Novel Lumped-Element Coplanar Waveguide-to-Coplanar Stripline Transitions

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Abstract — **Novel reduced-size lumped-element coplanar waveguide-to-coplanar stripline transitions are proposed, using the planar parallel inductor-capacitor (LC) circuits to realize an effective open circuit. A simple equivalent-circuit model is also established, from which characteristics of various lumped-element transition structures are examined. Specifically, lumped-element transitions with bandwidth ranging from 1.8:1 to 3:1 and 1/12 the size of conventional ones can be achieved.**

I. Introduction

Coplanar waveguide (CPW) and coplanar stripline (CPS) are widely used in the design of uniplanar MMIC's. To fully utilize the advantages of CPW and CPS, an effective interconnection between them is of crucial importance. 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 from DC to RF, 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, a novel lumped-element CPW-to-CPS transition with small size and moderate bandwidth is proposed to provide a compact and effective interconnection between CPW and CPS. The proposed lumped-element transition makes use of a planar parallel LC circuit instead of the conventional $\lambda/4$ transformer structure as in the case of CPW-to-slotline transitions [4]. This makes the transition size much smaller and the center passband frequency predictable and adjustable. For design purpose, a simple equivalent-circuit model is also established.

II. Basic Lumped-Element Transition Structure

Consider the basic lumped-element CPW-to-CPS transition structure shown in Fig. 1(a). To reduce the transition size, a planar parallel LC structure composed of an interdigital structure and a shorter metal strip is utilized to replace the conventional $\lambda/4$ transformer structure. The interdigital structure can be viewed as 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 the finger and the ratio between finger width and gap width. The shorter metal strip is equivalent to an inductor provided that its length is much smaller than the wavelength. This planar parallel LC circuit is connected to one slot of CPW line as a shunt element, and gives an effective open circuit at $f_0 = 1/(2\pi\sqrt{LC})$, which determines the center frequency of transition passband. For suppressing the coupled slotline mode excited at the CPW-CPS junction, bondwires at suitable positions are included.

The capacitance of interdigital capacitor is computed by the close-form expressions under quasi-static approximation [5]. 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 available close-form expressions enable a fast and simple characterization of the interdigital capacitor, and are feasible for design purpose.

For calculating the inductance of the shorter metal strip, the quasi-static close-form formula [6] using partial-element equivalent-circuit model is adopted. The inductance value can be obtained when the strip length, width, thickness, and the conductivity are specified. Regarding the CPW-CPS T-junction, the three-port equivalent-circuit model in [7] is adopted. In this model, the CPW line is split into two transmission lines that separately support even CPW mode and odd CPW mode so as to describe the mode conversion effect at the junction.

By combining the abovementioned models, one may obtain the transmission-line equivalent-circuit model (Fig. 1(b)) for the lumped-element transition (Fig. 1(a)). This model is based on three assumptions. First, the CPW and CPS sections are modeled as transmission lines. Second, the discontinuity effect of the CPW-CPS T-junction is neglected. Third, the interactions between the lumped-element LC circuit and the transmission lines are not taken into account.

III. Results

A back-to-back lumped-element transition for Fig. 1(a) is fabricated on a FR4 substrate ($\varepsilon_r = 4.3$, $\tan\delta = 0.022$) with thickness h = 1.6 mm. 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 $100\ \Omega$ according to the close-form formulas in [8]. The four-finger interdigital capacitor in this case has a finger width of 0.5 mm, a finger length of 3.7 mm, and a gap width of 0.3 mm. For the shorter metal strip, its length and width are 12.05mm and 0.5mm, respectively. The total area occupied by the parallel LC circuit is about ($\lambda/28$)·($\lambda/14$), and this transition structure is obviously much smaller than the conventional ones using $\lambda/4$ transformer structures

The measurement of transition is done on a HP8510 network analyzer with TRL (Thru-Reflect-Line) calibration to the CPW-CPS junction, and the simulation is based on the equivalent-circuit model (Fig. 1(b)). The measured and simulated results are shown in Fig. 2. This transition exhibits a band-pass behavior as expected, and the 1.5 dB passband is in the 1.17 ~ 3.41 GHz frequency range. Good agreement between the measured and simulated results around the passband is observed. The equivalent capacitance of the interdigital capacitor for this case is 0.597 pF, and the equivalent inductance of the metal strip is 10.35 nH. This corresponds to a center passband frequency of $1/(2\pi\sqrt{LC}) \cong 2.02$ GHz, which agrees well with the measurement result. Although there is some discrepancy between measured and simulated results in the higher frequency range, the equivalent-circuit model (Fig. 1(b)) is still adequate in predicting the transition behavior around the passband. Note that all the components in this model are characterized by the close-form expressions, thus the simulation time may be largely reduced.

The bandwidth of the lumped-element transition can be adjusted by suitably choosing the relative values of L and C. Fig. 3 shows the layout of three transitions with different L and C values. For the metal strip, its width and total length are (a) 0.5mm, 8.05 mm, (b) 0.3mm, 9.05 mm, and (c) 0.3mm, 18.85 mm, respectively. The inductance values for these three cases are 6.27 nH, 8.09 nH, and 12.63 nH, respectively. The interdigital-capacitor structures change accordingly such that the corresponding capcitances are 0.6742 pF, 0.5753 pF, and 0.4374 pF, respectively. This gives the products of L·C values nearly the same for these three cases, thus the three transitions would be centered at about the same frequency. Shown in Fig. 4 are the measured results for these three transitions (Fig. 3) in a back-to-back configuration. Their passbands are all nearly centered at the same frequency of 2.4 GHz as expected. However, the 1.5dB relative bandwidths are 1.8:1, 2.25:1, and 3:1, respectively. The bandwidth of lumped-element transition can be increased by increasing the value of L. This phenomenon can be predicted from the input impedance characteristics of the LC section, whose magnitude is proportional to L near the resonant frequency.

The measured power loss of lumped-element transition structure (Fig. 3(b)) is compared with that of the broadband CPW-to-CPS transition using a slotline open structure [3]. As shown in Fig. 5, the normalized power loss of lumped-element transition is smaller than that of the broadband one over the passband frequency. High power loss of transition might cause unwanted crosstalk to other components in a circuit, and degrades the circuit performance. The low loss characteristic makes the proposed lumped-element transition feasible for uniplanar MMIC with high circuit density. The proposed transition is also suitable for use as a feeding structure for balanced antennas because of the lower interaction with the antenna, thus a lower level of cross-polarization wave can be expected.

IV. Conclusion

In this study, novel lumped-element CPW-to-CPS transition structures have been proposed and carefully examined. For design and modeling purposes, an effective and simple equivalent-circuit model has also been established. The proposed transition provides a low loss and compact interconnection between CPW and CPS, and is useful in implementing a MMIC component with moderate bandwidth requirement.

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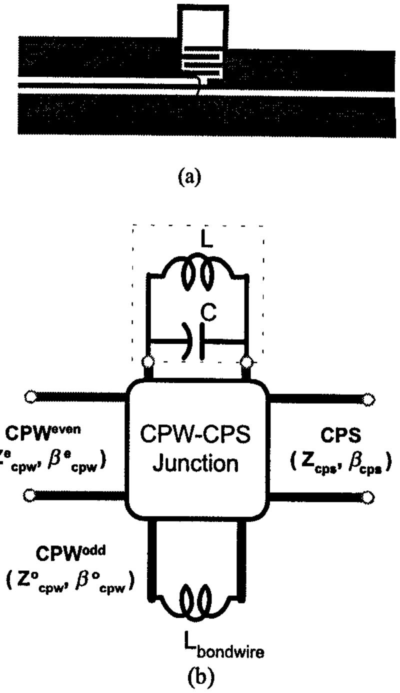

Fig. 1. Lumped-element CPW-to-CPS transition, (a) layout and (b) equivalent-circuit model.

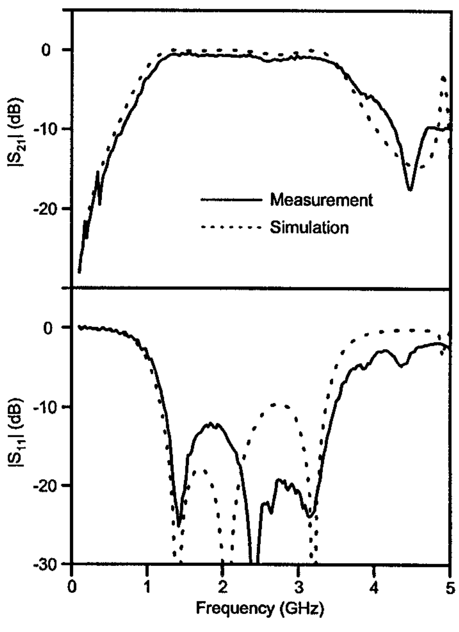

Fig. 2. Measured and simulated results for back-to-back lumped-element CPW-to-CPS transition shown in Fig. 1(a).

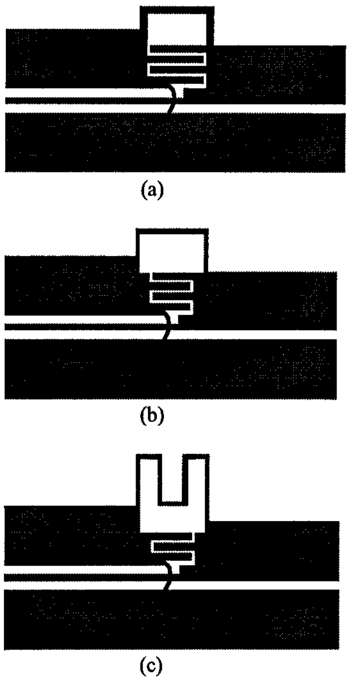

Fig. 3. Layouts of three lumped-element CPW-to-CPS transitions designed with same center frequency but with different L and C values.

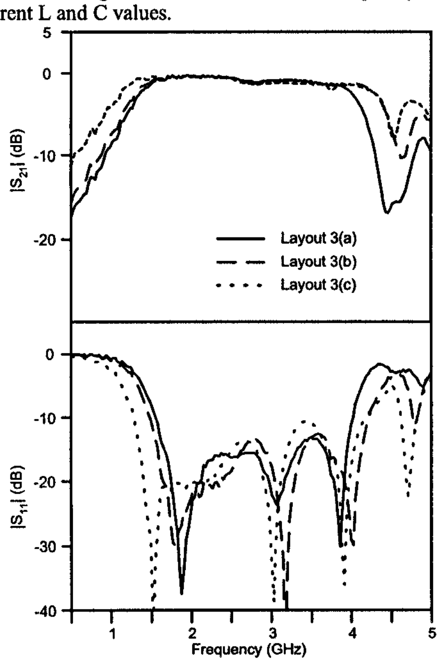

Fig. 4. Measured results for the three back-to-back transition structures in Fig. 3.

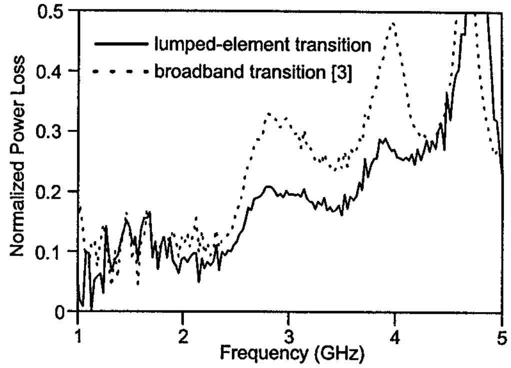

Fig. 5. Measured power losses of lumped-element transition and broadband transition structure [3].