PLANAR TRANSMISSION LINE TRANSFORMER USING COUPLED MICROSTRIP LINES

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ABSTRACT

A novel and simple configuration of the planar transmission line transformer using coupled microstrip lines is proposed. Design methodology is also presented. The simulated and measured results demonstrate broadband impedance transformation with good efficiency for RF and microwave circuit design. The effects of the deviation from the optimal characteristic impedance and transformation ratio are investigated as well.

INTRODUCTION

Transformers are important elements in RF and microwave integrated circuits. Normally, they are used in impedance matching networks, power splitters/combiners, and baluns. Conventional planar type transformers encompass quarter-wavelength, tapered line, spiral transformers, etc. The quarter-wavelength transformer has narrow band transformation and needs to have a quarter-wavelength transmission line, while the tapered line transformer can obtain broader bandwidth at the expense of a larger size. The planar spiral transformer not only exhibits an inefficiency in power transfer under magnetic coupling mechanism, but also limits its own useful bandwidth due to parasitic capacitance [1, 2].

The transmission line transformer (TLT) is designed by elaborately interconnecting the transmission line segments to achieve the power transfer under impedance transformation [3-6]. It can have a wider bandwidth and better transfer efficiency without unduly increasing the size. A planar TLT using broadside coupled lines for MMIC application has been proposed in [7]. Such a TLT in a multilayered structure demonstrated good electrical performance with wide bandwidth and compact size. This paper proposes a novel, yet simple TLT in a planar structure using coupled microstrip lines printed on a single substrate. This TLT can be applied to hybrid and monolithic microwave integrated circuits, and also to multilayered structures under certain modification. Simple and reliable methodology for designing the coupled microstrips is also presented.

CIRCUIT DESIGN

To demonstrate the TLT design of coupled microstrips, a typical 1:2 (voltage ratio) TLT for a design example is shown in Fig. 1(a). Note that the output port of conductor 2 is connected to the input port of conductor 1 with no phase delay. There are three steps in the design of the TLT.

1. Determine the optimal characteristic impedance of the transmission line associated with the port impedance. This also determines the dimensions of the transmission line.
2. Determine the length of the transmission line for the operating bandwidth.
3. Consider a layout to realize the configuration of Fig. 1(a).

The optimal characteristic impedance of the transmission line is chosen as R_L/n for a 1:n transformer with a load impedance R_L [5], i.e., the geometric mean value of the port impedances. Choosing the optimal characteristic impedance Zop can minimize the return loss of the transformer within the bandwidth. In this work, we are using symmetrical coupled microstrip lines to realize the transmission line in a TLT. Simultaneously, both even (unbalanced) and odd (balanced) modes can propagate on the coupled lines. It was found that the unbalanced current is suppressed on most of the TLTs, particularly at high frequencies [4, 7]. This phenomenon was also evidenced by observing the simulated current on the proposed

TLT. However, it is still difficult to obtain the characteristic impedance of the transmission line in the present TLT because the unbalanced (even) mode is not entirely suppressed. Therefore, we use a 3-port model as shown in Fig. 1(b) to determine the characteristic impedance of the coupled microstrip lines. We simulated the coupled-lines model with a full-wave EM simulator to obtain 3-port network parameters while one end of the second line is short-circuited to the ground plane, and then we obtain the input impedance by grounding both ports 2 and 3. We can derive the characteristic impedance and the effective dielectric constant of the coupled lines of Fig. 1(b) from the simple formula, Zin =j Zo tanβl, of the input impedance looking into a short-circuited transmission line.

At the optimal characteristic impedance Zop, based on the formula in [Eq. (15), 5], the frequency dependent transformation ratio of the TLT can be modified as

$$n_l^2 = \frac{n^2 \sin\beta l - j2n(1+\cos\beta l)}{\sin\beta l - jn\cos\beta l} \quad (1)$$

The reflected power ratio associated with the 1:n TLT is given as

$$\left| \frac{n_l^2 - n^2}{n_l^2 + n^2} \right|^2 \quad (2)$$

Consequently, Eqs. (1) and (2) will determine the upper frequency limit.

At low frequencies, the TLT can be considered as a conventional transformer, i.e., an ideal 1:n transformer shunted with an inductor having an equivalent inductance that is associated with the transmission line at low frequencies. This equivalent inductance determines the lower frequency limit. On the one hand, the TLT with a shorter transmission line can operate at higher frequencies; on the other hand, a longer transmission line will have larger inductance, and thus result in better low frequency performance. As a result, the trade-off between the limits of the upper and lower frequencies will determine the length of the transmission line.

To realize the schematic of Fig. 1(a), the best way is to wind up the transmission lines. The layout of the coupled microstrips TLT is shown in Fig. 2. In addition, the winding of the TLT also results in a more compact size and if with multiple-turn arrangement yields more inductance. We develop two 1:2 coupled microstrips TLTs for different port impedances following the preliminary design procedure mentioned above. We use symmetrical coupled microstrip lines with strip width of 16/5 mil and strip spacing of 10/6 mil for the two TLTs. They are placed on a 15.7-mil substrate with εr=4.7 (FR4). Table I lists the predicted bandwidth at -10 dB reflection. In the low-frequency case, the lower frequency limit at the return loss of -10 dB is equal to 3 Zref1 / 4 π L_{11}.

The two coupled microstrips TLTs are also analyzed by a full-wave EM simulator. Figs. 3 and 4 illustrate these results when referenced to respective impedance prescribed at both port one and port two. The lower frequency limits for both TLTs agree excellently with the predicted values listed in Table I. However, the upper frequency limits are higher than the expected values. Using Eqs. (1) and (2) to predict the high frequency performance of the present TLTs seems to give less consistent results. Fig. 5 plots the measured results of the TLT which is simulated in Fig. 3. The dimensions of this TLT were chosen for easy fabrication. The simulated and measured results are in good agreement. These results show efficient and wideband power transfer of the coupled microstrips TLTs.

In practical cases, exact values for the optimal characteristic impedance Zop of the transmission lines are often difficult to implement. It is commonly acknowledged that some deviation from the optimum is tolerable with only minor sacrifices in performance [8]. For the case of Fig. 3, the transformation performance of the TLT is investigated by changing reference port impedances to yield different optimal characteristic impedance Zop’s and different impedance transformation ratios. The simulated results are displayed in Figs. 6 and 7, respectively. It is seen that a moderate deviation from the optimal design can also achieve acceptable performance. In other words, a TLT for a specific transformation ratio and port impedances may apply to different port impedances and different transformation ratios that will still have sufficient bandwidth and transfer efficiency.

CONCLUSION

A novel transmission line transformer with a simple structure of coupled microstrip lines has been developed and tested. Its wideband performance is demonstrated by the simulated and measured results of 1:2 transformer examples. The described design procedure can be immediately extended to implement TLTs with other transformation ratios, by properly connecting multiple pairs of coupled lines. For broadband performance, the proposed TLT can be very compact if a thin substrate is used.

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REFERENCE

[1] E. Frlan, S. Meszaros, M. Cuhaci, and J.S. Wight, "Computer aided design of spiral transformers and inductors," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 661-664, 1989.
[2] G.E. Howard, J. Dai, Y.L. Chow, and M.G. Stubbs, "The power transfer mechanism of MMIC spiral transformers and adjacent spiral inductors," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1251-1254, 1989.
[3] C.L. Ruthroff, "Some broadband transformers," *Proc. IRE*, vol. 47, pp. 1337-1342, Aug. 1959.
[4] P.L.D. Abrie, *The Design of Impedance-Matching Networks for Radio-Frequency and Microwave Amplifiers*, Artech House, Inc., 1985.
[5] M.A. Morrill, V.A. Caliskan, and C.Q. Lee, "High-frequency planar power transformers," *IEEE Tran. Power Electron.*, vol. 7, no. 3, pp. 607-613, July 1992.
[6] C.C. Kuo, M.Y. Kuo, and M.S. Kuo, "Modeling and analysis of wideband power transmission line transformers," *Proc. 11th Annual Applied Power Electon. Conf. and Expos.*, pp. 441-446, 1996.
[7] M. Engles, R.H. Jansen, W. Daumann, R.M. Bertenburg, and F.J. Tegude, "Design methodology, measurement and application of MMIC transmission line transformers," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1635-1638, 1995.
[8] O. Pitzalis and T.P.M. Couse, "Practical design information for broadband transmission line transformers," *Proc. IEEE*, vol. 56, pp. 738-739, 1968.

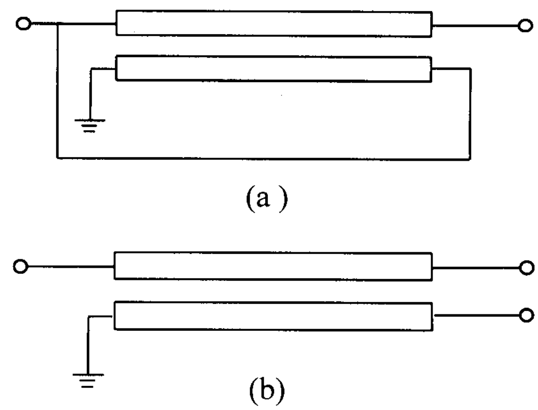

Fig. 1 (a) A 1:2 transmission line transformer and (b) the model for obtaining the characteristics of the coupled microstrip lines.

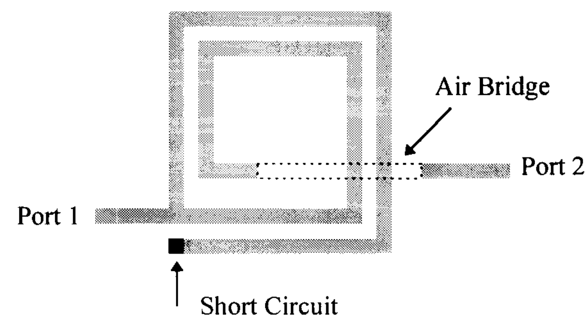

Fig. 2 Layout of a coupled microstrips TLT.

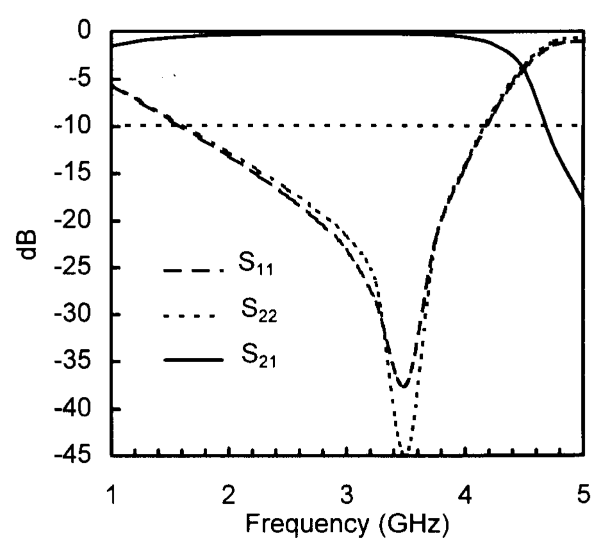

Fig. 3 Simulated S-parameters of the coupled microstrips TLT of Fig. 2 in the first case of Table I. Zref1 = 35 Ω, Zref2 = 140 Ω.

Zref1 : Zref2	L_{11}	f_l	$l$tl	f_h
35 Ω : 140 Ω	5 nH	1.67 GHz	516 mil	2.98 GHz
50 Ω : 200 Ω	7.9 nH	1.51 GHz	486 mil	3.43 GHz

Table I The predicted bandwidth at -10 dB reflection of the 1:2 TLTs for different combination of reference port impedances. L_{11}, $l$tl: total inductance and equivalent length of the wound transmission line; f_l, f_h: lower and upper frequency points at -10 dB reflection.

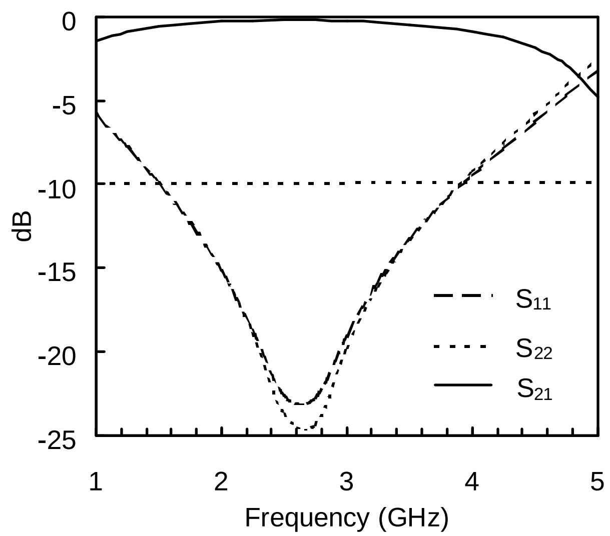

Fig. 4 Simulated S-parameters of the coupled microstrips TLT of Fig. 2 in the second case of Table I. Zref1 = 50 Ω, Zref2 = 200 Ω.

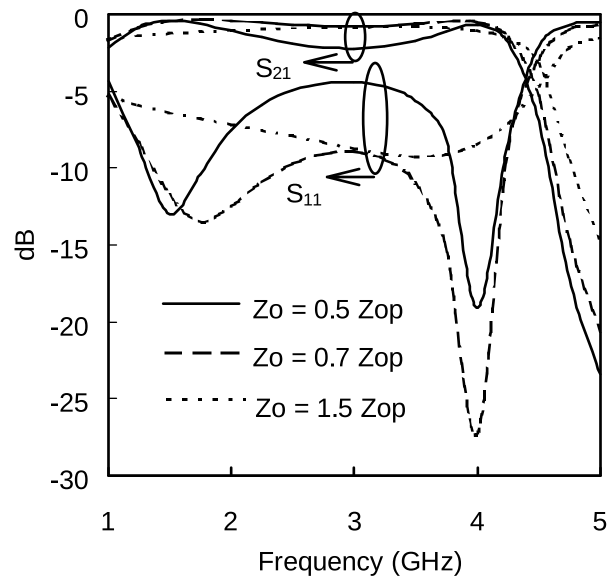

Fig. 6 Simulated S-parameters for different Zo's of the transmission line in the 1: 2 TLT of Fig. 3.

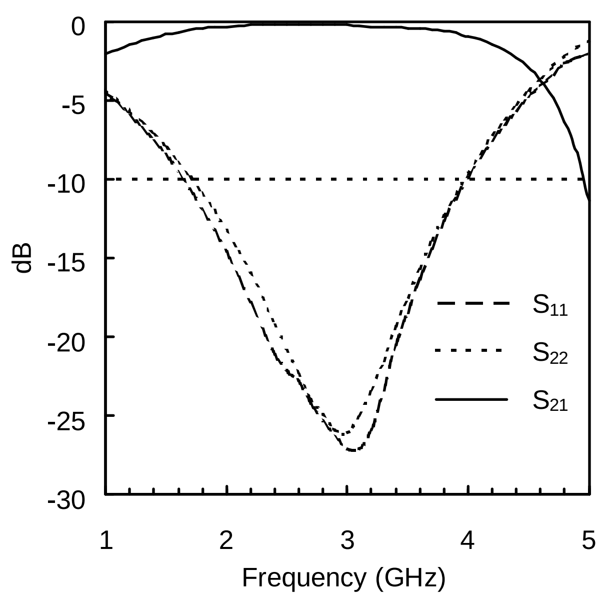

Fig. 5 Measured S-parameters of the coupled micro-strips TLT as in Fig. 3. Zref1 = 35Ω, Zref2 = 140 Ω.

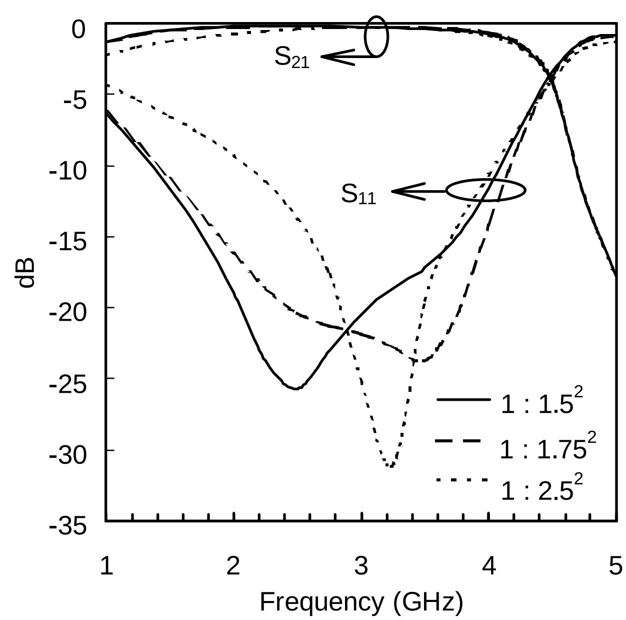

Fig. 7 Simulated S-parameters for different trans-formation ratios of the TLT in Fig. 3 with Zo = Zop.