Design Optimization of Meta-Material Transmission Lines for Linear and Non-Linear Microwave Signal Processing

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***Abstract*— The possibility to use CRLH (Composite Right-/Left-Handed) cells to realize both distributed wide-band filters for linear signal processing and non-linear devices like frequency doublers is investigated analytically and numerically. Full-wave electromagnetic simulations are performed for the filtering structure by means of a commercial software package and confirm the validity of the analytic results. Numerical results for CRLH NLTL (Non-Linear Transmission Line) obtained by using the Microwave Office are discussed, providing design considerations about the synthesis of such a component.**

I. Introduction And Background

COMPOSITE Right-/Left-Handed (CRLH) transmission lines are the key elements for a new class of small-size microwave devices such as couplers, antennas, power dividers and filters, which may be fabricated in hybrid or monolithic technology [1]-[4]. Usually, the CRLH consists of series connected capacitors (having an equivalent series inductance) working as series resonators, and parallel connected transmission lines working as parallel resonators. For the CRLH structures there are two frequencies of resonance (for the capacitors and for the transmission lines) and also two cut-off frequencies (corresponding to Left-Hand and Right-Hand behavior), which strongly affect their behavior for a particular application. The four frequencies must be well controlled during the design procedure, because they should be equal between them in order to have a balanced structure [1]. In this way a pass-band filter behavior is obtained. The condition to have the same frequency of resonance is not a simple task, because the inductance of the series capacitor which fixes the frequency of resonance depends on the capacitance, so it is not a free parameter in the design. Moreover, the values for the all components of the CRLH structures are also important when the cut-off frequencies are imposed. When non-linear components are involved, such a balance has to be guaranteed in spite of the signal dependent values for the equivalent lumped components. In this paper, two structures will be presented, to be used as a filter and as a frequency doubler respectively, and they have been optimized in terms of the number of cells and of their electrical matching performances.

II. RESULTS

A new structure of CRLH for linear signal processing, where the inductance series connected to the capacitor is replaced by a transmission line, is proposed (Fig. 1a). In this way, during the CRLH design, the value of the inductance is practically decoupled with respect to the value of the capacitance. With this method, a linear meta-material CRLH band-pass filter is designed by using an analytical technique confirmed by full-wave electromagnetic simulations. More in detail, the image parameter approach previously used for distributed coupled-lines band-pass filters [5] has been here applied for the synthesis of wide band meta-material filters. The image impedance of the whole structure, composed by several series connected basic cells shown in fig. 1a, can be easily obtained. Staring from this analytic result the cut-off frequencies of the component are computed. Another equation is provided by imposing the matching condition at the central working frequency. The magnitudes of S_{11} and S_{21} for the filtering structure consisting of four cascaded cells, each one having the layout given in fig. 1a, are shown in fig. 2.

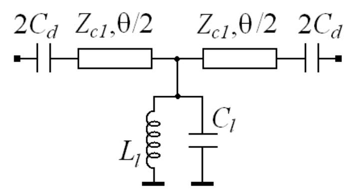

Fig. 1a. The basic cell adopted for the filter design.

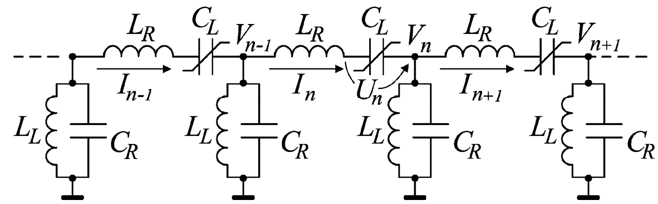

Fig. 1.b. Schematic representation of the cascaded CRLH structure used for the simulations. The capacitor C_L depends on the signal amplitude in non-linear regime only.

If the series linear capacitors of the balanced CRLH TL are replaced by non-linear capacitors a CRLH NLTL (Non-Linear Transmission Line) is obtained, consisting of cascaded non-linear CRLH (fig. 1b). Due to the nonlinearity introduced by the nonlinear capacitances, frequency harmonics are generated along the line. If these frequency harmonics are low enough comparing to the frequencies of resonance for the resonators computed in small-signal regime, the effects of the series inductances and parallel capacitances may be neglected and the behaviour of the structure is described by the NLS (Non-Linear Schrödinger) equation [6].

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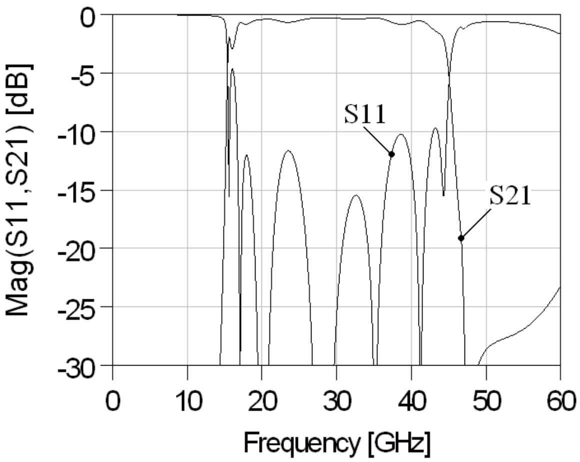

Fig. 2. The magnitudes of S_{11} and S_{21} for a filter consisting of four cascaded structures.

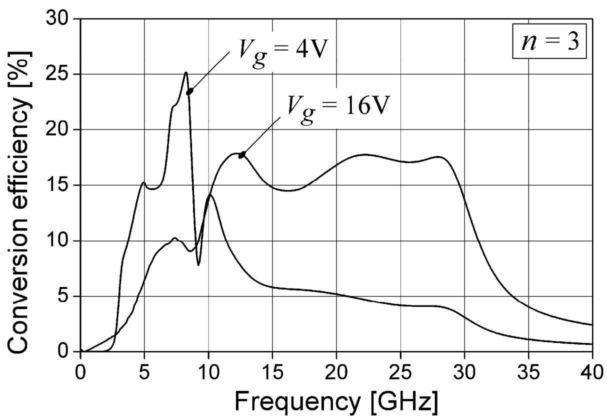

Fig. 3. Conversion efficiency versus input frequency for the CRLH NLTL. Vg is the bias for the non-linear capacitor.

Numerical results are presented in fig. 3 and were obtained by means of the Microwave Office software [7] which used the harmonic balance method to analyse the non-linear circuits. The conversion efficiency has been computed as the ratio between the output voltage on the second harmonic and the input voltage on the fundamental frequency. It is assumed that the nonlinearity is introduced by nonlinear capacitances modelled by hyper-abrupt junction varactor diodes. In fig. 3 it is also observed the influence of the amplitude of the input voltage source V_g on the conversion efficiency. As it was expected, increasing V_g the conversion efficiency increases as the nonlinearity of the diode capacitance increases. Moreover, it is worth noting that the frequency doubler based on non-linear CRLH cells needs low number of cells comparing to the classical distributed frequency doubler consisting of series inductances and parallel capacitances [8].

III. CONCLUSION

In this paper, both a balanced CRLH filter and a CRLH NLTL are analysed analytically and numerically, in order to evaluate the possibility to use them for linear and non-linear signal processing at millimetre wave frequencies. In the NLTL the condition to maximize the conversion efficiency of this type of frequency doubler is developed and analysed. High values for the conversion efficiency are obtained with a device composed by only three cascaded cells.

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