Antenna Analysis Using FDTD and Equivalent Circuits

Yong Wang and Scott Langdon
Remcom Inc., 315 S. Allen St., Suite 416, State College, PA 16801, USA
yong.wang@remcom.com, scott.langdon@remcom.com

***Abstract*—To simulate RF devices characterized by the measured S-parameters, the passivity enforcement method is first applied to extracting the rational models. The equivalent circuits can then be generated from the rational models. The RF devices are finally simulated using the FDTD and equivalent circuit co-simulation method. The numerical results of several examples have shown the efficacy and accuracy of the presented approach. The approach can be applied to simulating the broadband features of antennas which includes RF devices, complex geometries and materials in a single run.**

***Index Terms*—RF device, equivalent circuit, FDTD method, S-parameters.**

I. Introduction

RF devices characterized by the measured S-parameters can be simulated using the FDTD algorithm with the piecewise linear recursive convolution (PLRC) method [1]. The measurement data of the S-parameters or other parameters for these RF devices are generally available from manufacturers. Rational models can be created from the measured parameters of the RF devices by extracting the pole-residue pairs. These RF devices can then be simulated by the FDTD algorithm with the PLRC method using the rational models.

In this paper, the rational models are first represented by equivalent circuits which are then simulated in the time domain by using an FDTD and circuit co-simulation method. The simulation results of a number of examples obtained from the FDTD and circuit co-simulation are validated by the comparison with the FDTD algorithm with the PLRC method and the original measurement data. The equivalent circuit extraction process and the FDTD and circuit co-simulation method can find extensive applications in analyzing antenna systems with RF devices and complex geometries and materials.

II. The Approach

When the measured S-parameters of the RF devices are available from the manufacturers, the S-parameters matrix can be converted to the admittance Y-parameters matrix which can then be fitted by the rational models. The rational models can be expressed in the form of the pole-residue pairs. To ensure a stable circuit simulation in the time domain, the inverse eigenvalue passivity enforcement method [2] is first applied to the extraction of the pole-residue pairs because it guarantees causality and passivity.

The rational models extracted from the RF devices can then be represented by equivalent circuits [3]. The equivalent network is generated from the poles and residues using an RLC circuit. The equivalent circuits for the constant and linear terms in the rational function of the admittance are equivalent to a resistor and a capacitor, respectively. The real poles are equivalent to a series RL circuit. The equivalent circuit for a complex pole-residue pair has a series RL and R||C circuit. The equivalent circuit for a complex pole-residue pair can also be a series RLC with a voltage controlled current source (VCCS). For multiple pole-residue pairs, these equivalent circuits are parallel with each other.

The FDTD method is popularly used for the EM simulation of complex geometries and materials; however, the full wave EM method has limitations in simulating complex circuits. It will make the FDTD solver more powerful if it can be combined with a time domain circuit solver. It is straightforward to link the FDTD solver with a time domain circuit solver as described in [4]. In the integrated EM circuit environment, each circuit takes only one Yee cell edge in the FDTD meshes as shown in Fig. 1. The extracted equivalent circuits of the RF devices can be imported as a netlist file and simulated in this integrated EM circuit environment.

For a 2-port circuit such as the T-type or Pi-type circuit, the circuit can be integrated with the discrete source in the FDTD simulation. The FDTD solver and the circuit solver communicate with each other using the current and voltage at the Yee cell at each time step. In particular, the current at the Yee cell calculated from the FDTD solver is passed to the circuit solver and the voltage at the Yee cell calculated from the circuit solver is passed to the FDTD solver at each time step.

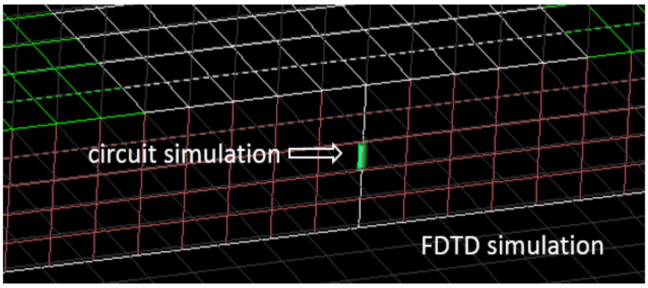


Fig. 1. FDTD and circuit co-simulation

III. Numerical Results

The approach presented in the previous section is applied to the simulation of a number of RF devices and antenna systems. The following examples are given to illustrate the efficacy and accuracy of the approach.

A chip inductor LQP03PN-02 and a ceramic capacitor GRM0332C2A4R0BA01 from Murata are analyzed as examples by the presented approach. The rational models [1] are used to generate the equivalent circuits with and without the VCCSs. The equivalent circuits are validated in a frequency domain circuit solver by comparing the admittance with the original measurement data and the curve-fitted results.

The equivalent circuits of the chip inductor and the ceramic capacitor were imported using netlist files as loads to a microstrip line and simulated by the FDTD and circuit co-simulation method. The simulation results using the equivalent circuits with and without the VCCSs are almost identical and are close to those obtained using the FDTD algorithm with the PLRC method [1].

Fig. 2 shows the simulated S_{11} of a patch antenna with a Tee matching circuit composed of the chip inductor and the ceramic capacitor. It is seen that the S_{11} results using the equivalent circuits with and without VCCS are almost identical; however, they are different from those using the Tee matching circuit composed of the ideal inductors and capacitors with constant values. Therefore, it is important to simulate the matching circuits using the real-world lumped components instead of the ideal ones.

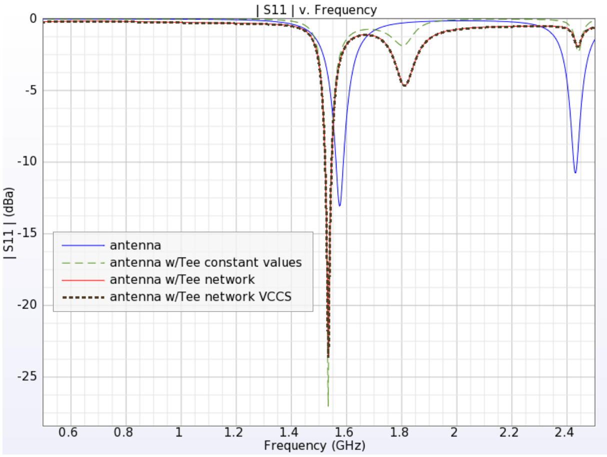
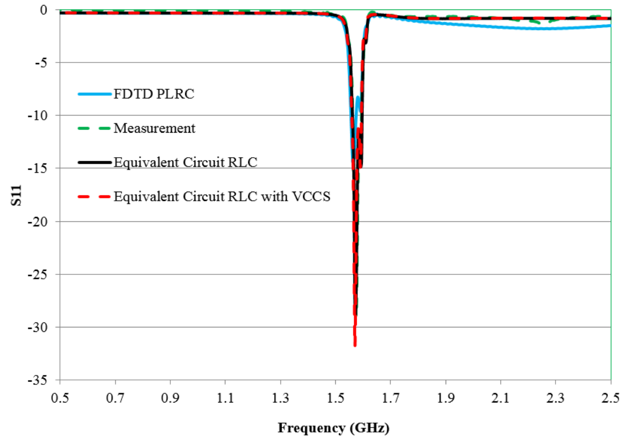
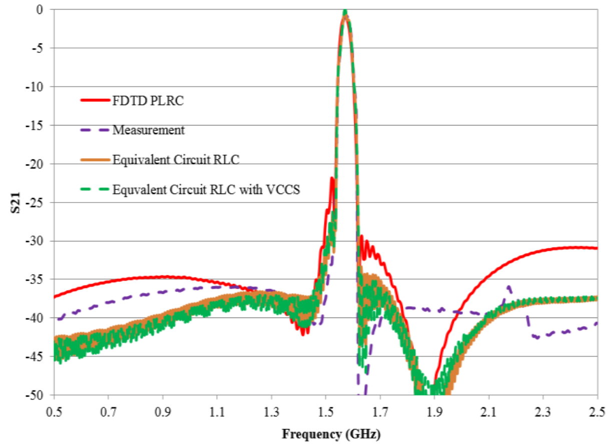


Fig.2. Simulated S_{11} of the patch antenna with matching circuit composed of the chip inductor and ceramic capacitor by using the equivalent circuit method and constant values.

A GPS SAW bandpass filter 856561 from TriQuint was simulated by the presented approach. It is a 2-port RF device and the measured S-parameters matrices are available from the manufacturer. In this case, fourteen complex poles and residues and a constant term are extracted from the admittance matrices [1]. This two port device is equivalent to a Pi-type circuit with and without the VCCSs. The equivalent circuits with and without the VCCSs are integrated with a discrete source respectively and connected with a microstrip line. The equivalent circuits are simulated using the FDTD and circuit co-simulation method. Fig. 3 shows the S_{11} and S_{21} of the bandpass filter simulated by using the Pi-type equivalent circuits with and without the VCCSs, and the FDTD algorithm with the PLRC method versus the original measurement data. It is seen that both the reflection coefficient and the insertion loss obtained from the equivalent circuits agree quite well with those obtained from the FDTD algorithm with the PLRC method and the original measurement data. This has demonstrated that the equivalent circuits represent the original device quite well and the 2-port RF devices can be simulated by using the FDTD and circuit co-simulation method. An antenna which is connected with the GPS filter is simulated using the the FDTD and equivalent circuit co-simulation method. It is observed that the signal which is not in the pass band is filtered out.



(a)



(b)

Fig. 3. The S-parameters of the bandpass filter simulated by using the equivalent circuits with and with the VCCSs and the FDTD algorithm with the PLRC method versus the original measurement data (a) S_{11} (b) S_{21}

ACKNOWLEDGMENT

The authors would like to thank our colleagues Gregory Moss and Joseph Warren for their assistance on the netlist input for the FDTD and circuit co-simulation.

REFERENCES

[1] Y. Wang and S. Langdon,"FDTD simulation of real lumped components and RF devices," European Conference of Antenna and Propagation (EuCAP), Davos, Switzerland, April 2016.

[2] C. Saunders and M. Steer, "Passivity enforcement for admittance models of distributed networks using an inverse eigenvalue method," IEEE Trans. Microwave Theory Tech., vol.60, no.1, pp.8-20, Jan. 2012.

[3] G. Antonini, "SPICE equivalent circuits of frequency-domain responses," IEEE Transactions on Electromagnetic Compatibility, vol. 45, no. 3, pp. 502-512, Aug. 2003.

[4] N. M. Kriplani, J. Fletcher, S. Langdon, C. W. Penney, S. A. Fast and M. B. Steer, ''Integration of FDTD EM analysis and transient circuit simulation of RF systems,'' IEEE International Microwave Symposium, Boston, 2009.