was modified by adding a second radiator element to obtain dual band operation.

The antenna in this application note was matched narrowband and the internal losses changed with frequency. For this reason, it was best to simulate the antenna gain at the exact operating frequency. The easiest method was to create a copy of the EM structure and simulate that for a single frequency point 2.45 GHz (no sweep, no adaptive frequency sampling).

How were the antenna annotation parameters set for a 3D far-field pattern? Figure 7 shows what settings were needed to plot the antenna gain (dBi)

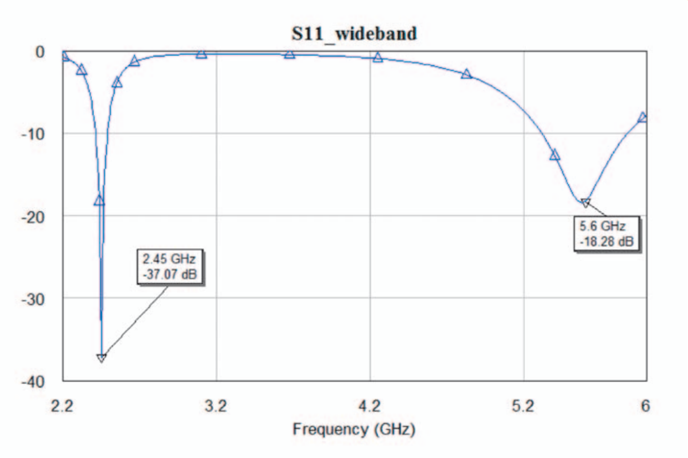


Figure 11. Optimized dual band antenna impedance.

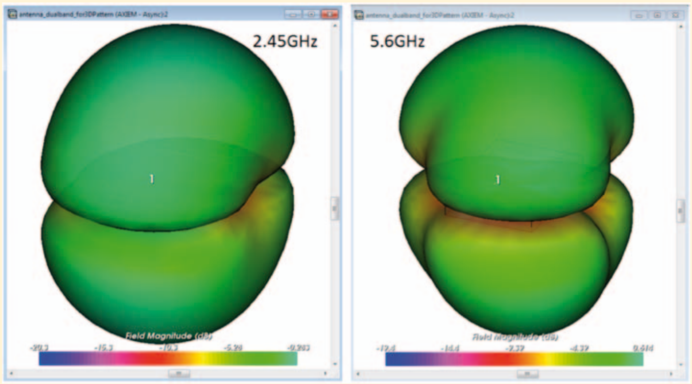


Figure 12. The 3D antenna gain annotation was calculated by copying the EM Structure and simulating that copy at two frequencies only: 2.45 GHz and 5.6 GHz (no sweep, no AFS).

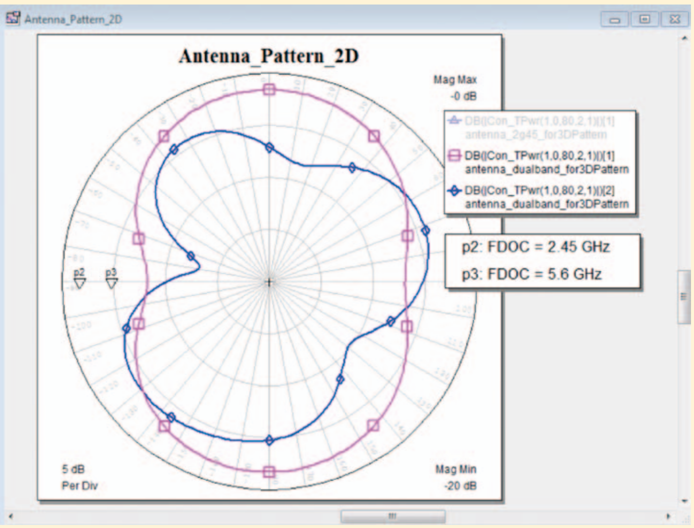
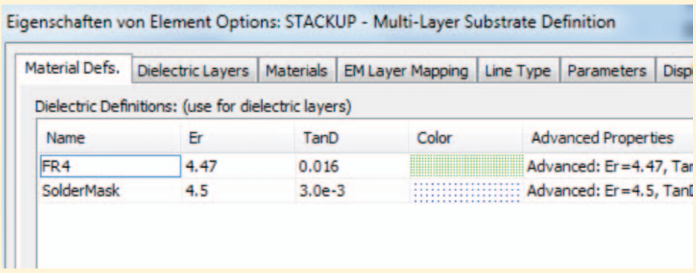


Figure 13. The antenna performed reasonably well, with about 0dBi peak gain. At 5.6 GHz the pattern was more directed (blue trace). The 2.4 GHz performance was very similar to the single band version (magenta trace).


Eigenschaften von Element Options: STACKUP - Multi-Layer Substrate Definition

Material Defs. | Dielectric Layers | Materials | EM Layer Mapping | Line Type | Parameters | Disp

Dielectric Definitions: (use for dielectric layers)

Name	Er	TanD	Color	Advanced Properties
FR4	4.47	0.016		Advanced: Er=4.47, Tar
SolderMask	4.5	3.0e-3		Advanced: Er=4.5, TanI

Figure 14. FR4 dielectric constant was set to 4.47 for this project.

with losses in the antenna included. By disabling the "Included Resistive Losses" checkbox, the antenna directivity could be calculated instead of the gain.

The resulting pattern is shown in Figure 8. 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 caused a drop in simulated gain at the horizon (theta=90°). The true pattern shape was continuous at the horizon, with no such drop.

The directivity (without losses) was around +2 dBi peak and the gain (including resistive losses) was about 0 dBi peak gain. This means that the antenna had reasonable efficiency, with approximately 2 dB losses in conductors or dielectrics, or both. Besides the 3D pattern that gives a good overview of the radiation characteristics, the "classical" antenna parameters can also be plotted in 2D polar format. Figure 9 shows the result for the gain (total over all polarizations) at theta=80°, which was 10° above the PCB plane.

If the antenna had excessive losses such as a large difference between gain and directivity, the origin of these losses could then be investigated. This could be done by selectively setting only the metals or only the PCB dielectric to lossless to investigate what was causing the losses.

Modifying the Antenna to Dual Band: 2.45 GHz and 5.6 GHz

After investigating the simple single band antenna, a dual band operation at 2.45 GHz and 5.6 GHz was examined. The layout was modified by adding a second radiator element, as shown in Figure 10.

First, the appropriate radiator lengths for 2.45 GHz and 5.6 GHz were roughly set. To have good matching, more inductance was needed between the feed tap and ground. This was achieved by adding a meander line instead of the straight-line segment. Also, the tap location was moved again to find the best matching point for both 2.45 GHz and 5.6 GHz. Finally, the lengths were fine tuned to the target frequencies. (Figure 11).

The 3D antenna gain annotation was calculated by copying the EM structure and simulating that copy at two frequencies only: 2.45 GHz and 5.6 GHz (no sweep, no AFS) (Figure 12). It can be seen that the antenna performed reasonably well, with about 0 dBi peak gain. At 5.6 GHz the pattern was more directed. The 2.4 GHz performance was very similar to the single band version (Figure 13).

The topic of PCB F-antenna simulation wouldn't be complete without a look at tolerances: the usual FR4 PCB material is poorly specified and large tolerances in permittivity must be expected.

PCB Sensitivity

The final investigation on these antennas was the sensitivity to spread in FR4 dielectric properties. That value depends on the resin/fiber mixture of the board material and different manufacturers provide different materials. They all fall into the large "FR4" group, but it is really different materials from an RF viewpoint. Reported values for FR4 dielectric constant are somewhere in the range 4.0 to 4.9. Simulations so far were performed with

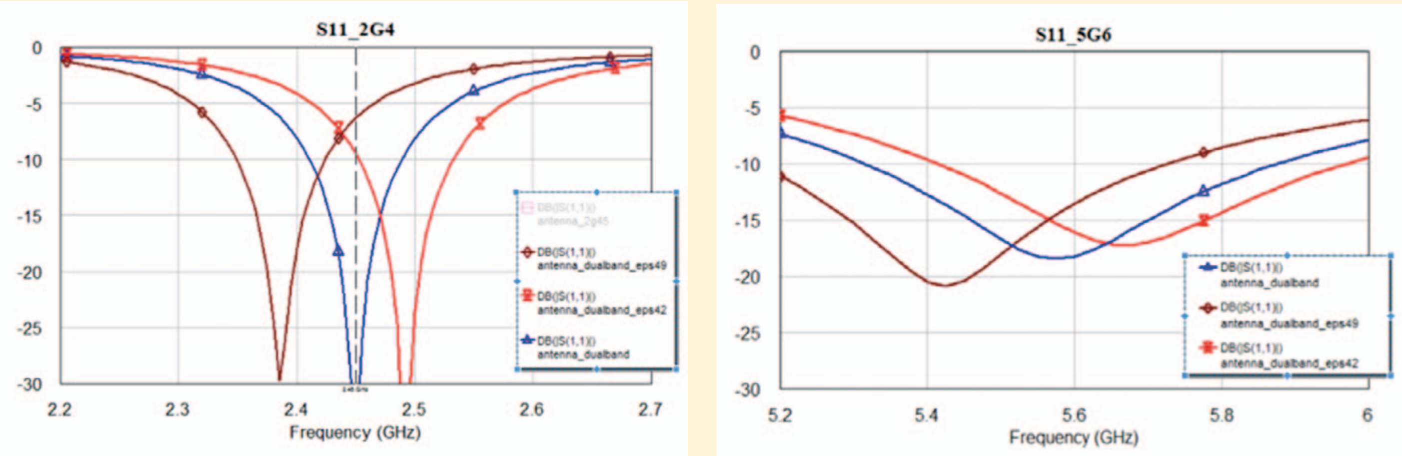


Figure 15. Results after re-simulating with er=4.2 (red trace) and er=4.9 (brown trace) instead of 4.47 (blue trace).

a value of 4.47, as set in the Microwave Office template for 2-layer FR4 (Figure 14).

So how does the resonance shift when simulated with er=4.2 and er=4.9 instead of 4.47? The dual band antenna was copied and modified and Figure 15 shows the result after resimulating with the new values. Now depending on the requirements, it can be decided if this possible mismatch is acceptable, or whether an alternative PCB material with tighter tolerances would be better.

Conclusion

This application note has discussed the design and simulation of a simple PCB antenna for 2.4 GHz and 5.6 GHz. PIFA shapes usually have a metal bracket as the radiating element, however, this application described the design of a truly planar PCB antenna where PCB conductor layers are used to form an inverted-F shape rather than a bracket.

Three examples were used to illustrate this design. The first example was a 2.45 GHz single band antenna, the second example was a dual band version for 2.4 GHz and 5.6 GHz, and the third example investigated sensitivity to PCB material tolerances.

AWR Group, NI would like to thank Dr. Ing. Volker Mühlhaus, Dr. Mühlhaus Consulting & Software GmbH, for his contributions to this application note.
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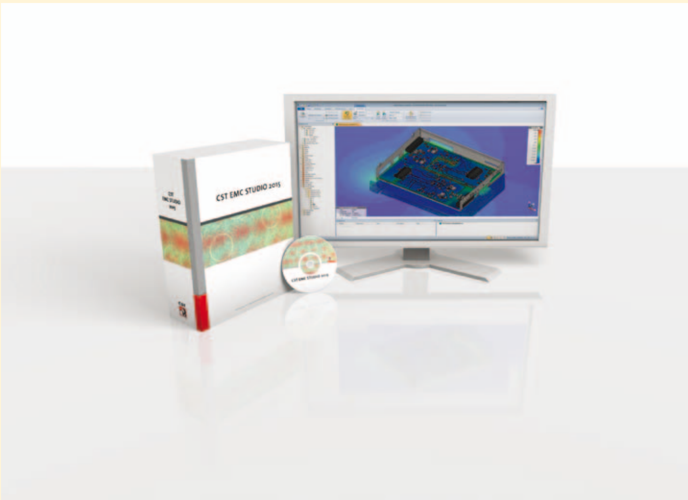
News

CST Offers CST EMC STUDIO University Seats

CST – Computer Simulation Technology (CST) announces educational seats for CST EMC STUDIO, a simulation tool for electromagnetic compatibility (EMC) analysis, at the 2015 IEEE Symposium on Electromagnetic Compatibility and Signal Integrity.



EMC is an important consideration in a wide range of applications, and an increasing number of universities have set up courses and research groups for its study. CST develops electromagnetic simulation solutions that are widely used in academia, research and industry, and has long supported universities through discounted licenses and co-operation programs. In order to provide the EMC engineers of the future with the tools and experience they need, CST is now expanding this program to include university seats for its latest product, CST EMC STUDIO.

CST EMC STUDIO contains a toolkit of proven solver technology for the study of EMC effects, with general purpose 3D modules for time and frequency domain simulation alongside more specialized solvers. In particular, it includes the 3D transmission line matrix (TLM) method solver, which implements technology that simplifies numerical EMC analysis, such as compact models and octree meshing. The bidirectional cable/field simulation enables more realistic modeling of noise propagation and radiation over cables. True transient EM/circuit helps analyze the effect of nonlinear circuitry on EMC performance. For analyzing printed electronics, the powerful import functionality and the rule checker are useful.

Among the topics which CST EMC STUDIO can be used to help teach and study are electrostatic discharge (ESD), radiated and conducted emissions, EMC performance of printed electronics, and susceptibility to environmental electromagnetic effects (E3) such as lightning strikes, high-intensity radiated fields (HIRF) and electromagnetic pulses (EMP).

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