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Simulation of Circuits Including Non-linear and Dispersive Media

Mohamed H. Abd. El-Azeem *

Abstract

The TLM (SCN) algorithm has been modified to simulate structures which include non-linear and dispersive media. There are a wide variety of practical problems which include non-linear and dispersive media and these so far have not been fully simulated using TLM. Furthermore, all dielectric media possess some dispersion characteristics and these characteristics should be included if an accurate simulation is to be performed. We describe in this paper how the TLM (SCN) algorithm can be modified to include non-linear and dispersive media.

1. Introduction

In the symmetrical condensed node (SCN) formulation of the TLM method [1], the dielectric properties of the media can be simulated by three open circuited stubs, one for each direction of propagation and the magnetic properties by three short circuited stubs. Losses are simulated by three terminated stubs [2].

In the modified algorithm the non-linearity of the dielectric media is taken care of by making the characteristic admittance of the open circuited stubs at each node a function of the electric field at that node. If the relative dielectric constant $\varepsilon_r(E(t))$ is now a function of the instantaneous electric field at each node, the characteristic admittance of each open circuited stub will be given by

$$Y(E(t)) = 4(\varepsilon_r(E(t))-1) \qquad \text{(la)}$$

The scattering matrix at each node is now also a function of the electric field *E(t)* and following the notation in [1,2], the scattering and connecting processes are given

$$V^r{}_k = S(E(t))V^i{}_k \qquad \text{(Ib)}$$

$$V^i{}_{k+1} = CV^r{}_k \qquad \text{(Ic)}$$

where *S(E(t))* is the scattering matrix, V^r and V^i are the reflected and incident voltages and *k* is the solution time point, while *C* is the connection matrix.

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* Associate Professor, Electronic Department, Military technical College, Cairo, Egypt.

Similarly , for dispersive material in which the relative dielectric constant ε_r is a function of the time derivative of the electric field, the characteristic admittance of the open circuited stub will be given by

$$Y(dE(t)/dt) = 4(\varepsilon_r (dE(t)/dt) - 1) \quad (2a)$$

and

$$V^r_k = S(dE(t)/dt)\ V^i_k \quad (2b)$$

$$Vik+1 = C\ Vrk \quad (2c)$$

Anisotropic materials can be dealt with by setting different characteristic admittances for the three open circuited stubs representing the dielectric constant in all three directions.

For non-linear magnetic materials, the procedure is identical to that in a above except that short circuited stubs are used and the magnetic fields is used to update the permeabilities.

For non-linear conductivity, a similar procedure is used with three terminated transmission lines. The conductivity could either be a function of the electric or magnetic fields.

2. Simulation of pulse propagation in non-linear media

The TLM (SCN) method has been modified using equations (1) to simulate pulse propagation in non-linear media. TEM lines with non-linear dielectric constant $\varepsilon_r\ (E(t))$ which is a function of the instantaneous electric field strength have been simulated. The non-linear dielectric constant is in the form

$$\varepsilon_r\ (E(t))= \varepsilon_{ro}\ (1+aE(t)) \quad (3)$$

where a is a constant

The results are shown in Fig. 1 and 2 Gaussian pulse propagates along the line is distorted as the speed of propagation is not constant and is a function of the field strength. The upper part of the pulse travels quicker or slower than the lower part depending on the nature of the non-linearity. Shock wave is formed.

3. Simulation of pulse propagation in dispersive media

The TLM (SCN) method has also been modified to simulate pulse propagation in dispersive media. TEM lines with dielectric in which the relative dielectric constant $\varepsilon_r\ (dE(t)Idt\ )$ is a function of the time derivative of the electric field have been simulated. The dispersive relative dielectric constant is in the form

$$\varepsilon_r\ (dE(t)/dt) = \varepsilon_{ro}\ (1+bdE(t)/dt) \quad (4)$$

where b is a constant

The TLM simulation results are shown in Fig. 3 and 4. The speed of propagation is not constant and is a function of the rate of change of the electric field. This results in compression or expansion of the pulse. Pulse amplitude obtained from simulation increases or decreases as pulse is compressed or expanded respectively. Energy contained in the pulse is conserved using this modified TLM (SCN) algorithm.

4. Simulation of dispersion in ferrite materials

In the conventional TLM (SCN) method magnetic loss is emulated by a series resistance. This series resistance emulates the permeability of a material with a constant real part and a imaginary part which varies inversely with frequency. Most material for example ferrite exhibit a change in both real and imaginary parts of the permeability with frequency. The variation of permeability of ferrite material with frequency can be approximated by the function

$$\mu_r(\omega) = 1 + (\mu_{ro} - 1)/(1 + j\omega/\omega_r) \qquad (5)$$

where μ_r is the complex permeability, μ_{ro} is the real part of the permeability of the material, ω is the angular frequency and ω_r is the angular frequency at which the real and imaginary parts of the susceptibility are equal in magnitude to implement the above function the resistance of the magnetic loss resistance R added to the short circuit stub is placed in parallel with the impedance of the stub rather than in series [3]. The TLM method was modified to include such change. The reflection coefficient of a 6.3mm ferrite tiles was determined from simulation using the manufacturer's supplied parameters. The reflection coefficient for a 6.3mm ferrite tile with μ_{ro} =1051, ω_r =44.1079 MHz and ε_r =12 are determined from the modified TLM simulation. Fig. 5 and 6 show the TLM results and the analytical results calculated by the manufacturer. Good agreement is shown between the TLM and analytical results.

5. Non-Linear compensation of dispersion

A dispersive microstrip structure with width w=0.2mm and height h=0.2mm on a linear and nonlinear substrate were simulated. The non-linearity of the substrate was used to compensate for the dispersion of the structure. In practice the non-linearities can be achieved by depositing the metallic pattern on a semiconductor substrate and creating a Schottky barrier between the metal and the substrate. The capacitive non-linearity of the Schottky barrier is represented by an equivalent dielectric for the substrate. In order to match both the input and output impedances of the microstrip line, a TEM line consisting of two electric and two magnetic walls was used. It has been shown that the TEM line gives a very good match to the microstrip line. The input excitation plane was placed inside the TEM line. The structure simulated is shown in Fig 7 and 8 and was first simulated using a substrate with constant relative dielectric constant of 2.3. Fig.9 shows the output response for any impulse input. The effect of the dispersion is clearly seen in spreading of the response. In communication systems, in particular for high speed digital communications, this is a highly unsatisfactory response. Non-linearities are then added to the substrate representing a Schottky barrier between the metal and a semiconducting substrate as explained above. In this case the dielectric constant of the substrate is given by

$$\varepsilon_r(V_k) = 2.3 / (1 - V_k/\Phi_0)^{1/2} \qquad \text{for } V_k \le \Phi_0/2 \qquad (6)$$

$$\varepsilon_r(V_k) = 3.25\,(1 + V_k/\Phi_0) \qquad \text{for } V_k > \Phi_0/2 \qquad (7)$$

where Φ_0*is* the built in voltage and is equal to 0.7Volt. Fig. 10 shows the response of the non-linear structure and the compensating effect can be clearly seen. Fig. 11 and 12 shows a comparison between the frequency responses of the linear and non-linear structures. It can be clearly seen that the non-linear structure has a much improved high frequency response. This is to be expected since from the impulse response a greater high frequency output is to be expected

6. Conclusion

Conventional TLM (SCN) method for linear, non-dispersive media has been modified to simulate non-linear and dispersive materials. Non-linear and dispersive effects such as shock wave generation, pulse compression and expansion , and dispersion in ferrite are obtained from the modified simulation. The TLM results for ferrite tile agree with results from analytical method. Non-linear effect can also be used to compensate for the dispersion effect.

References

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[2] C.E. Tong and Y.Fujino,"An efficient algorithm for TLM analysis of electromagnetic problems using the symmetrical condensed node", pp. 1420-1424, IEEE Transaction MTT, Vol.39, August 1997

[3] J.F. Dawson, "Improved magnetic loss for TLM", pp467-468, Electronic Letters Vol.29. No.5 1999

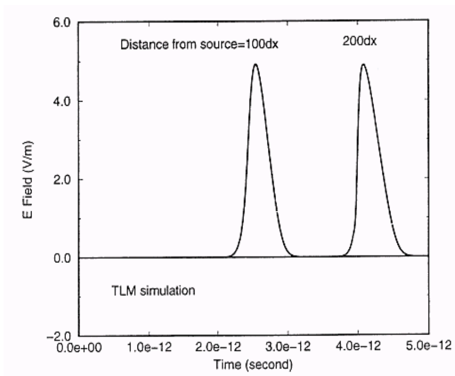

Figure 1 Pulse propagation in non-linear TEM line a= 0.01

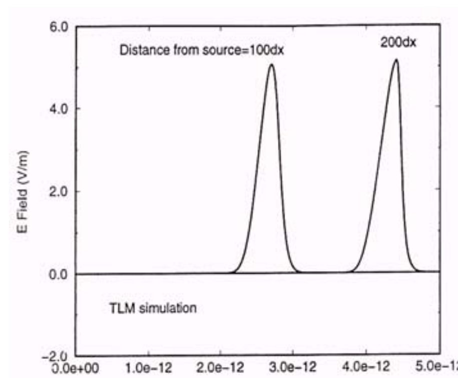

Figure 2 Pulse propagation in non-linear TEM line a= -0.01

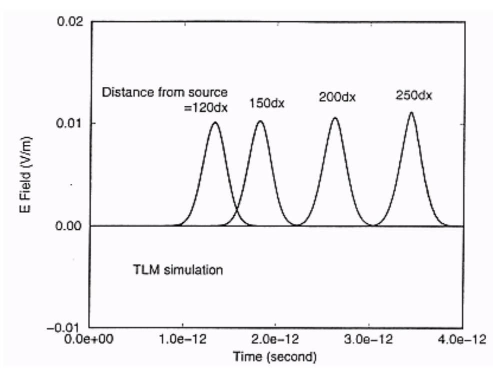

Figure 3 Pulse propagation in dispersive TEM line b= 1.0e-13

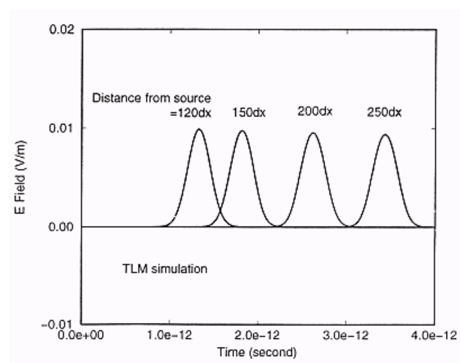

Figure 4 Pulse propagation in dispersive TEM line b= -1.0e-13

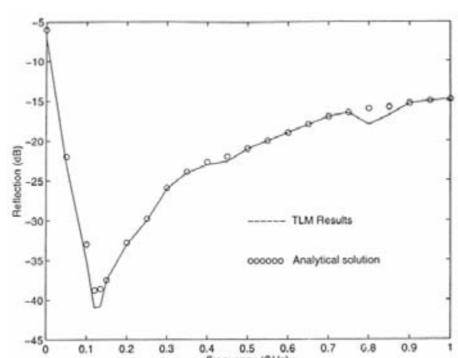

Figure 5 magnitude of the reflection coefficient of the ferrite tile.

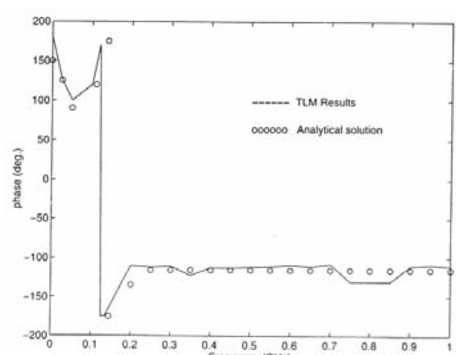

Figure 6 phase of the reflection coefficient of the ferrite tile.

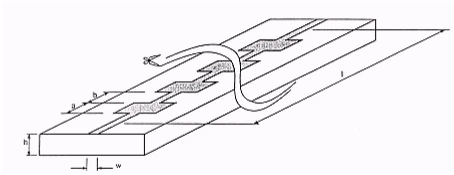

Figure 7 simulated microstrip structure, 20 sections

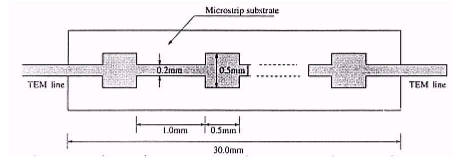

Figure 8 side view of the simulated microstrip structure

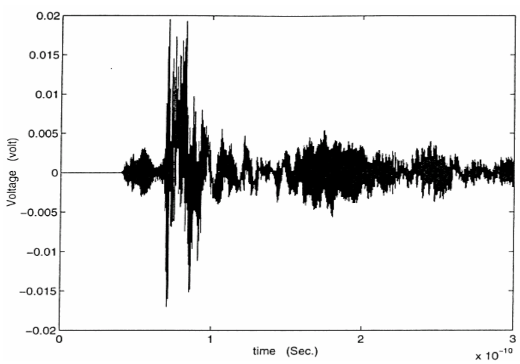

Figure 9 time domain response of the linear microstrip structure

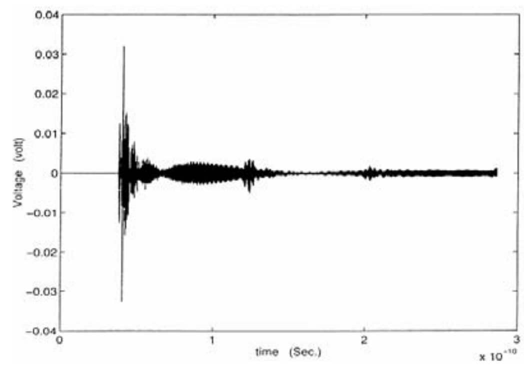

Figure 10 time domain response of the non-linear microstrip structure

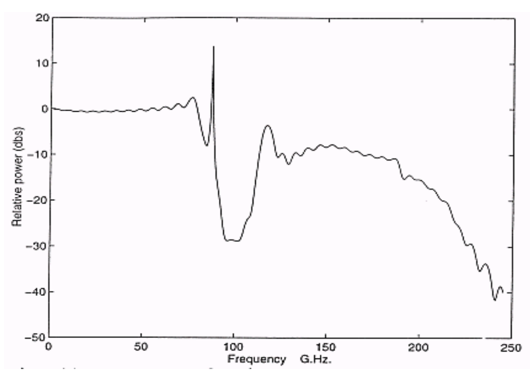

Figure 11 frequency domain response of the linear microstrip structure,

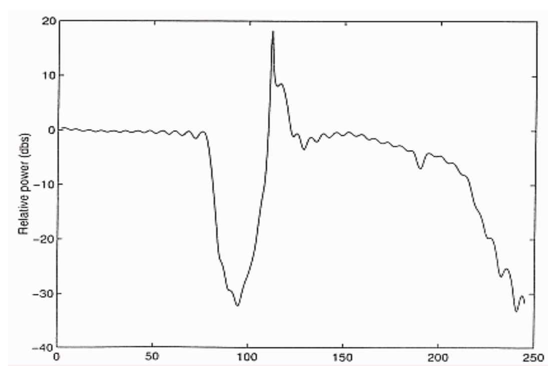

Figure 12 frequency domain response of the non-linear microstrip structure,