Circuit Model of Multiconductor Lines Excited by an Incident Plane Wave

Moustafa Raya, Sergey V. Tkachenko and Ralf Vick
Chair for Electromagnetic Compatibility
Otto von Guericke University Magdeburg
Magdeburg, Germany
moustafa.raya@ovgu.de

Abstract—This work presents a circuit model for multiconductor lines excited by an incident plane wave suitable for SPICE simulations. Multiconductor lines are divided into segments and represented as *LC* components and controlled sources appropriate for circuit solvers. The advantage of the presented model is that EMC engineers can calculate field coupling on conductors directly in circuit simulators without using field simulation programs. The developed model can be used directly in the frequency domain or in the time domain containing nonlinear elements without the need for an inverse Fourier transform.

Keywords- Circuit model; multiconductor lines; field coupling

I. INTRODUCTION

The analysis of field coupling on transmission lines (TLs) is considered one of the most important topics in the EMC world. However, there has always been an interest in developing circuit models of TLs for SPICE simulation. Full-wave simulations quickly reach their limits, especially when simulating large cable lengths. An ideal solution would be to simulate the field coupling on TLs directly in circuit solvers without requiring a higher computational effort. This problem is addressed in this paper by presenting a lumped circuit model for TLs that can be directly integrated into the SPICE environment. The model accounts for the field coupling of a plane wave without the need for field simulations.

II. CIRCUIT MODEL

Agrawal *et al.* presented the field coupling on *n*-conductor lines as follows [1]:

$$\frac{d\mathbf{V}^{s}(z)}{dz} + j\omega\mathbf{L}'.\mathbf{I}(z) = \mathbf{V}'_{\tan}(z) \quad (1)$$

$$\frac{d\mathbf{I}(z)}{dz} + j\omega\mathbf{C}'.\mathbf{V}^{s}(z) = 0. \quad (2)$$

The $n\times n$ matrices $\mathbf{L}'$ and $\mathbf{C}'$ are the inductance and the capacitance of the lines per unit length (p.u.l.). The $n\times 1$ vectors $\mathbf{I}(z)$ and $\mathbf{V}^{s}(z)$ are the total current and the scattered voltage. The p.u.l. voltage induced by the tangential electric field on the conductors is represented by the $n\times 1$ vector $\mathbf{V}'_{\tan}(z)$ and is given for the *i*-th conductor above a ground plane by $\mathrm{V}'_{\tan,i}(z) = E_z^{in}(h_i, z) + E_z^{re}(h_i, z)$, where h_i is the height of the *i*-th conductor above the ground. An equivalent circuit can be interpreted from (1) and (2) as LC components with the voltage source $\mathbf{V}'_{\tan}(z)$ to represent the field coupling. A time domain solution for $\mathrm{V}'_{\tan,i}(z)$ was found as follows:

$$V_{tan,i}^{k} = \Gamma_i.\frac{\mathrm{d}E_0(t-T_{i,k})}{\mathrm{d}t}, \quad (1)$$

where k is the order of the section at the *i*-th conductor. The element Γ_i is proportional to the angle of incidence of the wave θ and h_i. This solution can be easily interpreted as a circuit model in SPICE, where the time shift of $E_0(t)$ can be realized by a matched TL and the time derivation by calculating the current of a 1F capacitor for a defined voltage source. Three conductors of $2\,m$ length with a height $h_1 = 10\,mm$, $h_2 = 20\,mm$ and $h_3 = 40\,mm$ are shown in Fig. 1. The diameters are $d_1 = 1\,mm$, $d_2 = 0.5\,mm$, and $d_3 = 2\,mm$. The element D_1 is a diode of type MBR0520L. The loads are set to $R_{1-6} = 75\,\Omega$.

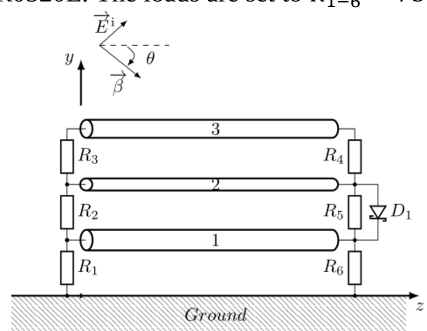

Figure 1. Three wires over a ground plane.

An incident plane wave was excited with an angle θ = 45° and an electric field strength of $100\,V/m$. It has a trapezoidal time function with rise, fall and hold times of $2\,ns$, $3\,ns$ and $10\,ns$, respectively. The induced voltage across D_1 is compared to CST simulations in Fig. 2.

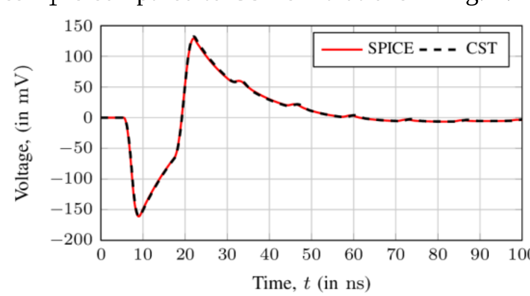

Figure 2. Voltage response across D_1.

REFERENCES

[1] A. Agrawal, H. Price, and S. Gurbaxani, “Transient response of multiconductor transmission lines excited by a nonuniform electromagnetic field,” in 1980 *Antennas and Propagation Society*, June 1980, pp. 432–435