SYNTHESIS OF IMPEDANCE MATCHING CIRCUITS USING ARBITRARY NONUNIFORM TRANSMISSION LINES

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Abstract: An efficient approach for the synthesis of impedance matching circuits using arbitrary nonuniform transmission lines is proposed. The proposed technique is first summarized and its merits are discussed. Several practical examples are then considered and different matching circuits are synthesized covering wide impedance and frequency ranges. The results obtained by the proposed approach are compared to measured data as well as to those obtained by a commercial simulator using a full wave analysis.

INTRODUCTION

Impedance matching circuits are key components of microwave circuits and subsytems. Their design or, preferably, synthesis can represent chanllenges of varying degrees of difficulty and complexity. Still, the most common approaches for impedance matching are based on classical techniques using lumped or mixed lumped/distributed elements, eg. [1]. However, at higher frequencies, these techniques have limitations due to the difficulties in realizing lumped elements and to the effects of the discontinuities [2]. One possible way to overcome these problems is to use distributed nonuniform transmission line sections. Despite the advantages that nonuniform transmission lines can offer, their use in the design of matching circuits is still limited and the nonuniform transitions used to date can only match two real impedances [3-4] or be used as impedance transformers for specified complex load impedances [5]. This is due in major part to the difficulties associated with direct synthesis of matching circuits based on nonuniform transmission lines. In particular, the alternative line shapes that can be considered are limited to a few, relatively well known, profiles which in turn leads to limitations on the kind of matching circuit application.

In this paper, a fast impedance matching synthesis approach based on an optimization technique coupled with a fast numerical method for nonuniform transmission line simulation is proposed. Results of this approach for several impedance matching cases are given with comparison to measurement and a commercial full wave field solver.

APPROACH

An efficient and fast numerical method was developed to simulate arbitrary nonuniform lines. This method, which uses a method of moments approach to solve the Telegrapher's equations, has been implemented and tested on a wide number of microstrip and coplanar arbitray shaped transitions with excellent accuracy [6]-[7]. Given the efficiency of this simulation method, a synthesis procedure for impedance matching circuits using nonuniform transmission lines can now be realistically considered. In this procedure, we characterize the saught impedance matching circuit, i.e., the one which will yield the specified matching, by its desired S-parameters (S_d) or, equivalently, its desired $VSWR_d$. Then, for the nonuniform transmission line we compute $VSWR_c$. An error term between the desired and computed VSWR is then defines as:

$$Err = \sum_{i=1}^{N} \left[VSWR_d\left(f_i, \vec{x}\right) - VSWR_c\left(f_i, \vec{x}\right) \right]^2 \quad (1)$$

where N is the number of frequency points and $\vec{x}$ is a vector of the parameters defining the geometry of the nonuniform line. The

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synthesis problem consists then of mininizing the error term *Err* subject to the applicable constraints on the vector $\dot{x}$ (these constraints depend among other things on the type of transmission line used). This accomplished via an optimization algorithm based on the conjugate gradient method.

APPLICATIONS

One of the advantages of the above approach is that, by proper choice of the nonuniform line shape, we can match any point within the 1+jX circle in the impedance or the admittance charts to 50 Ω with only one section of nonuniform line. The cosine modulated line, $w(z) = w_o\left(1 \mp m\cos\left(\frac{\pi z}{L}\right)\right)^2$, has been found to give such performance as illustrated by Figures 1 through 6. It should be noted that this performance cannot be achieved with other nonuniform transistions such as those with linear or quadtratic profiles [5]. Table I shows the different loads to be matched to 50 Ω over the range 3-5 GHz and gives the corresponding parameters of the cosine modulated line synthesized with the proposed approach. Figures 1 to 6 show the measured and synthesized input impedances of the designed nonuniform lines, and their profiles, terminated with the specified load, for a microstrip substrate with ε_r=2.33 and h=20mil. A good agreement is seen in all cases. As an aditional validation, Figure 1 and figure 2 also show the good agreement of our results with those obtained with HP'S MOMENTUM, which uses a rigourous integral equation based field solution. Similar agreement has been observed for all other cases. Also, it should be noted that despite the wide range of load impedance values considered, the length of the synthesized line remained quasi constant which is important for keeping circuit sizes to a minimum. This behavior cannot be achieved with other techniques [5].

As another application, a matching circuit between two complex, frequency-varying impedances is considered. Table II gives the values of the two impedances as a function of frequency. Figure 7 shows the profile of the synthesized nonuniform transition using continuous sections of the cosine modulated line and the resulting VSWR which remains less thatn 1.2 (S11 < -20dB) over the entire frequency band considered. Measurements of the synthesized line, realized on an alumina sbustrate ε_r=10 and h=10mil, relative to 50 Ω are shown in the inset of Figure 7 and are compared to those obatined by our simulation with very good agreement.

Finally, a study of the group delay properties of the synthesized matching circuits show that they have a more constant behvior over frequency compared to conventional matching circuit designs.

CONCLUSION

An efficient approach for the synthesis of impedance matching circuits using nonuniform lines has been presented. The accuracy of the proposed approach was proven by comparison to measured data. It was shown that a significant improvement in the matching bandwidth can be achieved with nonuniform lines. The developed approach is also being used to design a matching circuit with a quasi-constant group delay function shape for feedforward amplifier applications and also to design multiharmonic matching circuits suitable for power amplifiers operating in class F.

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Table I. The parameters of the cosine modulated lines synthesized to match different loads to 50 Ω

Zl	Freq= 4 GHz	W_o (cm)	m	L(cm)
Load A	Rl=90 Ω Cl=2 pF	0.08156	0.240493	0.806647
Load B	Rl=160 Ω Cl=1.5 pF	0.05089	0.24122	1.0473
Load C	Rl=200 Ω Cl=0.397 pF	0.028826	0.240644	1.012733
Load D	Rl= 200 Ω Ll= 3.97 nH	0.034352	0.24075	1.402088
Load E	Rl= 20 Ω Ll=0.397 nH	0.359198	0.24067	0.65289
Load F	Rl= 20 Ω Cl= 3.97 pF	0.270158	0.2407	1.18785

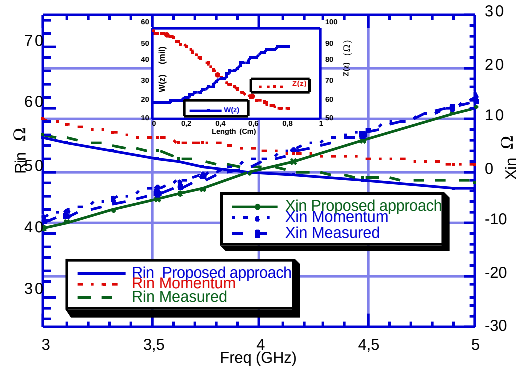

Figure 1. Computed and measured input impedance of the synthesized line for the load A. The line profile is shown in the inset.

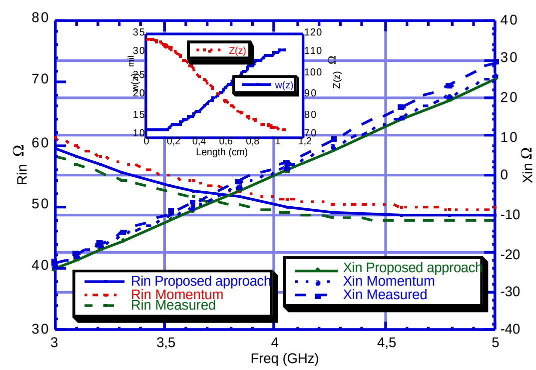

Figure 2: Computed and measured input impedance of the synthesized line for the load B. The line profile is shown in the inset.

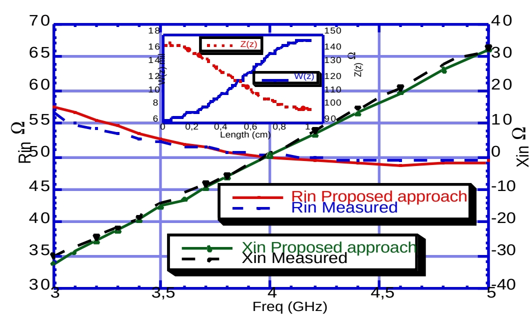

Figure 3. Computed and measured input impedance of the synthesized line for the load C. The line profile is shown in the inset.

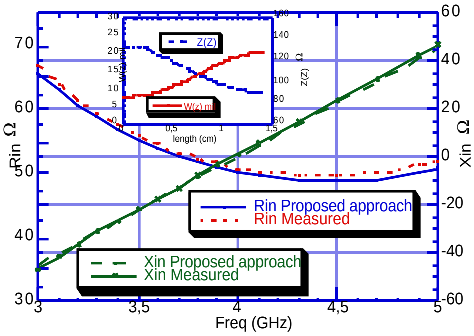

Figure 4. Computed and measured input impedance of the synthesized line for the load D. The line profile is shown in the inset.

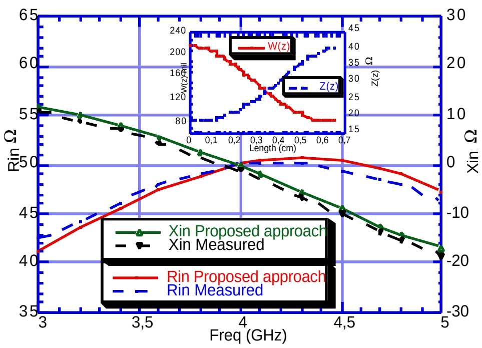

Figure 5. Computed and measured input impedance of the synthesized line for load E. The line profile is shown in the inset.

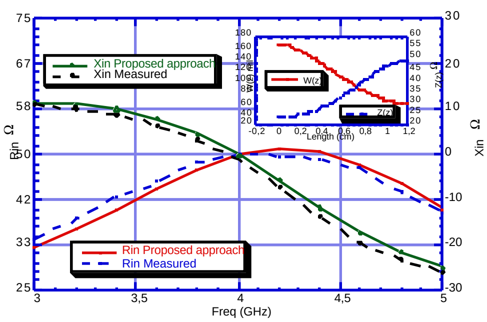

Figure 6. Computed and measured input impedance of the synthesized line of the load F. The line profile is shown in the inset.

Table II. Discrete values of two complex impedances to be matched over frequency band (2-2.6) Ghz.

f (GHz)	Rs Ω	-Xs Ω	Rl Ω	+Xl Ω
2.0	30.0	10.5	71.5	23.0
2.1	28.0	12.0	73.0	24.6
2.2	26.5	13.2	75.0	25.3
2.3	25.0	14.3	76.5	26.8
2.4	23.5	15.4	77.0	28.4
2.5	22.7	16.0	80.0	30.0
2.6	20.7	17.4	81.5	31.2

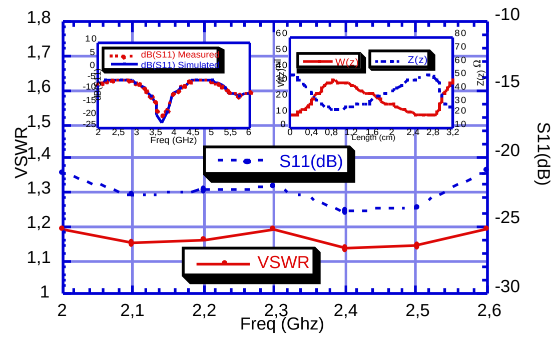

Figure 7. VSWR of the synthesized line for the impedances of table II. The line profile, the computed and measured S11 with respect to 50 Ω reference impedances are shown in the inset