Effective Antenna Design by EM-Circuit Co-Simulation

Introduction

The EM simulation of complex antenna systems presents a challenge for modern computational software. The goal of a circuit-EM co-simulation is to alleviate the computational complexity decomposing the complete system into parts that need to be simulated using full-wave approach, and parts that would be modeled by predefined library components. Encapsulation of proven parameterized antenna models and their reuse within the same or another project is essential in rapid development of complex systems. Being added to component library with specified externally visible parameters, these component models are easily reused with the possibility of further optimization within a composite system.

Co-Simulation in WIPL-D Microwave

The microwave (MW) circuit is composed of models of lumped elements, transmission lines and discontinuities which are characterized by relatively simple analytical equations based on physical and material properties of components. The circuit solver then uses the equation models to calculate S-parameters of components, and finally S-parameters of the entire circuit (in reference to its ports).

Main benefit of using circuit analysis is quickness of getting results. The circuit analysis is faster than full-wave EM analysis, even if done over a wide frequency range because of simple component models. Simulation time does not depend on the size of the circuit (in wavelengths).

However, the validity range of analytical models is most often small which significantly limits their applications. Besides, the circuit model described above takes into account conductor and substrate losses in a typical circuit, but not radiation mechanisms. It is also difficult to include enclosure effects, since there may be box resonances or waveguide modes in our physical implementation. Furthermore, parasitic coupling between various circuit component models is not accounted for.

The most significant drawback of the approach is that there is no possibility to model a device that can't be described by standard library analytical models.

Therefore, there is a clear benefit from inclusion of EM simulation capabilities into the circuit simulation. EM models imported into the circuit can be parameterized and treated as any other circuit components in an optimization cycle. EM models allow investigation of wanted or unwanted radiation and coupling mechanisms. Parts of the system whose radiation or EM coupling to other parts of the system is not crucial can be modeled analytically. Moreover, measured data over a frequency range can be imported as a component. Finally, a model of any antenna or antenna component of interest can be included and electromagnetically simulated, on-the-fly, at the circuit simulation runtime. Hence, antennas can be excited in ways that are closer to how the structures are used in practice.

WIPL-D Microwave offers all the possibilities mentioned above, as well as some additional features:

- Radiation pattern produced by all the radiating components in the circuit (Figure 1),
- A WIPL-D designed EM model of circuit components in the library (Figure 2) with calculation of de-embedded s - parameters,
- Mode-matching based models of the most important rectangular waveguide discontinuities,
- Library EM models of basic antennas and most often encountered implementation technology transitions (Figure 3),
- Impedance calculator which is built in each component specification window (Figure 3)

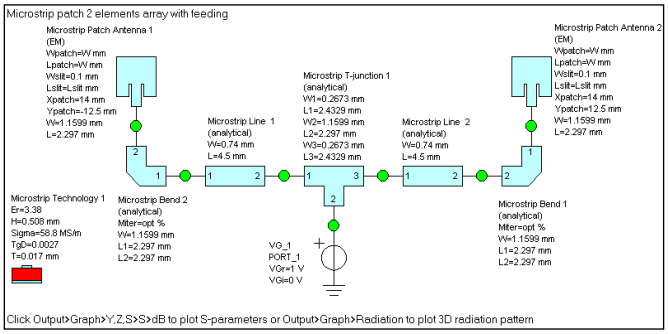

Figure 1. MW circuit

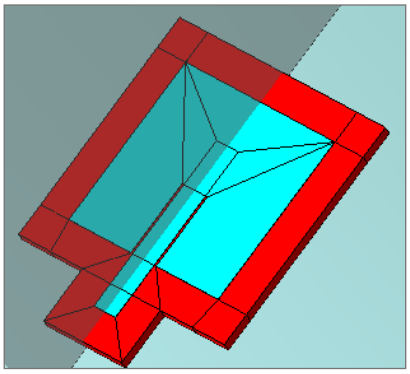

Figure 2. Full-wave microstrip patch antenna model

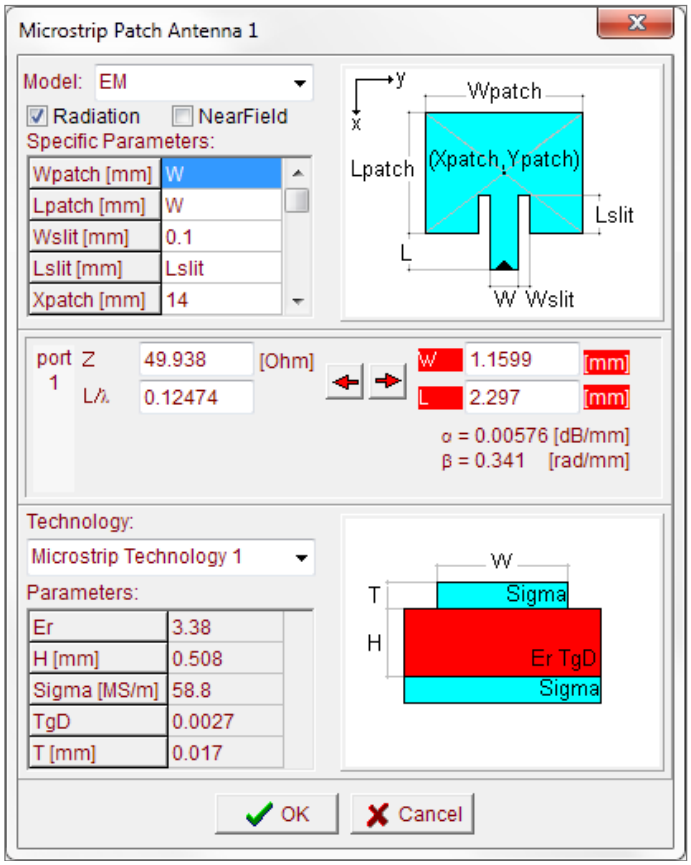

Figure 3. Library microstrip patch antenna model

Simulation Example

MW circuit shown in Figure 1 is analyzed using WIPL-D Microwave. Circuit is implemented in microstrip technology. It consists of two microstrip patch antennas and feeding network: microstrip lines, microstrip T-junction and bends. All of the circuit parameters are optimized in such way that antenna is matched at 10 GHz. Patch antennas are separated. Distance between them is 25 mm along x axes. Radiating of all of the circuit elements is not considered. We assume that radiating components are patch antennas only.

EM full-wave model of antenna created in WIPL-D Pro is shown in Figure 2. Library microstrip patch antenna model is shown in Figure 3. Specification of circuit component with built in impedance calculator is shown in Figure 3.

System is analyzed in frequency band 9 GHz up to 11 GHz in 9 uniformly distributed points. Central operating frequency is 10 GHz.

Parameter s11 is calculated in order to analyze antenna matching. Gain and near field are calculated at 10 GHz (frequency where matching is considered to be). Parameter s11 is shown in Figure 4.

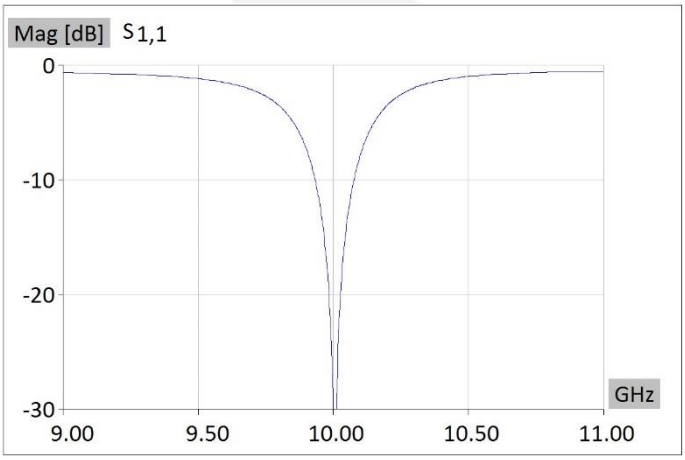

Figure 4. Parameter s11

Antenna gain in 3D is shown in Figure 5.

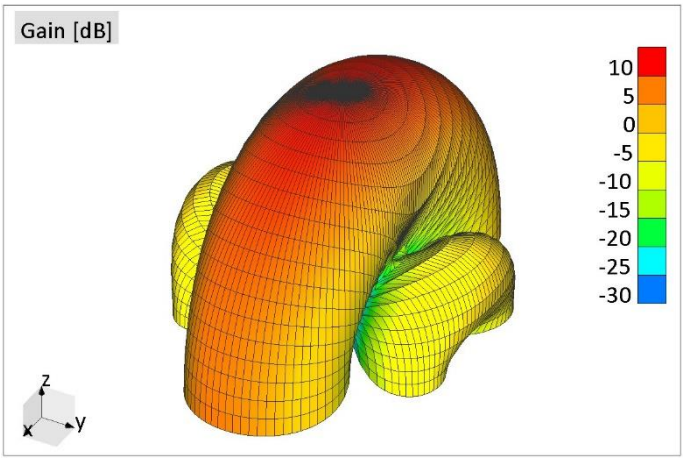

Figure 5. Gain in 3D

Calculated near field is shown in Figure 6. It should be noticed that antenna coupling is not considered.

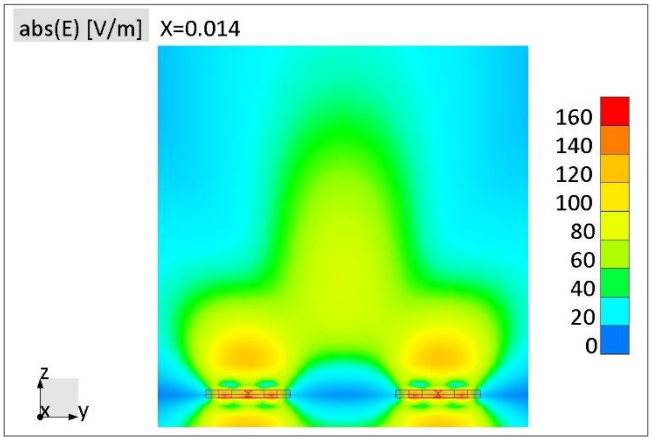

Figure 6. Near field

Computer needed for these calculations is any standard desktop or laptop PC. Simulation time is just a couple of seconds.

Conclusion

The goal of a circuit-EM co-simulation is to alleviate the computational complexity decomposing the complete system into parts that need to be simulated using full-wave approach, and parts that would be modeled by predefined library components. Encapsulation of proven parameterized antenna models and their reuse within the same or another project is essential in rapid development of complex systems.

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WIPL-D 3D EM solver and WIPL-D MW circuit solver present dynamically connected software. They are fast and accurate in co-simulation.

This kind of structures modeling can be used in antenna arrays with many elements. In co-simulation, number of unknowns is dramatically reduced because of separating one big EM computational problem into many small problems.