Second harmonic generation by means of double tapered non-linear transmission line

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Abstract

The second harmonic generation efficiency of a non-uniform non-linear transmission line (NLTL) has been theoretically investigated by using a single tapered NLTL and two tapered NLTLs in a cascade configuration. The optimization of the efficiency for frequency doubling purposes by using an input frequency f=40 GHz will be discussed.

Introduction

Non-linear transmission lines (NLTLs) are currently studied for pulse compression via the excitation of shock waves and solitons, and for harmonic generation purposes [1]. A typical NLTL is composed of series inductors separated by shunt-connected non-linear capacitors. Usually, the first ones are realized by means of coplanar wave (CPW) sections, and the second ones by means of Schottky diodes. Recently, non-uniform NLTLs have been proposed for high pulse compression ratios [2-4].
The elementary cell of the structure is depicted in Fig.1.

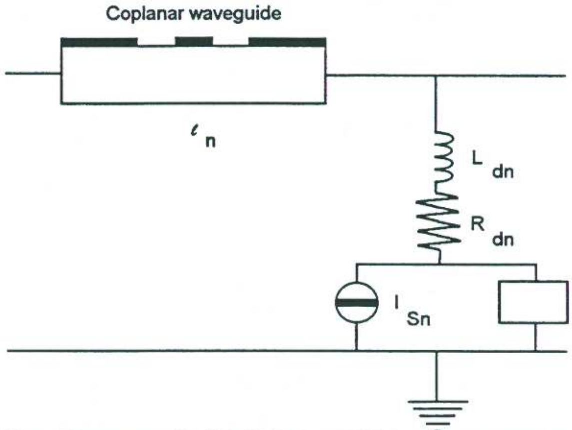

Fig.1. Elementary cell of the NLTL. A CPW is series connected to the diode, in which the equivalent circuit is composed of a current generator I_{Sn}, a non-linear capacitor C_n, parasitic inductance L_d and parasitic resistence R_d. In a tapered line, all the quantities depend on their n-th position along the NLTL.

Above result has been obtained by realizing a structure in which the diode capacitances C_n and the diode spacings ℓ_n have been tapered following an exponential trend.
C_n and ℓ_n depend on the tapering parameter pa as:

$$C_n = C_{0n} / (1 - V_n / V_0)^p; \qquad C_{0n} = C_{01} \cdot pa^{n-1}; \quad \ell_n = \ell_1 \cdot pa^{n-1}; \quad n = 1,N \tag{1}$$

where n is the current index and N is its maximum value, while C_{01}=300 fF is the capacitance of the first diode, and and ℓ_1=500 μm. The CPW characteristic impedance is Z=75 Ω. The pa-parameter accounts for the non-linear response of the components as a function of the voltage V_n, V_0=0.8 volt has been assumed, and $0 < pa \leq 1$ is the tapering parameter. In this case, p=0.87 has been imposed for the non-linear response of C_n.
The diode model used for the simulations has been improved with respect to that proposed in [3-4] by introducing a current source I_{Sn}, and a parasitic resistance R_{dn} and inductor L_{dn}. The diode current generator and the parasitic components are defined by:

$$I_{S_n} = I_{0n} \times \left\{ \exp\left(\frac{qV_n}{kT}\right) - 1 \right\}; \quad I_{0n} = I_{01} \times pa^{n-1}$$
$$R_{dn} = \frac{R_{d1}}{pa^{n-1}}; \quad L_{dn} = L_{d1} \tag{2}$$

where: I_{01}=1 nA is the current source, R_{d1}=3 Ω is the parasitic resistence, and L_{d1}=20 pH is the parasitic inductance for the first diode.
A tapered NLTL looks like that shown in Fig.2.

In this paper, the second harmonic generation efficiency of a non-uniform NLTL structure has been theoretically investigated for harmonic generation by using a single tapered NLTL and two tapered NLTLs in a cascade configuration. The optimization of the efficiency for frequency doubling purposes will be discussed.

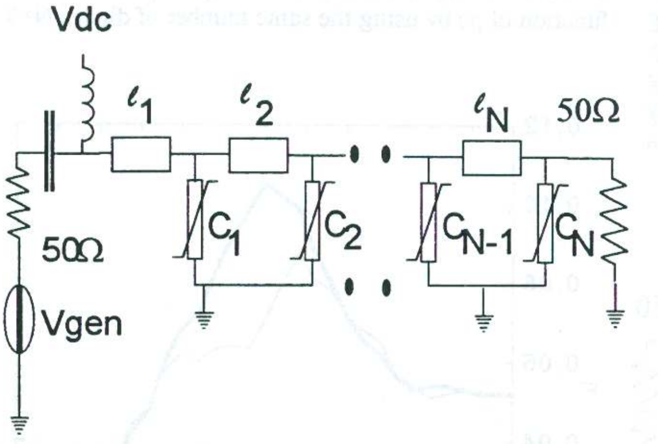

Fig. 2. Configuration of a tapered single NLTL. The tapering is provided by the tapering parameter pa.

Single tapered NLTL

The frequency multiplication of a single tapered NLTL has been studied by changing the number of diodes N and the tapering parameter pa, in order to optimize the efficiency of the device as a doubler. A *cw* signal having an input frequency f=40 GHz and an amplitude V_{gen}=7 volt has been imposed. The diodes have been biased by means of a voltage V_{bias}=-4 volt. As a first, the behavior of the maximum of the doubling efficiency η_{max} vs N and vs the pa-value correspondent to η_{max} (pa_{max}) has been inferred. The efficiency has been defined as:

$$\eta = \frac{P_2}{P_{in}} \tag{3}$$

where P_2 is the power released to the second harmonic and P_{in} is the input power of the NLTL.

As deduced from Fig. 3, the maximum for the efficiency can be achieved for N close to 10 and pa close to 0.8.

A further simulation has been performed to get the exact values of N and pa corresponding to the maximum η-value. The results are shown in Fig. 4 for three different values of the number of diodes N. The optimum value for the doubling efficiency for the single stage NLTL is η=8.7 %, inferred for N=9 and pa=0.83. The maximum for η corresponds to an input impedance Z=42.3+j32.2, but the NLTL is almost electrically matched for the entire range used for the simulations vs pa, changing from Z_1=39.4+j35.6 to Z_2=56.9+j32.9. By increasing the number of diodes, the efficiency decreases because of the diodes intrinsic losses. On the other hand, a low N value is not sufficient to activate the non-linear mechanism.

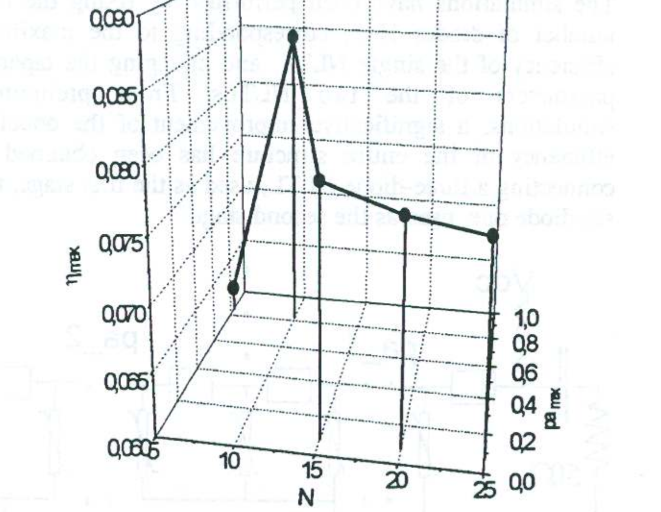

Fig. 3. Maximum of the doubling efficiency η_{max} vs the number of diodes N and vs pa_{max}, i.e. the pa-value correspondent to η_{max}.

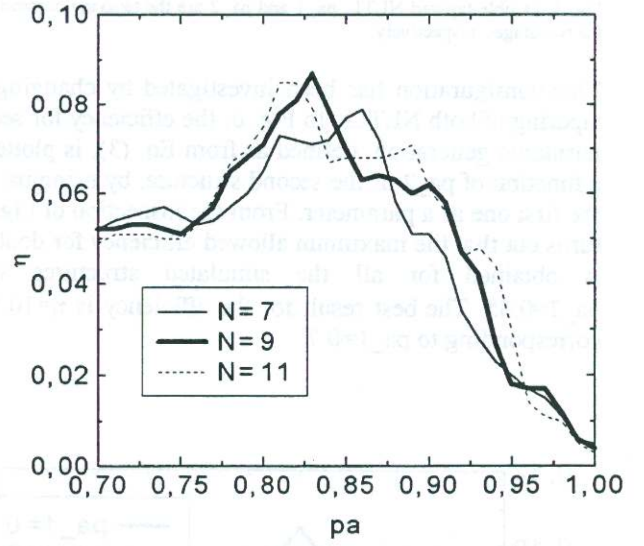

Fig. 4. Second harmonic generation efficiency η of a single tapered NLTL vs the tapering parameter pa for a different number of diodes N.

Double tapered NLTL

To investigate possible improvements of the efficiency in doubling the 40 GHz input frequency by using tapered NLTL structures, it has been simulated the behavior of two tapered NLTLs connected in cascade.

The exploited structure is shown in Fig. 5, where pa_1 and pa_2 are the tapering parameters of the two stages. The coonection law between the two NLTLs is given by:

$$C_{01} \times pa\_1^{N_1 - 1} = C_{02} \tag{4}$$

where N_1 is the number of diodes of the first NLTL, and C_{02} is the first capacitance of the second NLTL.
The simulations have been performed by fixing the total number of diodes N=9, corresponding to the maximum efficiency of the single NLTL, and changing the tapering parameters of the two NLTLs. From preliminary simulations, a significative improvement of the doubling efficiency of the entire structure has been obtained by connecting a three-diode NLTL, used as the first stage, to a six-diode one, used as the second stage.

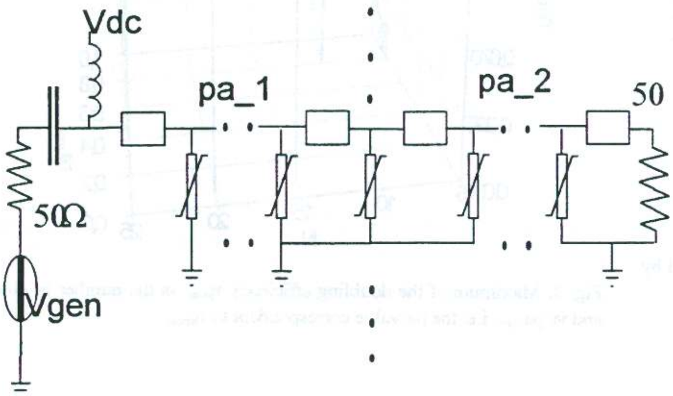

Fig. 5. Double tapered NLTL. pa_1 and pa_2 are the tapering parameters of the two stages, respectively.

This configuration has been investigated by changing the tapering of both NLTLs. In Fig. 6, the efficiency for second harmonic generation, defined as from Eq. (3), is plotted as a function of pa_2 of the second structure, by using pa_1 of the first one as a parameter. From the inspection of Fig.6, it turns out that the maximum allowed efficiency for doubling is obtained for all the simulated structures when pa_2=0.85. The best result for the efficiency is η=10.5 %, corresponding to pa_1=0.7.

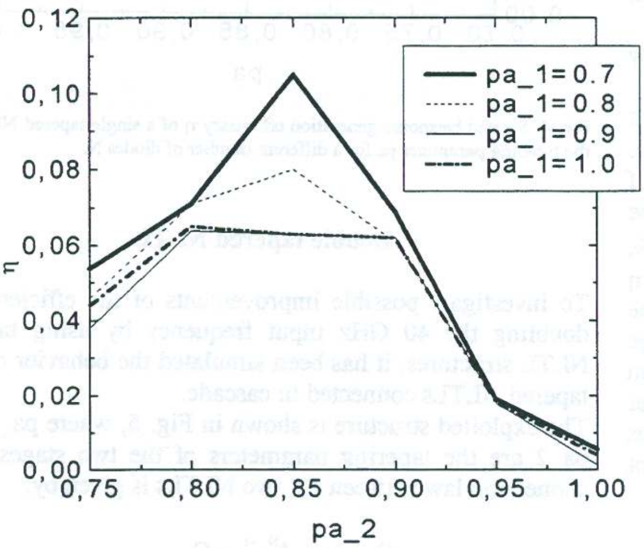

Fig. 6. Second harmonic generation efficiency of the double tapered NLTL vs pa_2 by imposing different pa_1 values.

In Fig. 7 η vs the tapering parameter pa_2 for the best curve of Fig. 6 is shown, as compared to the best result obtained for the efficiency of a single tapered NLTL as a function of pa by using the same number of diodes N=9.

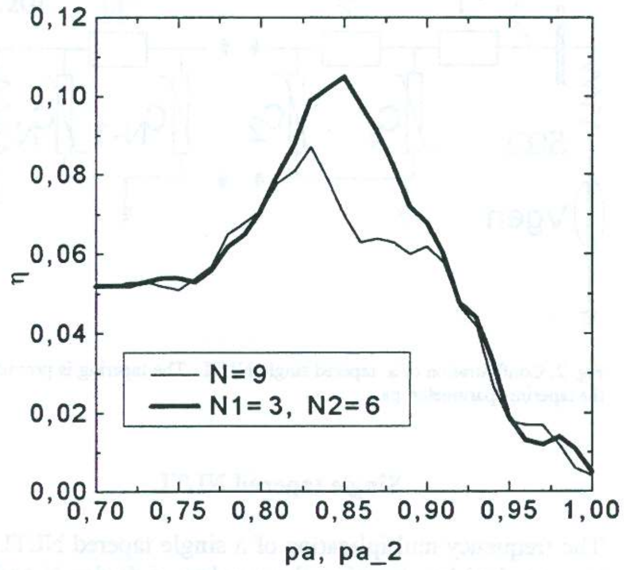

Fig. 7. Comparison between the doubling efficiencies of the single and of the double tapered NLTL. A 9-diode single tapered and a NLTL composed by N1=3 and N2=6 diodes have been used. An improvement of about 2 % is obtained by using the double tapered NLTL.

As it was in the case of the single stage NLTL, it is worthnoting that the deduced tapering parameter values, used for harmonic generation purposes, are lower than those proposed in [3,4], where pa≈0.95 is used for soliton excitation (pulse compression).
A low number of diodes (N=9) can be used in the double tapered two-stage NLTL to get a reasonable value of the doubler conversion efficiency and a clear improvement with respect to the single one.

Conclusions

Single and double tapered non-linear transmission lines (NLTL) have been simulated to evaluate their performances for second harmonic generation applications by using an input frequency f=40 GHz.
The doubling efficiency of a single tapered NLTL has been optimized as a function of the number of diodes N and of the tapering parameter pa, thus obtaining an efficiency η=8.7 % for N=9 and pa=0.83.
The double tapered NLTL has been investigated by assuming a total number of diodes N=N1+N2=9, i.e. two stages with different tapering parameters, pa_1 and pa_2 respectively, connected in cascade. The value N=9 has been chosen because it corresponds to the best result obtained for the single tapered NLTL.
From preliminary simulations, it turns out that a significative improvemnt is obtained for N1=3 and N2=6,

corresponding to pa_1=0.7 and pa_2=0.85, with an efficiency η=10.5 %
It is worthnoting that tapering parameters sensitively less than those used for pulse compression by means of a uniform NLTL can be used.

References

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