Novel Lumped-Element Coplanar Waveguide-to-Slotline Transitions

Yo-Shen Lin and Chun Hsiung Chen

Department of Electrical Engineering,
National Taiwan University,
Taipei, Taiwan 10617, ROC

Abstract

Novel reduced-size lumped-element coplanar waveguide-to-slotline transitions are proposed, using planar parallel LC circuits to replace the $\lambda/4$ transformer structure. A simple equivalent-circuit model is also established, from which various lumped-element transition structures are carefully examined. Specifically, a 'ring-type L' lumped-element transition with a 1.8:1 bandwidth and 1/12 the size of conventional ones is achieved.

1. Introduction

Coplanar waveguide (CPW)-to-slotline transition is an important component in uniplanar MMIC. The CPW-to-slotline transitions developed so far utilized either a $\lambda/4$ transformer structure or a non-ended/circular slotline open which occupies large circuit area especially in low frequency range [1]-[3]. In this study, two novel lumped-element CPW-to-slotline transitions with small size and moderate bandwidth are proposed to provide a compact and effective interconnection between CPW and slotline. The proposed lumped-element transitions make use of planar parallel LC circuits instead of the conventional $\lambda/4$ transformer structure such that their sizes are much smaller and are independent of frequency. For design purpose, a simple equivalent-circuit model is also established.

2. Basic Lumped-Element Transition Structure

Consider the basic lumped-element transition structure shown in Fig. 1(a). The structure is placed on a FR4 substrate (ε_r = 4.3, tanδ = 0.022) with thickness h = 1.6 mm. To reduce the transition size, an interdigital structure and a shorted slotline stub are utilized to replace the conventional $\lambda/4$ transformer structure. The interdigital structure can be viewed as

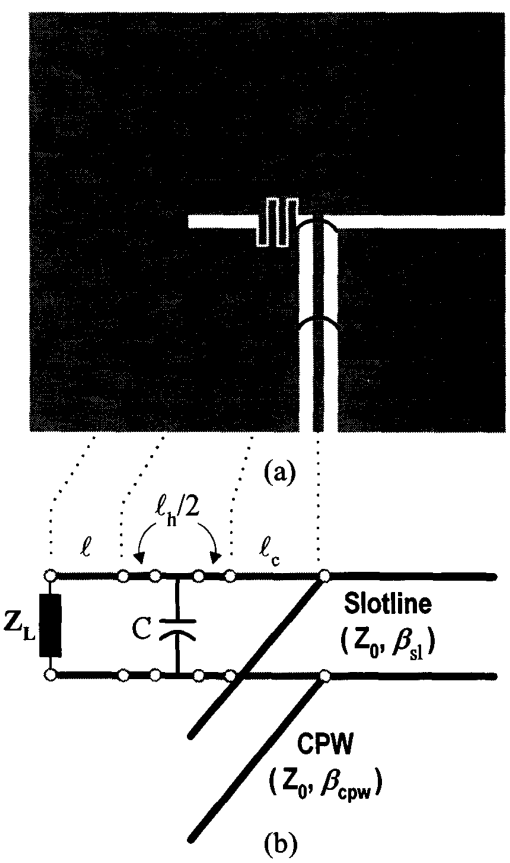

Fig. 1. Basic lumped-element transition structure, (a) configuration and (b) equivalent-circuit model.

0-7803-5135-5/99/$10.00 © 1999 IEEE

a capacitor as long as its size is much smaller than the wavelength. The capacitance is formed by the fringing field between each interdigital gap, and is proportional to the length of finger and the ratio between finger width and gap width. The shorted slotline stub is equivalent to an inductor as long as its length is much smaller than the wavelength. This planar parallel LC circuit gives an effective open circuit at $f_0 = 1/(2\pi\sqrt{LC})$ which determines the center frequency of transition passband. For suppressing the effect of coupled slotline mode excited at the CPW-slotline junction, bondwires at suitable positions are included in the structure.

The capacitance of interdigital capacitor is computed by the close-form expressions under quasi-static approximation [4]. The capacitance per unit length between each gap is first calculated using the conformal mapping technique. These per-unit length capacitances are multiplied by the finger length and are then added together to give the total capacitance. This enables a fast and simple characterization of the interdigital capacitor, and is feasible for design purpose.

For the short-circuited slotline stub section, the effect of shorted end must be taken into account to accurately model the effective inductance value. Several full-wave analyses discovered that the end reactance is inductive and increases with the slot width and h/λ ratio. In addition, the surface-wave and space-wave losses associated with the shorted end can be significant at high frequencies. This loss effect may be represented by an equivalent resistance. Since no close-form formulas are available for these elements, we use the full-wave mixed-potential integral-equation analysis [5] to simulate the input impedance Z_L of slotline shorted end. In this full-wave simulation, the conductor is assumed to be perfectly conducting and of zero thickness, and the dielectric loss is not included in the calculations. The short-circuited slotline section may then be modeled by a transmission line terminated by an impedance Z_L.

By combing the models of interdigital capacitor and short-circuited slotline section, we obtain the transmission-line equivalent-circuit model for the lumped-element transition (Fig. 1(a)) as in Fig. 1(b). This model is based on three assumptions. First, the CPW and slotline sections are modeled as transmission lines despite of the non-TEM nature of slotline. Second, the discontinuity effect of the CPW-slotline T-junction is neglected. Third, the interactions between the lumped-element LC circuit and the transmission lines are not taken into account.

A back-to-back lumped-element transition for Fig. 1(a) is fabricated and measured with TRL calibration to the CPW-slotline junction. The measured and simulated results are shown in Fig. 2 for comparison. This transition exhibits a band-pass behavior as expected, and the 1.5 dB passband is in

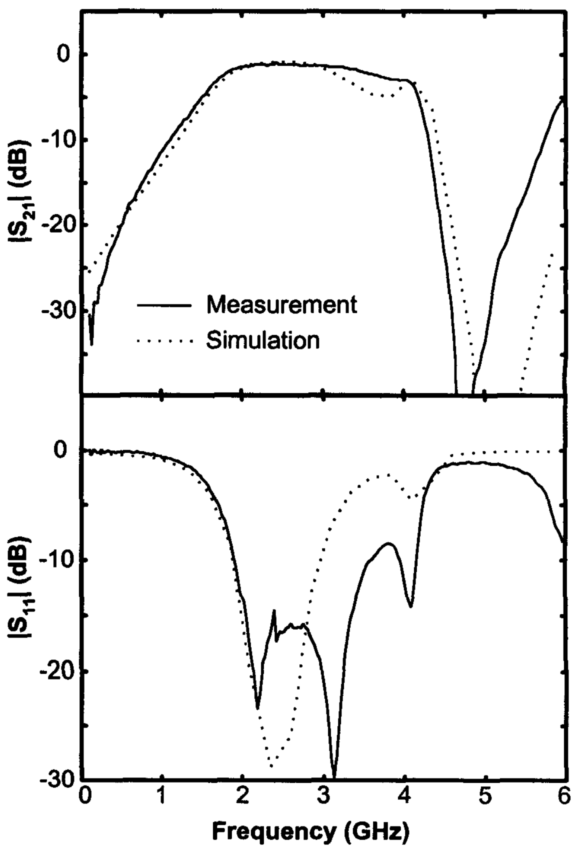

Fig. 2. Measured and simulated results for the lumped-element transtion shown in Fig. 1.

the 1.96 ~ 3.3 GHz frequency range. Good agreement between the measured and simulated results around the passband is observed. The equivalent capacitance and inductance of this structure are 0.6525 pF and 5.5 nH, respectively. This corresponds to a passband center frequency of $1/(2\pi\sqrt{LC}) \cong 2.65$ GHz which agrees well with the experimental result. The area occupied by this parallel LC circuit is about ($\lambda/28$)·($\lambda/12$), and this transition structure is obviously much smaller than the conventional ones with $\lambda/4$ transformer structures. Although there is some discrepancy between measured and simulated results in the higher frequency range, the equivalent-circuit model is still adequate in predicting the transition behavior around the passband. Note that all the components in this model except the slotline shorted end are characterized by close-form expressions, thus the simulation time may be largely reduced.

3. 'Ring-Type L' Transition Structure

To reduce the size of lumped-element transition even more, we propose the 'ring-type L' transition structure as shown in Fig. 3(a). Here two shorted slotline stubs instead of one are connected in series and are arranged to form a slotline ring. Being excited with a 180° phase difference, the two slotline stubs are now terminated by ideal short circuits in the equivalent-circuit model (Fig. 3(b)) and no full-wave simulation is needed. In addition, the size of transition is further reduced by this realization because the effective inductances of two stubs are added such that each stub can be made shorter; and the slotline stubs are curved such that the horizontal length of transition is reduced.

Measured and simulated results of this 'ring-type L' transition are shown in Fig. 4. The 1.5 dB passband is in the 1.53 ~ 2.76 GHz frequency range, which corresponds to a 1.8:1 bandwidth. The equivalent capacitance and inductance values are 0.6525 pF and 5.89 nH, respectively. The corresponding resonance frequency is 2.55 GHz, which again agrees with the measured passband center frequency.

The measured and simulated results for 'ring-type L' transition do not match well. One explanation is that all the discontinuity effects and losses associated with the parallel LC circuit are not taken into consideration. But this simplified model is still adequate in predicting the passband frequency range of transition and has the advantage of very short calculation time, a consequence of no full-wave analysis. Thus it is very suitable for CAD purpose.

For the 'ring-type L' transition, the size of interdigital capacitor is about ($\lambda/30$)·($\lambda/30$) and the radius of slotline ring $R_r \cong \lambda/36$. The transition size is

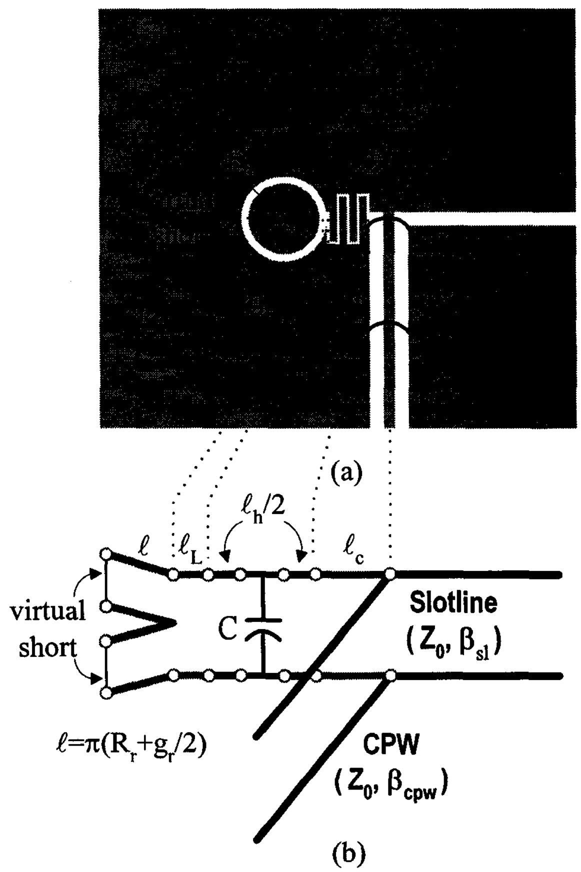

Fig. 3. 'Ring-type L' lumped-element transition, (a) configuration and (b) equivalent-circuit model.

about 1/12 smaller than the conventional slotline-radial-short transition [1]. This again reveals the effective size reduction capability of lumped-element transition.

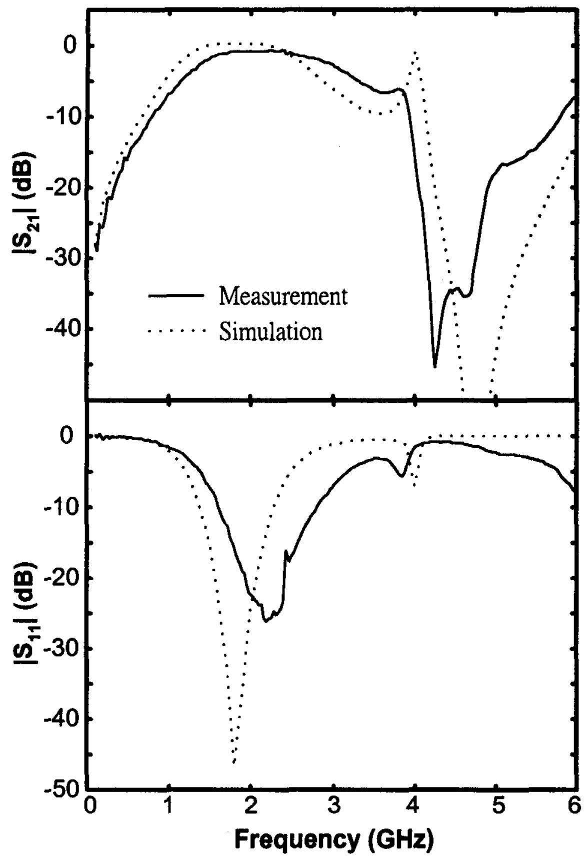

Fig. 4. Measured and simulated results for the 'ring-type L' lumped-element transition shown in Fig. 3.

4. Conclusion

In this study, two novel lumped-element CPW-to-slotline transition structures have been proposed and carefully examined. For design and modeling purposes, suitable equivalent-circuit model has also been established. The lumped-element transition is an easy and effective way to reduce the size of CPW-to-slotline transition with size reduction factor in the order of 1/12. Its reduced size and simple characterization properties are attractive in MIC/MMIC applications with moderated bandwidth requirements.

Acknowledgment

This research was supported by the National Science Council of Taiwan, ROC, under Grant NSC 88-2219-E-002-013.

References

[1] C.-H. Ho, L. Fan, and K. Chang, "Experimental investigations of CPW-slotline transitions for uniplanar microwave integrated circuits," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp.877-880, 1993.

[2] V. Trifunovic and B. Joknaovic, "Review of printed marchand and double Y baluns: characteristics and application," *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 4, pp. 1454-1462, Aug. 1994.

[3] K. Hettak, J. Ph. Coupez, T. L. Gouguec, S. Toutain, P. Legaud, and E. Penard, "Improved CPW to slotline transitions," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp.1831-1834, 1996.

[4] S. S. Gevorgian, T. Martinsson, L. J. P. Linner, and E. Kollberg, "CAD models for multilayered substrate interdigital capacitors," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 6, pp. 896-904, June 1996.

[5] F. L. Lin, C. W. Chiu and R. B. Wu, "Coplanar waveguide bandpass filter - a ribbon of brick wall design," *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 7, pp. 1589-1596, July 1995.