TIME AND FREQUENCY DOMAIN STUDY OF THE PROPAGATION IN LOSSY MULTILAYERED WAVEGUIDE AND ANTENNA STRUCTURES BASED ON A RIGOROUS FULL-WAVE ANALYSIS

Frank Olyslager, Tom Dhaene and Daniël De Zutter*
The authors are with the Laboratory of Electromagnetism and Acoustics,
University of Ghent, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium.
Tel.: 32/91643327 - Telefax: 32/91643593

1. THEORY

The structures analysed in this contribution consist of coupled waveguides with arbitrary cross-section in a general multilayered medium. The origin of losses can be due to the finite conductivity of the waveguides, due to losses in the layers or due to radiation losses in surface or space leaky waves as is the case for microstrip antennas.

First we determine the complex propagation constants $\gamma(\omega)$ and the line-mode impedance matrix $\mathbf{Z}(\omega)$ associated with fundamental and higher order eigenmodes propagated along these structures. For this purpose we use a full-wave integral equation technique. We start by writing the electromagnetic fields inside and outside the waveguides as an integral over the boundaries of the waveguides. The integral equation is than found by imposing the continuity relations between the inside and outside integral representations at the waveguide boundaries (see [1]). Finally the integral equation is solved numerically with Galerkin's method.

Losses inside the waveguides are determined in an exact way without making any approximations or perturbations. This allows us to incorporate the effect of losses for a very large frequency band and for a big range in waveguide conductance. The line-mode impedance matrix $\mathbf{Z}$, in which Z_{ij} is the impedance associated with waveguide i and mode j, is determined using the well accepted power-current (PI) definition.

In a second step we construct from the dispersion curves for $\gamma(\omega)$ and $\mathbf{Z}(\omega)$ a generalized high-frequency equivalent transmission line model. $\mathbf{V_c}(z)$ and $\mathbf{I_c}(z)$ represent the circuit dependent voltages and currents in the equivalent transmission line model. z is the propagation direction of the eigenmodes in the structure.

The circuit current $\mathbf{I}_{c,i}(z)$ is chosen to be identical to the total longitudinal current flowing along the i^{th} waveguide. Furthermore, both the equivalent coupled transmission line model and the real waveguide structure are required to have the same complex modal propagation constants and are required to propagate the same average complex power (see [2]). This leads to the generalized frequency dependent telegrapher's equations (see [3]):

$$-\frac{d}{dz}\,\mathbf{V}_c(z,\omega) = [\mathbf{R}(\omega) + j\,\omega\,\mathbf{L}(\omega)]\,\mathbf{I}_c(z,\omega) \qquad (1.a)$$

$$-\frac{d}{dz}\,\mathbf{I}_c(z,\omega) = [\mathbf{G}(\omega) + j\,\omega\,\mathbf{C}(\omega)]\,\mathbf{V}_c(z,\omega) \qquad (1.b)$$

where $\mathbf{R}(\omega)$, $\mathbf{G}(\omega)$, $\mathbf{L}(\omega)$ and $\mathbf{C}(\omega)$ are the generalized resistance, conductance, inductance and capacitance matrices respectively.

The frequency dependent characteristic impedance matrix $\mathbf{Z}_c(\omega)$ is also very useful for circuit simulations. It follows directly from (1):

$$\mathbf{Z}_c(\omega) = \{[\mathbf{R} + j\,\omega\,\mathbf{L}]\,[\mathbf{G} + j\,\omega\,\mathbf{C}]\}^{-0.5}\,[\mathbf{R} + j\,\omega\,\mathbf{L}] \quad (2)$$

This complex matrix is defined in an unambiguous way and can be seen as the input impedance matrix of the infinitely long coupled transmission line structure. The characteristic impedance matrix relates the circuit current waves to the circuit voltage waves traveling in positive z-direction. In the single mode case, the characteristic impedance is equal to the line-mode impedance.

2 CASE STUDY

Due to space limitations we limit ourselves to a simple example consisting of a thick microstrip (Fig. 1) with low conductivity σ = 100kS/m. Examples for coupled lines will be presented in the conference session. In Fig. 2 and Fig. 3 the complex propagation constant $\gamma = \beta - j\alpha$ and the complex impedance $Z = Z_c$ are represented for the lowest order mode for a frequency up to 100 GHz. The dip in β and in the real part of Z at low frequencies is a result of the fact that for this frequency range the fields penetrate deep into the strip where they see a high complex relative dielectric constant $\sigma/j\omega\varepsilon_0$. Skin-effect approximations are not valid in this frequency range. At high frequencies the losses and α decrease because the fields are pushed out of the strip.

In Fig. 4 and Fig. 5 the frequency dependency of C, L, R and G is shown. Using these network parameters we have calculated the scattering parameters of a 25 mm long lossy transmission line (inset of Fig. 6). $S_{11} = S_{22}$ and $S_{12} = S_{21}$ due to the symmetry and the reciprocity of the structure. The amplitudes of the elements of the scattering parameter matrix (reference impedance = 18 Ω) are shown in Fig. 6. The ripple superimposed on the S-parameter-curves (not visible on S_{12} due to the special dB scale) is caused by the interference of incident and reflected waves. At about 8 GHz, the characteristic impedance of the transmission line corresponds very well to the reference impedance ($|S_{11}| \sim -100$ dB). This can be seen in the evolution of the

S_{11}-parameter as a function of frequency. At higher frequencies, the S_{12}-parameter decreases and the S_{11}-parameter increases due to the losses in the line and due to the bad correspondence between the reference impedance and the frequency dependent chararcteristic impedance of the line.

Finally, the distortion of pulses due to dispersion and losses is investigated. A Gaussian pulse ($g(t) = \exp[-0.5\ (t / \sigma)^2]$, where $\sigma = 25$ ps) is propagated along the transmission line under study. The response of the propagating pulse is shown in Fig. 7 at different distances varying from 0 to 50 cm (increment 5 cm). Due to the dispersion, the different frequency components of the pulse travel at different speeds, and so the pulse-width increases and the amplitude decreases. Furthermore, due to the frequency-dependent losses, the amplitude of the different frequency components decreases.

3. ACKNOWLEDGMENT

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4 REFERENCES

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[2] N. Faché and D. De Zutter, "New High-Frequency Circuit Model for Coupled Lossless and Lossy Waveguide Structures," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-38, pp.252-259, March 1990.

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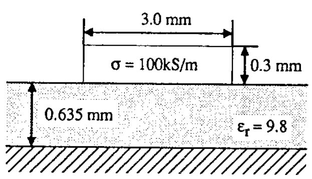


Figure 1

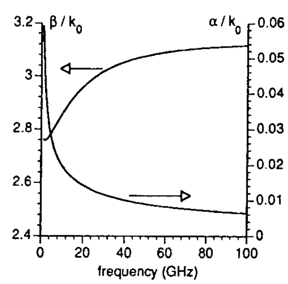
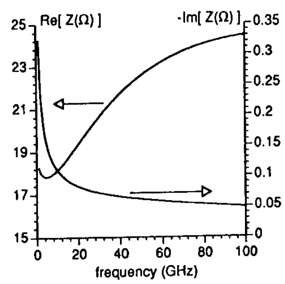


Figure 2



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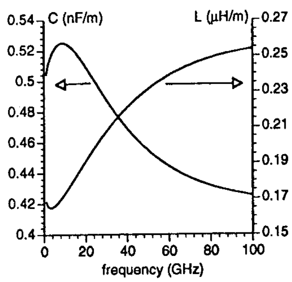
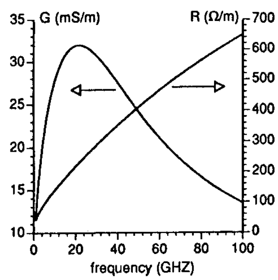


Figure 4



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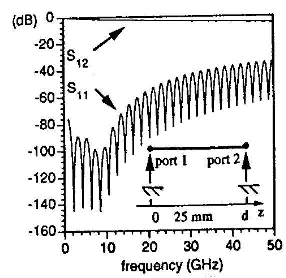

Figure 6

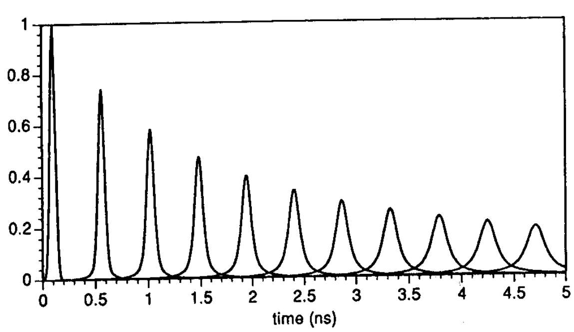

Figure 7