Strategies for Modeling the Interaction of Devices, Circuits and Fields

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Many of the microwave engineering developments have come about when the electromagnetic environment has been transformed into a circuit abstraction. Three particular developments exemplify this modeling procedure. The first of these is the modeling work undertaken for radar development during the Second World War: Marcuvitz's book [1] showed how discontinuities in waveguide could be modeled by lumped element equivalents. The second work, Collin's *Foundations of Microwave Engineering* book, presented a formalism for treating distributed structures as circuit elements [2]. A third example is the pioneering work of Eisenhart and Khan [3] which presented an approach to modeling waveguide-based structures as circuit elements. In this work it was shown that quite sophisticated and accurate models could be developed for three-dimensional waveguide systems.

One fundamental issue that arises in modeling electrically large systems as a circuit representation is the assignment of system ground. Currently circuit simulators use a nodal approach in which voltages are assigned to nodes and each of these voltages is referred to a common reference point commonly called ground. In a spatially distributed system, a common reference point cannot always be defined as the spatial separation of a node and its reference point cannot be tolerated. Microstrip networks are examples of distributed structures for which reasonable approximations have been made so that they can be treated as elements in conventional circuit simulators. So, the accepted view is that the ground plane can be treated as a global reference point (common ground) even though this implies, and requires, that charges can instantaneously redistribute on the ground plane.

In this talk the global modeling of distributed microwave circuits — such as a spatial power combiner — integrating electromagnetic, circuit and thermal modeling is discussed. The talk discusses the developments in circuit theory necessary to model distributed microwave circuits and thermal networks. Then a strategy for integrating electromagnetic models into steady-state (harmonic balance) and transient circuit analysis will be presented. Then integration of thermal analysis is described. Measured and simulated results for a grid amplifier are used to illustrate the discussion.

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[1] N. Marcuvitz, *Waveguide Handbook*. New York: McGraw Hill, Massachusetts Institute of Technology, Radiation Laboratory series, No. 10, 1951.
[2] R. E. Collin, *Foundations for Microwave Engineering*, Tokyo: McGraw-Hill, 1966
[3] R. L. Eisenhart and P. J. Khan, "Theoretical and experimental analysis of a waveguide mounting structure," *IEEE Trans. Microwave Theory Tech.*, Vol. 19, Aug. 1971, pp. 706-719.