FDTD and SPICE Simulations for Lossy and Dispersive Nonlinear Transmission Lines Used for Pulse Compression : a Comparison

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Abstract **- For the first time, we demonstrate the simulation of lossy and dispersive non linear transmission lines (NLTLs) used for pulse compression, by two different time-domain approaches : SPICE and a full wave 3D FDTD. Results show a good agreement between the two approaches. Output pulse risetime is very affected by DC and skin-effect losses.**

I. INTRODUCTION

NLTLs have been investigated since more than thirty years by Landauer [1]. More recently, Jäger [2] and Rodwell [3] have demonstrated the ability of NLTLs to both generate shock waves with subpicosecond fall time and to propagate ultra fast solitons. In the field of microwaves, when dealing with frequencies between a few GHz and a few hundreds of GHz, a NLTL generally consists of Coplanar Wave Guide (CPW) transmission lines of characteristic impedance Z_l, periodically loaded by reverse-biased Schottky contacts, which serve as voltage-variable capacitors.

The behavior of NLTL for pulse compression or harmonic generation is now well understood, but the simulation of lossy and dispersive CPWs used for NLTLs is still a problem.

In [4], microstrip NLTLs used for harmonic generation (with a sinusoidal excitation) are simulated by harmonic balance. But harmonic balance is not adapted for pulse compression where the excitation is a step-like waveform.

In this paper, **we compare two very versatile time-domain approaches : SPICE and FDTD**. The SPICE approach is based on the method published by Alonso [5], and adapted in [6] for NLTLs.

The 3D simulation is based on the standard FDTD method [7] also including transmission line losses.

To our knowledge, **it is the first time that lossy and dispersive NLTLs are simulated with the FDTD by a full wave 3D approach**. In [8], the FDTD was applied to NLTL and results were compared to SPICE.

But a lossless CPW was used, and a lumped-element model was implemented for the CPW in SPICE. It is clear that a distributed model must be implemented in SPICE because a lumped-element model fails when the frequency of the signal propagating along the NLTL reaches the Bragg frequency [3, 9].

After a brief description of NLTL principles, we explain SPICE and FDTD approaches and we show the comparison of simulation results. A good agreement is obtained.

II. NLTL BASIC PRINCIPLES

The NLTLs we consider in this paper consist of CPW transmission lines of characteristic impedance Z_l and propagation constant $\gamma = \alpha + j\beta$, periodically loaded by reverse-biased Schottky contacts, which serve as voltage-variable capacitors (fig. 1).

The CPW is described by a distributed model as explained below (see fig. 2).

The diode is described by a series lumped-element model, the voltage-variable capacitance $C_d(V)$ and the series resistance R_d.

$C_d(V) = C_{j0} \cdot f(V)$ where C_{j0} is the zero-biased diode capacitance value and the expression of $f(V)$ depends on the doping profile of the diode. In our case, a uniform doping profile has been used, then : $C(V) = \dfrac{C_{j0}}{\sqrt{1+\dfrac{|V|}{\phi}}}$, where $\phi \approx 0.7V$.

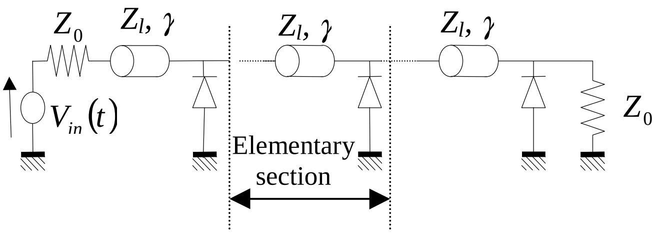


Figure 1. NLTL circuit diagram with input signal $V_{in}(t)$.

III. NLTL CONCEPTION

The NLTL has been realized on an AsGa substrate. The method used for its conception is described in [9,10].

It consists of a hundred elementary sections NLTL with CPW characteristic impedance Z_l equal to 70 Ω and a zero-biased diode capacitance C_{j0} equal to 26 fF. The large NLTL characteristic signal impedance is equal to 50 Ω. The Bragg frequency is about 250 GHz.

Table 1 gives the parameters value used for the CPW.

W_g (µm)	S (µm)	W (µm)	σ (S/m)	t (µm)	h (µm)	ε_r (AsGa)
60	10.5	4.6	37.10^6	0.5	200	13.1

Table 1. CPW characteristics.

IV. SIMULATION APPROACHES

A. FDTD

In the 1D approach the coplanar line is approximated by a parallel plate waveguide resulting in a constant characteristic impedance and phase velocity. With this approach, only DC-losses can be modeled.

For modeling the attenuation of a transmission line in the 3D FDTD, a wide band approximation of metallic losses using the surface impedance approach based on a two-port model for the surface is included. A plane conducting sheet is assumed where the electric and magnetic fields on the top and the bottom side are described by an impedance matrix [11] derived from a plane wave approach. This leads to a boundary condition for the magnetic field components surrounding the metal sheet.

In both cases the diodes are incorporated into the FDTD method as lumped elements described in [12].

B. SPICE

Each NLTL section is simulated by the T-block shown in figure 2.

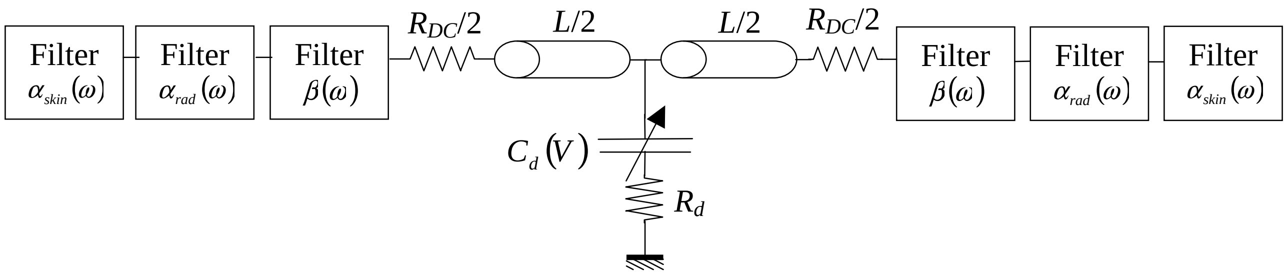


Figure 2. T-block for the simulation of each section of the NLTL in SPICE.

The CPW transmission line is simulated by using the ideal transmission line model implemented in SPICE ($L/2$), a series resistance simulating R_{DC} (DC losses) and filters used to simulate skin-effect losses ($\alpha_{skin}(\omega)$), radiative losses ($\alpha_{rad}(\omega)$) and dispersion ($\beta(\omega)$). These filters are calculated by using the method described by Alonso in [5]. For the calculus of $\alpha_{skin}(\omega)$, skin-effect losses formulas developed by Heinrich are used [13], for radiative losses and dispersion, we use Frankel's formulas [14].

V. SIMULATION RESULTS

The input pulse generator $V_{in}(t)$ is a step-like waveform with $V_h = 12V$, $V_l = 0V$ and a risetime of 20 ps.

A. CPW losses

Before comparing simulation results for NLTLs, we must verify that losses are correctly simulated by the two approaches, SPICE and FDTD. To achieve this, we have considered only CPW transmission lines without diodes and compared results obtained after simulation with Heinrich's formulas [13].

For low losses, we can consider that the CPW is matched to the generator and load impedance. Then the CPW $S_{21}(\omega)$ parameter, calculated from FDTD and SPICE simulations, is equal to $exp(-\alpha l)$. $S_{21}(\omega)$ is calculated as follows :

$$S_{21}(\omega) = \frac{FT[\text{Output signal}(t)]}{FT[\text{Input signal}(t)]}$$ where FT denotes Fourier Transform.

Results are shown in figure 3. FDTD attenuation is bigger to 50 GHz and smaller for higher frequencies. SPICE attenuation is lower than Heinrich's model above 20 GHz. This is due to problems encountered for the simulation of R_{DC}. The deviation between Heinrich's formulas and FDTD are mainly based on the coarse grid which is used for the cross section of the CPW.

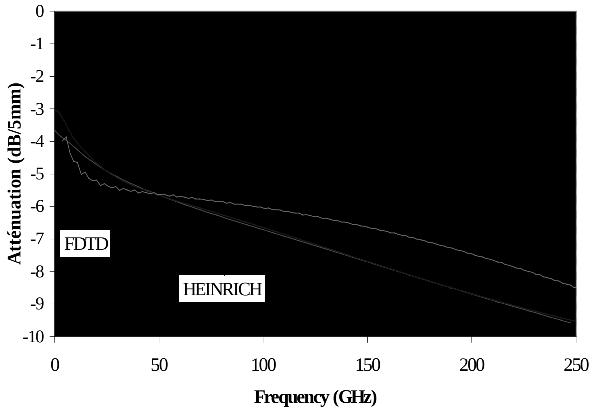
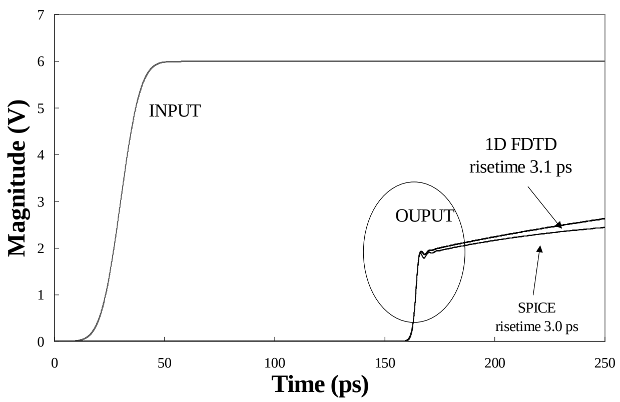


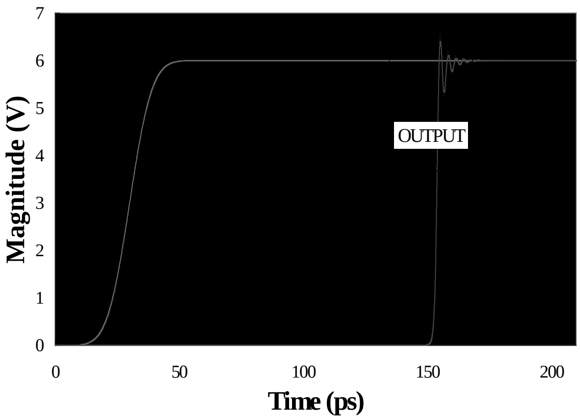
Figure 3. Attenuation obtained by FDTD and SPICE approaches for CPW (without diodes).

B. NLTL

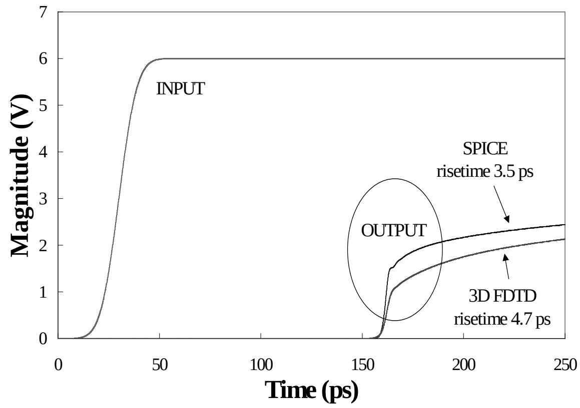
Comparison of SPICE and FDTD approaches is shown in figure 4.



(a)



(b)



(c)

Figure 4. (a) 1D FDTD and SPICE simulation results when only DC losses are considered.
(b) 3D FDTD and SPICE simulation results when lossless CPWs are considered.
(c) 3D FDTD and SPICE simulation results when all losses (DC, skin-effect and radiation) and dispersion are considered.

When only DC losses are considered, comparison between 1D FDTD and SPICE show a good agreement (fig. 4(a)).

For 3D FDTD compared with SPICE for lossless CPW, the agreement is very good (fig. 4(b)). This demonstrates the validity of distributed CPW SPICE approach.

When lossy CPWs are considered, we can see that the agreement is acceptable if we consider risetimes, but we can note some differences in the magnitudes of output pulses (fig. 4(c)). These differences are related to low frequencies. So we think that this is mainly due to the differences in the simulation of the attenuation due to DC and skin-effect losses shown in figure 3.

VI. CONCLUSION

We have demonstrated SPICE and full wave FDTD simulations of lossy and dispersive NLTLs. The agreement between the two approaches is very good when considering 1D FDTD with CPWs DC losses or 3D FDTD with lossless CPWs. When we consider real CPWs, including DC, skin-effect, radiation losses and dispersion, the comparison show a more severe attenuation for FDTD simulations. This difference seems to be related to differences in the attenuation obtained with the two approaches. Simulations also show the effect of CPW losses (mainly DC and skin-effect losses) on the output pulse risetimes (1.7 ps without losses and more than 3 ps with losses) and magnitude (6V to about 2V).

VII. REFERENCES

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