A Full – Wave Transmission Line Theory: Global Parameters

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Linear structures constitute an essential part in electrical and electronic circuits, switch boards, devices, systems, and buildings. In electrical engineering, one essential tool to describe electromagnetic field coupling to these linear structures, i.e. conductors, at not too high frequencies, is the so-called transmission-line theory (TLT). There are many approaches and standard numerical computer programs for the fast solution of the belonging telegrapher equations for uniform as well as for nonuniform conductors. However, these equations do not contain radiation phenomena and higher order modes. Because of these additional effects, which occur especially at higher frequencies up to several GHz, the transmission-line theory is not applicable anymore.Therefore, one may raise the question whether the telegrapher equations can be extended and generalized to include radiation effects (with the correct current distribution) in the high-frequency regime, while retaining their formal structure. This new full-wave transmission-line theory has to be capable of modeling very complex geometries, like finite lines, bends, nonuniform line conduction with curvatures and torsion, including periodic structures; it has to include radiation losses and non-TEM modes at higher frequencies.

One can distinguish two classes of problems, which ought to be considered by this generalized transmission-line theory. During the design phase of electronic systems one needs to consider the propagation of signals along the finite linear structures with a lumped source at one terminal and a lumped impedance (load) at the other terminal. In many EMC problems also the interaction of external electromagnetic fields with a loaded transmission lines has to be considered.

The general method to develop such theory was proposed in (H.Haase and J.Nitsch, Proc.14th Int. Zurich Symp. on EMC, Feb.2001, 235-240; H.Haase, T.Steinmetz, and J.Nitsch, IEEE Tran. Elect. Comp., vol. 47 2004; H. Haase, J.Nitsch, and T.Steinmetz, Radio Science Bulletin*,* vol. 307, 2003, 33-60; J.Nitsch and S.Tkachenko, Radio Science Bulletin, vol. 312, March 2005, 21-31). The method is based on the representation of the exact integro-differential equations as a system of first order differential equations for the conductor currents and some auxiliary quantity. The choice of this auxiliary function is not unique. One may choose, e.g. the charge density or a scalar potential in one of the different gauges. The most important cases for practical purposes is the scalar potential in the Lorenz gauge. In this case the integro-differential (Pocklington) equation is transformed into the transmission-line-like system for the current and potential. The resulting coordinate-dependent parameter matrix contains also diagonal terms. In contrast to classical transmission-line approximation these parameters depend on the frequency and are related to the radiation of the system. They contain all information about the electrodynamic properties of the system and its environment (they are functionals of the Green's function of the system). We call them global parameters. These parameters can be obtained with the aid of a iteration procedure. Also these parameters can be obtained by the analysis of the results of a method of moment solution for the current (K.K.Mei, Radio Science Bulletin, vol. 305, 2003, pp.6-13). Finally, the amplitudes of the lumped sources and impedances fix the boundary conditions of the system.

If external fields are involved, the intergro-differential equations can also be cast to the generalized telegrapher equations with these global parameters, however, with renormalized sources. These sources are different from the tangential components of the external field. This renormalization procedure can be carried out iteratively and already the first iteration yields good results.

The application of the developed theory for different configurations of practically important wiring systems gives a good agreement with numerical calculations and measurements.