Via-less Microwave Crossover Using Microstrip-CPW Transitions in Slotline Propagation Mode

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Abstract — This paper presents the design of a microstrip-CPW transition where the CPW line propagates close to slotline mode. This design allows the solution to be determined entirely though analytical techniques. In addition, a planar via-less microwave crossover using this technique is proposed. The experimental results at 5 GHz show that the crossover has a minimum isolation of 32 dB. It also has low in-band insertion loss and return loss of 1.2 dB and 18 dB respectively over more than 44 % of bandwidth.

Index Terms — Coplanar waveguides, microstrip transitions, microwave circuits.

I. INTRODUCTION

Microwave crossovers are indispensable components in the microwave systems that require complex wiring such as in the beam-forming networks, microwave switch matrices. They allow two microwave signals to cross in two planes with an acceptable isolation, which enable compact realization of the complex microstrip circuits on a chip.

Planar crossovers can be constructed using wire bond or air bridges [1]. In addition, they can be constructed using vias wiring though additional substrate layers [2-3]. However, these solutions may require multiple substrate and conductor layers, increase fabrication complexity, and may require additional circuit elements to compensate for via's or bridge's parasitic when operated at mm-wave frequencies. One of the approaches to reduce fabrication complexity is to use via-less microstrip to co-planar waveguide (CPW) transitions [4-6], where CPW is on the ground plane layer of the microstrip. However the design in [4] and [5] requires large ground plane slot and narrow microstrip line at the transition to allow broadband microstrip-CPW mode conversion. As a result, it produces high radiation losses. In addition, these designs are based upon the empirical solution that requires extensive computation time to fine-tune the response in electromagnetic simulation software. Girard et al. proposed a broadband transition with low radiation loss [5]. However, this work did not explain the technique to determine the optimal microstrip and CPW characteristic impedance at the transition.

In this paper, we propose an analytical technique to design a via-less microstrip-CPW transition. In addition, a new microwave crossover was developed using this technique. The proposed crossover is designed to have low radiation loss, high isolation and broadband frequency responses. The design of microstrip-CPW transition and crossover will be discussed in section II and III, respectively. The hardware implementation and measurement will be discussed in section IV. Finally, the conclusion remarks are made in section V.

II. MICROSTRIP-CPW TRANSITIONS

A CPW line contains three conductor strips that can support both odd and even mode. Although symmetric CPW line supports only an even mode propagation as shown in Fig. 1(a), it can be visualized as two slotlines driven out-of-phase. The electric field lines in each slot are highly dependent on the center conductor width \( W_g \) of the CPW and the slot width \( W_s \). For small \( W_g/W_s \) ratio as in Fig 1(a), the CPW propagates in quasi-transverse electromagnetic (quasi-TEM) mode. If a microstrip line is transformed to a CPW line in this mode though broadside coupling, four connector strips will be involved in the line impedance computation and can be solved by using complex full wave equations [5].

On the other hand, when two slots are widely spaced as shown in Fig. 1(b), their electric fields become less dependent on each other. Once two slots become so wide that the voltage potential in the center conductor becomes less dependent on the position in conductor plane, the CPW no longer propagate in quasi-TEM mode. The CPW becomes two slots with wave
Fig. 2. The characteristic impedance of the Co-planar waveguide line with \( W_s = 102 \) µm in comparison with the slotline characteristic impedance with same \( W_s \) value. Both on 0.254mm-thick substrate with \( \varepsilon_r = 10.2 \).

In this condition, the characteristic impedance of the CPW also approaches half of CPW’s slot line impedance \( Z_s \) as shown in Fig. 2. Since there is only one propagating mode in transitions combined in parallels as shown in Fig. 3(a).

In addition, both slots must be physically separated apart around the microstrip line port to minimize the effect of slotlines on the microstrip input characteristic impedance. The quarter-wavelength line with the characteristic impedance of \( Z_0 \) of 40.6 Ohm (corresponding to a width of \( W_{0i} \)) is used to transform the port impedance \( Z_0 \) of 50 Ohm to two microstrip lines with the characteristic impedance of \( Z_s \) combined in parallel.

The microstrip-CPW transition can be modeled using transmission lines and transformer as shown in Fig. 3(b). To minimize signal reflection at the transition, value \( Z_0 \) is matched to \( n^2Z_s \) where \( n \) is the microstrip-slotline equivalent transformer ratio. This ratio is highly dependent on the dielectric thickness and the angle between microstrip and slotline [8]. In a thin substrate relative to guided wavelength and with 90-degree intersection between the microstrip and slotline, the value \( n \) is approximately one.

The impedance at port 2 is matched to \( Z_s/2 \) as opposed to the CPW characteristic impedance. This assumption is valid only when the two slots have minimal interaction in quasi-TEM mode and when slotlines does not strongly affect the microstrip lines characteristic. To validate this assumption, method-of-moments electromagnetic (EM) simulations were performed. The results were compared with that obtained from the circuit model. In the EM simulation, two slots are defined as a CPW port with the characteristic impedance of 40 and 34.6 Ohm for \( W_s/W_s = 6.25 \) and 12.5, respectively. The EM simulation results of the transition designed at 5 GHz shows good agreement with that using the proposed circuit model as shown in Fig. 4, especially when CPW propagation mode approaching the slotline mode (when \( W_s/W_s = 12.5 \)).

Fig. 4. The simulated frequency response of the microtrip-CPW transition in Fig 3(a) on 254µm-thick substrate with \( \varepsilon_r = 10.2 \) and using EM simulator with \( W_s/W_s = 6.25 \) and 12.5, and \( W_s = 102 \) µm in comparison with that using circuit model in Fig 3(b) and parameters shown in Table I.

III. CROSSOVER DESIGN USING VIA-LESS MICROSTRIP-CPW TRANSITIONS

The proposed via-less microstrip-CPW transition can be combined in a back-to-back configuration to produce a microwave crossover with no additional substrate layers or airbridge required at the crossing plane as shown in Fig. 5(a).

The microwave signal crossing occurs between the microstrip and the CPW layer is also served as the ground plane for the microstrip line. In addition, both slots must be physically identical to suppress CPW odd-mode propagation.

To increase the crossover isolation, the crossing area between the microstrip and CPW lines must be minimized.
The CPW line is tapered from line width $W_{g1}$ at the transition area to $W_{g0}$ at the center of the crossover. By changing $W_{g0}$ from 0.381 to 0.076 mm, isolation between two lines increased by approximately 7 dB with minimal effect on the transmission for both vertical and horizontal branch as shown in Fig. 6.

To minimize the total crossing area and increase the bandwidth of the crossover in the microstrip section, we incorporate a fourth-order stepped impedance low-pass filter [8] into the crossover. The impedance contrast is adjusted such that the low-pass filter's 3dB corner frequency is set at 17 GHz. Using this technique, the crossover can be constructed using transmission lines as shown in Fig. 5(b). Due to limited crossover area, the low impedance section of the filter is replaced with opened-end microstrip lines $Z_{m2}$ with the line width of $W_{m2}$. They are folded parallel to the narrow line $W_{m1}$ to minimize the parasitic coupling between two crossing signals. The circuit and physical parameters for both microstrip-CPW transitions and the microstrip crossover are provided in Table I.

### IV. Hardware and Experimental Results

The broadband via-less crossovers was fabricated on the 0.254 mm thick substrate as shown in Fig. 7. The microstrip and CPW lines are made with gold-plated 16 µm-thick copper. These crossovers are terminated with 2.4 mm end-launch connectors. The two-port Thru-Reflect-Line (TRL) calibration is performed using the Agilent 8510 Network analyzer to define the reference planes near the crossover input on the substrate. The crossovers were measured two ports at a time and the device is placed at 10 mm above the earth ground.

In addition, the measured S-parameters of device were in good agreement with the simulated results as shown in Fig. 8(a) and 8(b). The proposed crossovers are able to provide in-band return loss above 18 dB from 3.9 GHz to 6.1 GHz in all ports. The average in-band insertion loss observed in horizontal and vertical branch are 0.65 and 1.21 dB,
respectively. The isolation between the horizontal and vertical branch is greater than 32 dB. The majority of loss in the structure originated in the narrow line sections in the microstrip and CPW crossover. Given at the room temperature resistivity of copper, the line width of 0.102 mm is too thin to provide sufficiently low loss transmission at 5 GHz. The crossover can be designed with wider line width and thickness to reduce the current density at the crossing junction.

The transmission loss of the horizontal branch is higher than that of the vertical branch due to the width $W_{g0}$ being narrower than the designed value. $W_{g0}$ was approximately 0.076 mm narrower due to the ground plane being over-etched in the photolithography fabrication process.

The total loss of the crossover in the vertical and horizontal branch can be approximated using $1-|S_{11}|^2 - |S_{21}|^2$ and $1-|S_{33}|^2 - |S_{43}|^2$, respectively. Fig. 9 shows that the maximum radiation loss occurs around at 7.9 GHz and 8.7 GHz for vertical and horizontal branch, respectively. At these frequencies, slot lines length $V$ and $H$ shown in Fig. 5(a) become half-wavelength long and produces strong radiation. The vertical microstrip branch is less susceptible to this loss as it is not designed to couple directly to slotlines.

When the crossover is placed 150 mm above the earth ground, we observed small increase in the total loss by approximately 0.6% in the horizontal branch. This result suggested that the radiation loss is significantly smaller than the ohmic loss in the system.

V. Conclusion

We proposed an analytical design solution for a broadband microstrip-CPW transition and incorporated this component in a crossover design. The stepped impedance low pass filter techniques were implemented in the crossover design to produce a compact transition area with high isolation between two signal lines. In addition, the design is simple to fabricate using only two metalized layers on a dielectric substrate.

REFERENCES