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DIFFUSION CAPACITANCE EFFECT ON THE RESPONSE OF MONOLITHIC NONLINEAR TRANSMISSION LINES

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***Abstract** : In this paper, the effect of the diffusion capacitance upon the electrical performances of the nonlinear transmission lines (NLTLs) is investigated. A comparison between the results obtained for the second harmonic generation by modeling the NLTL with and without the diffusion capacitance is presented. Numerical simulations, performed by means of the harmonic balance method implemented on the Hewlett Packard Microwave Design System Software Package, show significant differences when the diffusion capacitance is included in the NLTL model in comparison with the standard modeling of the NLTL by neglecting this capacitance.*

Introduction

Nonlinear transmission lines (NLTL) are currently studied for pulse steepening and compression, and for harmonic generation purposes [1,2,3]. A typical NLTL configuration is composed by coplanar waveguide (CPW) sections separated by shunt connected hyperabrupt Schottky diodes. The response of the diodes is usually accounted by voltage dependent depletion nonlinear capacitors. In this paper, it is presented a novel model for NLTLs, including the effect of the diffusion capacitance of the diodes. In particular, the aim of this work is to study the second harmonic generation response of the NLTL and the changes introduced in its performances owing to the diffusion effect. This contribution to the total capacitance is due to the recombination time delay of the minority carriers, and it has been recently considered to explain the onset of instabilities in an one diode doubler [4]. The diffusion capacitance can not be neglected as compared to the depletion capacitance when the diodes are driven into the forward conduction. Due to the nonlinear character of the NLTL, based on the capacitance nonlinearity under large signal condition, a large conversion efficiency of the second harmonic is obtained when the NLTL operates in the forward conduction of the Schottky diodes. Therefore, the effect of the diffusion capacitance has to be accounted for an accurate design of the NLTL.

Modeling and results

The equivalent circuit of a cell of the exploited NLTL is shown in Fig.1, while the diode model used for our simulations is shown in Fig. 2, where the diffusion capacitance C_d and parasitic effects of the diode have been included, further to the usual voltage dependent nonlinear capacitance C_b. The equations for the diode model are written as follows:

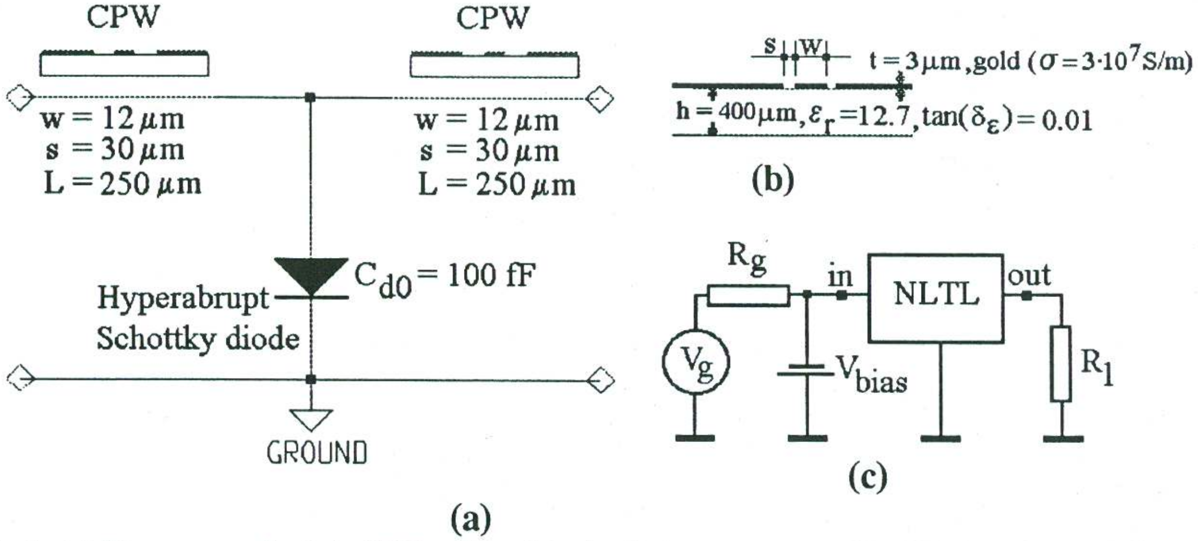

Fig. 1. *(a) Elementary cell of the NLTL, where (b) the diodes are separated by high impedance (75Ω ca.) CPW sections to obtain (c) a NLTL composed by 14 elementary cells. This structure has been used for the following simulations, and it is connected to the generatorV_g and to the load R_l.*

$$
\begin{aligned}
C_b &= \frac{C_{d0}}{\left(1-\frac{V}{V_0}\right)^p} \\
I_d &= I_0 \times \left\{ \exp\left(\frac{qV}{kT}\right) - 1 \right\} \qquad (1) \\
C_d &= \tau \frac{dI}{dV} = \tau I_0 \times \frac{q}{kT} \times \exp\left(\frac{qV}{kT}\right)
\end{aligned}
$$

where C_b is the barrier nonlinear capacitance and V is the voltage across the diode (see Fig.2), while $V_0=0.8$ V and $p=0.8$. I_d is the diode current and $I_0=1$ nA. C_d is the diffusion capacitance and τ is the recombination delay of the minority carriers.

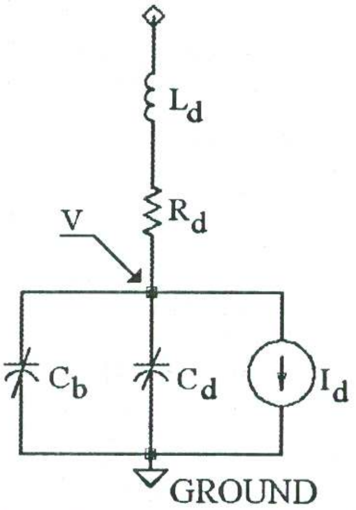

Fig. 2. *Equivalent circuit of the diode. L_d and R_d are the parasitic inductance and resistance, respectively. C_b is the nonlinear, voltage dependent capacitance usually included to account for the diode nonlinear response, while C_d is the diffusion capacitance included in the present study. I_d is the diode current.*

The losses contribution of the diodes has been accounted by introducing the parasitic diode resistance, R_d , while the parasitic inductance, L_d , is introduced in order to take into account the electrical behaviour of the metallic strips connecting the diode to the CPW ground planes. In the present case, they were $R_d = 3\ \Omega$ and $L_d = 5$ pH.

The simulations have been performed by means of the Harmonic Balance method implemented on the Hewlett Packard Microwave Design System software package.

The structure is composed by 14 diodes separated by CPW sections. The geometrical parameters of the CPWs are those shown in Fig. 1. The τ value has been set to $\tau=0$ and $\tau=0.1$ ns. The bias voltage V_{bias} and the RF voltage V_{ac} have been both sweeped to evaluate the difference in the NLTL performances introduced by the diffusion effect. In particular, two plots have been produced by changing: (i) V_{dc} between -3 volt and -0.5 volt with V_{ac}=4 volt, and (ii) V_{ac} between 4 volt and 7 volt with V_{bias}=-2 volt.

An input microwave signal of the form $V_g=V_{ac} \sin(2\pi ft)$ has been assumed, where f=20 GHz.

The simulation results are shown in Figs. 3-5.

A significative change of the second harmonic amplitude has been obtained passing from a vanishing value of τ to a non-zero value, especially when the bias value is close to the maximum of the curves (Figs.3,4).

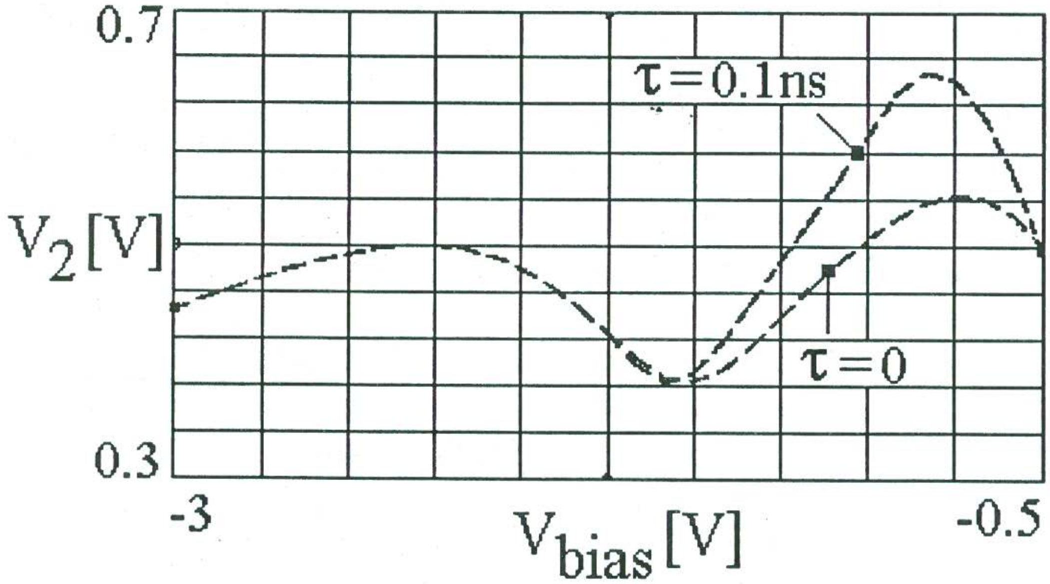

Fig. 3. *Second harmonic voltage at the output of the NLTL by sweeping the bias voltage V_{bias}. The values for τ (as shown in the plot) are 0 and 0.1 nsec. V_{ac}=4 volt.*

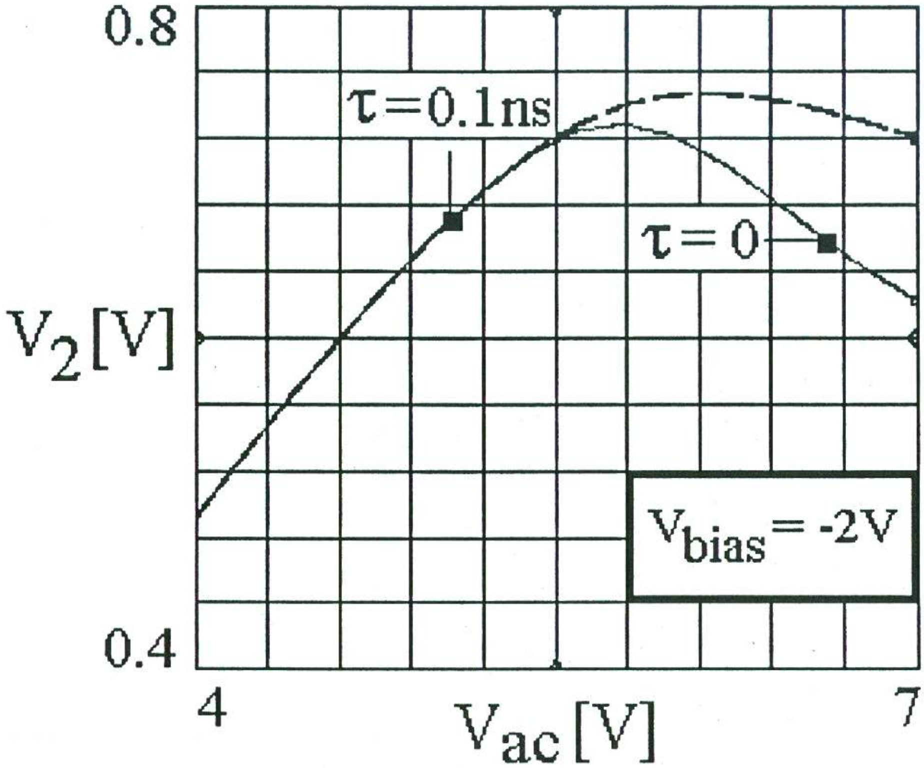

Fig. 4. *Second harmonic voltage at the output of the NLTL by sweeping the voltage amplitude of the microwave source, V_{ac}. The same τ values as in Fig. 3 have been imposed, and V_{bias}=-2 volt.*

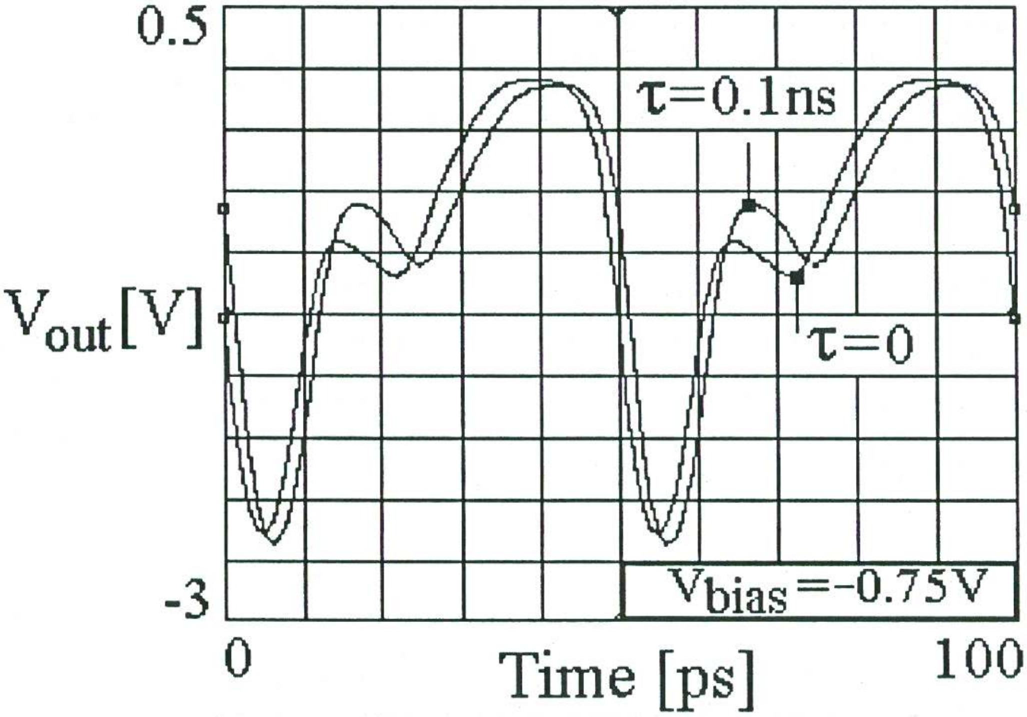

Fig. 5. *Output waveforms of the NLTL, for the same τ values as in Fig.3. V_{bias} =-0.75V and V_{ac} =4V.*

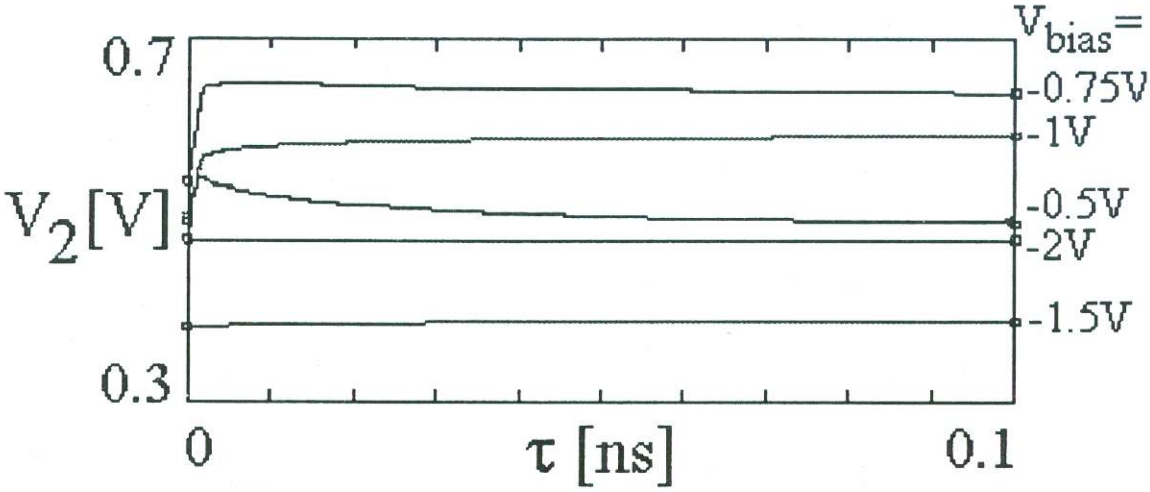

Fig. 6. *Second harmonic voltage at the output of the NLTL by sweeping the τ values between 0 and 0.1 nsec, for different values of V_{bias}..*

In these regions, due to the values of the V_{bias} and V_{ac}, the Schottky diodes operate also into the forward conduction, where the diffusion capacitance has a large value as compared to the depletion capacitance. Therefore, the nonlinearity of the circuit introduced by both the voltage dependent capacitances increases, and the voltage amplitude of the second harmonic at the output of the NLTL increases, too. The difference between the curves obtained in Figs.3,4 for τ = 0 and τ = 0.1 ns is a demonstration that the effect of the diffusion capacitance on the NLTL response should be taken into consideration during the design procedure. Moreover, the operating regime of the diodes into the forward conduction is recommended for a high conversion efficiency (if the NLTL is designed as a frequency multiplier) or for very short step function generation (based on shockwave propagation on a less dispersive NLTL). From Figs.3,4 it is observed that there is an optimum V_{bias} and an optimum V_{ac} in order to obtain a maximum value for the output voltage amplitude on the second harmonic, V_2 . If V_{bias} or V_{ac} are increased over these optimum values, then V_2 decreases because of the drastic increase of I_d (see Fig.2 and Eq.(1)) above ~0.4 V, and the signal (including its second harmonic) is shunted to the CPW grounds.

In Fig.6 the variation of the voltage amplitude of the second harmonic versus the τ, for different values of the V_{bias} is shown. It is observed a large difference for V_2 when τ = 0.1 ns as compared to the corresponding value at τ = 0, but for τ greater than ~100 ps, V_2 is practically independent of τ. Therefore, the simulation results obtained by introducing the diffusion capacitance into the equivalent circuit of the Schottky diodes fit well the practical situations without knowing exactly the τ value (τ depends on the technological processes, being difficult to predict its value very accurately).

Conclusions

The effects of the diffusion capacitance upon the output voltage of the second harmonic generation has been investigated by computer simulation, sweeping both, the bias voltage and the input voltage amplitude of the microwave signal. The new model for the Schottky diodes, including the diffusion capacitance, is proposed for an accurate design of the NLTL, when the diodes operate into the forward conduction, this operating region being the best choice for an high conversion efficiency of the NLTL used as a frequency multiplier. The simulation results show a good stability to a large range of the recombination delay of the minority carriers, parameter which depends strongly on the technological processes.

References

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