Proceedings of APMC2001, Taipei, Taiwan, R.O.C.

LUMPED-ELEMENT MARCHAND-BALUN TYPE COPLANAR WAVEGUIDE-TO-COPLANAR STRIPLINE TRANSITIONS

YO-SHEN LIN and CHUN HSIUNG CHEN
Department of Electrical Engineering and
Graduate Institute of Communication Engineering,
National Taiwan University
Taipei 106, Taiwan, R.O.C.
E-mail: chchen@ew.ee.ntu.edu.tw

Novel reduced-size lumped-element coplanar waveguide (CPW)-to-coplanar stripline (CPS) transitions are proposed, using planar parallel and series inductor-capacitor (LC) circuits to realize the effective open circuit and short circuit, respectively. In this study, various compact lumped-element Marchand-balun type CPW-to-CPS transition structures are developed and carefully examined. The design of proposed transitions can easily be accomplished by the use of conventional filter synthesis techniques. Simple equivalent-circuit models are also established, from which the passband behavior of the lumped-element transition structures may be characterized.

1 Introduction

Uniplanar transmission lines like coplanar waveguide (CPW) and coplanar stripline (CPS) are widely used in monolithic microwave integrated circuits (MMIC) for their superior performance than the conventional microstirp structure. To fully utilize the advantages of these uniplanar lines, suitable transitions between them are needed. Various CPW-to-CPS transitions have been developed and examined [1]-[3], due to their wide range of applications in the implementation of balanced mixers, multipliers, and antenna feeding structures. The ideally all-pass double Y junction balun [1] suffers from the junction parasitic effects, which lead to a limited operation bandwidth. The transition based on a quarter-wavelength ($\lambda/4$) transformer structure [2] occupies large circuit area, and is not suitable for use in the design of MMIC especially in the low frequency range. The transition utilizing a slotline open structure [3] has a wide bandwidth, but no explicit design formulas are available to predict its upper passband frequency. Also, it has the drawback of higher power losses because the slotline open structure would act as a radiated element.

In this study, novel lumped-element Marchand-balun type CPW-to-CPS transitions with small size and moderate bandwidth are proposed to provide a compact and effective interconnection between CPW and CPS. The proposed lumped-element transitions make use of planar parallel and series LC circuits instead of the conventional $\lambda/4$ transformer structures. This makes the transition size much smaller than the conventional ones. The design of proposed transitions can easily be accomplished by the use of conventional filter synthesis techniques, thus the transition center passband frequency and bandwidth may be predictable and adjustable. Simple equivalent-circuit models based on close-form expressions are also established, from which the passband behavior of the lumped-element transition structures may be characterized.

2 Lumped-element Marchand-balun type CPW-to-CPS transitions

Fig. 1 (a) shows the layout of proposed lumped-element Marchand-balun type CPW-to-CPS transition. Here, the series and parallel LC circuits, respectively, are used to replace the opened and shorted $\lambda/4$ stubs in the conventional designs so as to minimize the transition size. The planar LC circuits are realized by shorter metal strips (L_p, L_s) and interdigital capacitors (C_p, C_s). The parallel and series LC circuits are designed such that they are resonant at the same frequency, which is the desired transition center frequency.

The equivalent-circuit model shown in Fig. 1(b) is used to discuss the transition characteristics. 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. The quasi-static close-form formula associated with the partial-element equivalent-circuit model [5] is adopted for the inductance calculation. The inductance value can be obtained when the strip length, width, thickness, and the conductivity are specified. Regarding the CPW-CPS cross junction, the six-port equivalent-circuit model in [6] is adopted. In this model, the CPW line is represented by two transmission lines that separately support even CPW mode and odd CPW mode so as to describe the mode conversion effect at the junction. All the elements in the proposed equivalent-circuit model (Fig. 1(b)) can be described by close-form expressions, thus the computation time may be largely reduced.

By discarding the cross junction model, the equivalent circuit model in Fig. 1(b) may be identified with a second order bandpass filter. So, the conventional filter synthesis technique can easily be incorporated into the design of a lumped-element Marchand-balun type transition. Here, the second order maximally flat response is employed. By giving the desired center frequency f_0, relative 3dB bandwidth, and transmission-line characteristic impedance, one may get the required design values for L_s, C_s, L_p, and C_p by the filter transformation formulas. This may facilitate the design of a lumped-element Marchand-balun type transition according to a given specification.

3 Results

A lumped-element Marchand-balun type CPW-to-CPS transition (Fig. 1(a)) with a back-to-back configuration is built on the FR4 substrate (ε_r = 4.3, tanδ = 0.022, and thickness h = 1.6mm). The CPW line has a strip width of 0.45mm, a slot width of 0.6mm, and a finite ground-plane width of 4mm. The CPS line has a strip width of 4mm and a slot width of 0.6mm. Both CPW and CPS lines are designed to possess a characteristic impedance of 100Ω according to the close-form formulas in [7]. The measured and simulated results are shown in Fig. 2. This transition is designed with a center frequency at 3GHz, a relative 3dB bandwidth of 200%, and the transmission-line characteristic impedance of 100Ω. The required LC structures have the values L_s = 3.75 nH, C_s = 0.75 pF, L_p = 7.5 nH, and C_p = 0.375 pF, according to the filter design formulas for a maximally flat response. The transition exhibits a band-pass behavior as expected, with a center frequency at 3 GHz and a 3dB bandwidth of 1.2 ~3.7GHz. Note that the transition response and bandwidth are different from those of the ideal maximally flat response, because of the associated parasitic effects and its back-to-back configuration with a slotline of 30mm in between. The agreement of measured and simulated results is good. The sizes of parallel and series LC structures in this case are about (λ/13)*(λ/12) and (λ/8)*(λ/16), respectively, making the transition much smaller than the conventional ones.

Fig. 3(a) shows the layout of another lumped-element Marchand-balun type CPW-to-CPS transition in which a metal-insulator-metal (MIM) structure is employed to implement the capacitor C_s. This transition also has the same equivalent-circuit model as shown in Fig. 1(b). By utilizing the MIM capacitor, one may achieve a much larger capacitance for a given area compared to its interdigital counterpart. Here, a duroid substrate (ε_r = 10.2, tanδ = 0.002, and thickness h = 0.635 mm) together with top and bottom metals are used to implement the MIM capacitor. In this design, the CPW line has a strip width of 0.45mm, a slot width of 0.6mm, and a finite ground-plane width of 4mm. The CPS line has a strip width of 1mm and a slot width of 1mm. The resulted characteristic impedances of CPW and CPS are 100Ω and 150Ω, respectively, thus the load impedance to source impedance ratio of 1.429 is selected in the maximally flat formulas. This transition is designed with a center frequency of 3GHz, and a relative 3dB bandwidth of 200%. The required LC structures have the values L_s = 1.84 nH, C_s = 1.52 pF, L_p = 4.35 nH, and C_p = 0.647 pF, according to the filter design formulas. The measured and simulated results of this transition with a back-to-back configuration are shown in Fig. 3(b). Again, a good match between them is observed. The transition 3dB bandwidth is in the

1.43~3.23 GHz frequency range, and the sizes of parallel and series LC structures in this case are about (λ /13)*(λ /13) and (λ /10)*(λ /15), respectively.

4 Conclusions

In this study, novel lumped-element Marchand-balun type CPW-to-CPS transitions have been proposed and carefully examined. The proposed transitions may easily be characterized by adopting the conventional filter synthesis formulas. For design and modeling purpose, effective and simple equivalent-circuit models have also been established. The proposed lumped-element transitions have the merits of very compact size, low power losses, moderate bandwidth, and easy characterization, thus providing simple and effective interconnections between CPW and CPS. They are attractive in implementing the uniplanar MMIC components.

Acknowledgment

This work was supported by the Ministry of Education and National Science Council of Taiwan, R.O.C., under Grants 89-E-FA06-2-4 and NSC 89-2219-E-002-045.

References

[1] V. Trifunovic′ and B. Jokanovic′, "Review of printed Marchand and double Y baluns: Characteristics and application," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 1454–1462, Aug. 1994.

[2] L. Zhu and K. Wu, "Hybrid FGCPW/CPS scheme in the building block design of low-cost uniplanar and multilayer circuit and antenna," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1999, pp.867-870.

[3] S.-G. Mao, C.-T. Hwang, R.-B. Wu, and C. H. Chen, "Analysis of coplanar waveguide-to-coplanar stripline transitions," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 23-29, Jan. 2000.

[4] S. S. Gevorgian, T. Martinsson, L. J. P. Linner, and E. L. Kollberg, "CAD models for multilayered substrate interdigital capacitors," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 896-904, June 1996.

[5] A. E. Ruehli, "Inductance calculations in a complex integrated circuit environment," *IBM J. Res. Develop.*, vol. 16, pp. 470-481, Sept. 1972.

[6] M. Ribo and L. Pradell, "Circuit model for a coplanar-slotline cross," *IEEE Microwave Guided Wave Lett.*, vol. 10, pp. 511-513, Dec, 2000.

[7] K. C. Gupta, R. Garg, and I. J. Bahl, *Microstrip Lines and Slotlines*, 2nd ed., Artech House, Mass., 1996, ch. 5 and ch. 7.

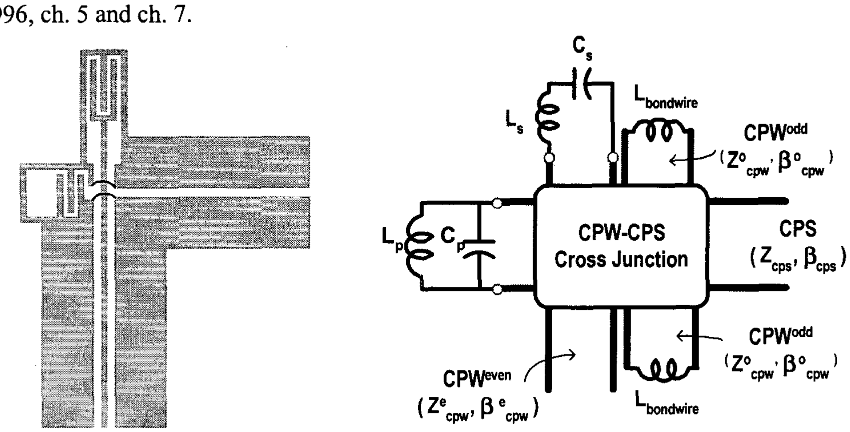


Fig. 1. Lumped-element Marchand-balun type CPW-to-CPS transition, (a) layout and (b) equivalent-circuit model.

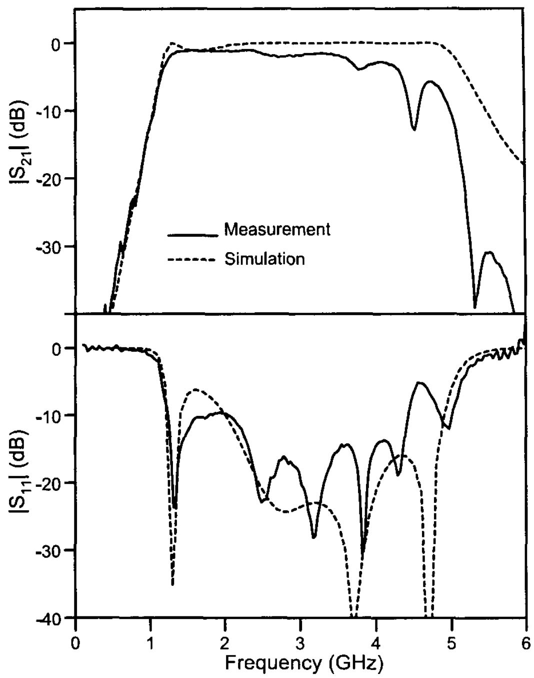
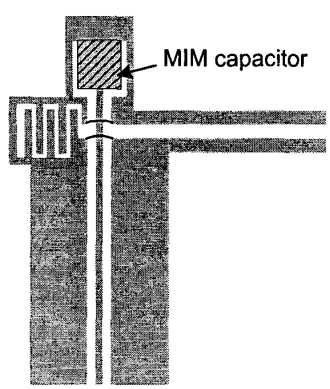
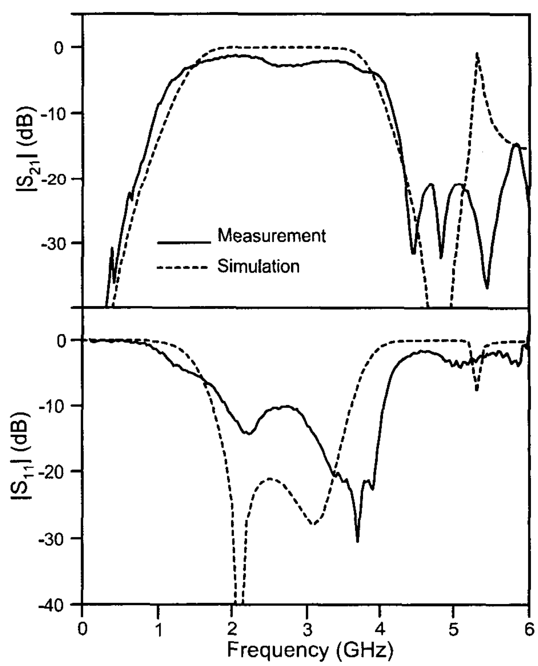


Fig. 2. Measured and simulated results for the back-to-back lumped-element Marchand-balun type CPW-to-CPS transition shown in Fig. 1(a).



(a)



(b)

Fig. 3. Lumped-element Marchand-balun type CPW-to-CPS transition implemented with a MIM capacitor, (a) layout and (b) measured and simulated results.