Design of a Broadband Microstrip-to-Microstrip Vertical Transition

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Abstract **─** A broadband microstrip-to-microstrip vertical transition is presented in this paper. The proposed transition consists of two quarter-wavelength microstrip stubs and a half-wavelength slotline Stepped Impedance Resonator (SIR) on the common ground plane. The low-impedance section of the microstrip stub is formed by three single arms connecting in parallel, while the high-impedance section of slotline SIR is formed by four single arms connecting in series. A sample transition is designed and measured. Experimental results indicate that over 143% bandwidth with better than 10 dB return loss and below 2 dB insertion loss can be achieved.

Index Terms **─** Microstrip transition, multilayer circuits, slotlines, Stepped Impedance Resonator (SIR).

I. INTRODUCTION

In high-density multilayer integrated circuits such as Monolithic Microwave-Integrated Circuits (MMIC's), microstrip-to-microstrip vertical transitions are essential. Typically there are three methods to achieve microstrip vertical transitions. The first method is based on a via hole or via hole array [1-2]. This type of transition exhibits a low-pass behavior. Thus, the performance of the via-hole transition will be reduced as the operating frequency increases. The second method is based on the slot/aperture-coupled structure. The slot/aperture-coupled transition is basically a band-pass circuit and is realized via electromagnetic coupling through the slot/aperture on the common ground. By using wide aperture whose length is quarter-wavelength at the center frequency, a bandwidth (at 8 dB return loss) of 4-12 GHz is obtained in [3] and a bandwidth (at 12.5 dB return loss) of 3-11 GHz is achieved in [4]. In [5-6], the wideband microstrip vertical transitions are obtained by using slot, which is quarter-wavelength away from the open end of the microstrip stubs. Different slot shapes are investigated in [5] in order to enhance the bandwidth. In [6], a bandwidth (at 10 dB return loss) of 3.1-11.56 GHz is obtained by using a half-wavelength U-shaped slot on the common ground. The third method is based on cavity-coupled structure [7-8]. This kind of transition needs to construct a cavity in a thick common ground, which increases the complexity of the circuit processing.

As is known to all, how to improve the bandwidth of the microstrip-to-microstrip vertical transition is a key consideration for the designers. Therefore, the motivation of this paper is to design a microstrip-to-microstrip transition with enhanced bandwidth. The main innovation of this work is to propose a new microstrip vertical transition with two major low-impedance microstrip stubs and a slotline SIR on the common ground. With this new structure, a transition with good performance can be obtained. Furthermore, this new design scheme can realize more design flexibility, as the bandwidth and impedance-matching of the transition can be easily controlled by changing the length of the high-impedance section of the slotline SIR. Measured results show that the proposed transition provides a bandwidth of 2.3-

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14 GHz with return loss better than 10 dB.

II. MICROSTRIP VERTICAL TRANSITION DESIGN

The layout of proposed transition is shown in Fig. 1, and the transition structure parameters are shown in Fig. 2. We can see that the transition mainly consists of two parts. The first part is the port and the quarter-wavelength microstrip stub that is composed of a short microstrip line and a low-impedance microstrip stub on the top/bottom layer. The structure of the quarter-wavelength microstrip stub is shown in Fig. 3. It should be mentioned that the low-impedance stub acted as the major part of the quarter-wavelength microstrip stub and is constructed by three single arms connecting in parallel. With this form in the resonator, we can avoid the propagation of microstrip higher order modes and can reduce the radiation effects as analyzed in [10]. The second part is a half-wavelength slotline SIR on the common ground, which is at the middle layer of the structure. The high-impedance section of the slotline SIR is realized by four single arms connecting in series.

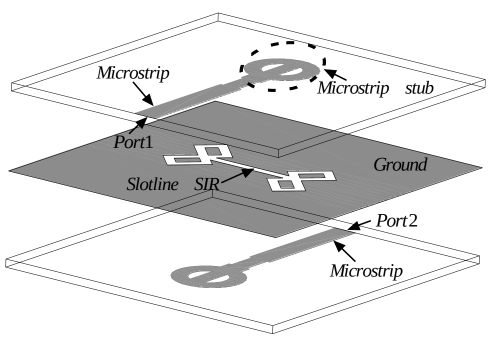

Fig. 1. Layout of the proposed microstrip-to-microstrip vertical transition.

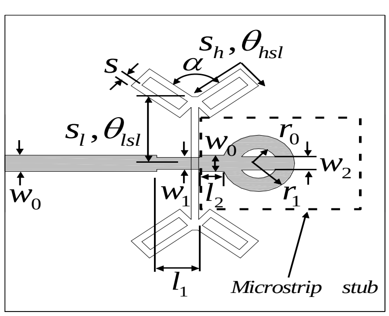

Fig. 2. Structure parameters of the proposed transition.

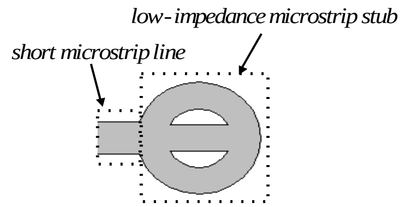

Fig. 3. Structure of the quarter-wavelength microstrip stub.

To illustrate the design theory of the proposed transition, the effect of the stubs impedance on bandwidth is primary analyzed. The equivalent circuit of presented transition is shown in Fig. 4, when the microstrip stubs and slotline stubs are uniform. The impedance looking into A-A′ plane can be expressed as (assumed $\theta_{ms} = \theta_{sl} = \Phi$):

$$z_{in} = z_0 \frac{1 - j2\frac{z_{ms}}{z_0}\cot\phi - 2\frac{z_{ms}}{n^2 z_{sl}}\cot^2\phi + j2\frac{z_{ms}^2}{n^2 z_0 z_{sl}}\cot^3\phi}{1 - j2\frac{z_0}{n^2 z_{sl}}\cot\phi - 2\frac{z_{ms}}{n^2 z_{sl}}\cot^2\phi}, \quad (1)$$

where n is slowly varying functions of frequency as described in [9], Z_{ms} is the characteristic impedance of microstrip stub, Z_{sl} is the characteristic impedance of slotline stub, and Φ is the electrical size of microstrip stub and slotline stub. If we set:

$$z_{ms} = \frac{z_0^2}{n^2 z_{sl}} \text{ and } \frac{z_{ms}^2}{n^2 z_0 z_{sl}} \to 0, \quad (2)$$

equation (1) will be simplified as $Z_{in}=Z_0$. Replacing Z_{ms} by $Z_0^2/n^2 Z_{sl}$, the impedance Z_{in} becomes:

$$z_{in} = z_0 \frac{1 - j2\frac{n^2 z_0}{z_{sl}}\cot\phi - 2\frac{n^4 z_0^2}{z_{sl}^2}\cot^2\phi + j2\frac{n^6 z_0^3}{z_{sl}^3}\cot^3\phi}{1 - j2\frac{n^2 z_0}{z_{sl}}\cot\phi - 2\frac{n^4 z_0^2}{z_{sl}^2}\cot^2\phi}. \quad (3)$$

That is to say, when Z_{ms} means a low impedance and Z_{sl} means a high impedance, a wide bandwidth can be obtained.

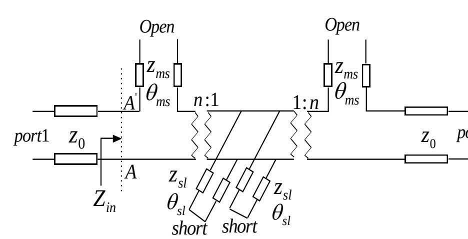

Fig. 4. Equivalent circuit of the presented transition with uniform microstrip and slotline stubs.

In order to realize broad bandwidth and good impedance-matching, here, the high-impedance slotline stubs are replaced by a slotline SIR. To illustrate this point, the performance of the proposed transition varies with the high-impedance section of the slotline SIR and is simulated and shown in Fig. 5, while the total length of the slotline SIR keeps half-wavelength. As can be seen from Fig. 5, a larger θ_{hsl} can achieve a wider transition bandwidth, yet degrade the impedance-matching performance. Thus, choosing suitable θ_{hsl}, both wide bandwidth and good impedance-matching can be realized. Moreover, the width W_1 is another important factor in the presented transition as it affects the coupling coefficients between the microstrip and the slotline SIR.

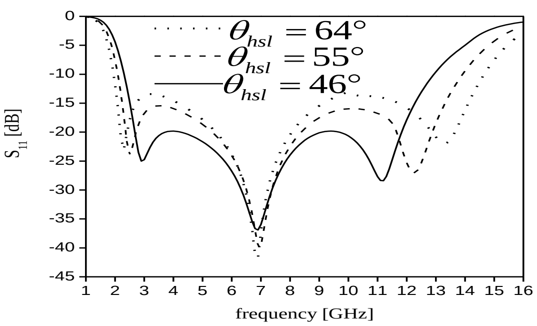

Fig. 5. S_{11} with different high-impedance slotline stub length θ_{hsl}.

III. SIMULATION AND MEASUREMENT RESULTS

Simulation was accomplished by using EM simulation software ANSOFT HFSS 12. Measurement was carried out on an Agilent 8722ES network analyzer. To verify the design, the proposed microstrip vertical transition is fabricated on the substrate with dielectric constant of 3.38 and a thickness of 0.508 mm. Figure 6 is the photograph of the proposed transition. The center frequency is designed at 8 GHz. The structure parameters are: w_0=1.1 mm, w_1=0.8 mm, w_2=0.9 mm, l_1=1.5 mm, l_2=1.1 mm, r_0=1 mm, r_1=1.9 mm, S=0.3 mm, S_l=2.9 mm, S_h=4.5 mm, and α=100˚. Three microstrip arms are considered to have approximately the same length of 4.6 mm. The low-impedance microstrip stub is 20 Ω with an electrical size of 72˚. The total electrical size of the microstrip stub is approximately 89˚. For the low-impedance section of the slotline SIR, it has an impedance of 110 Ω and an electrical size θ_{lsl} of 35˚, while the high-impedance section of the slotline SIR features with an impedance of 440 Ω and an electrical size θ_{hsl} of 55˚. The total electrical size of the slotline SIR is 180˚. Notice that all these electrical parameters are estimated at 8 GHz.

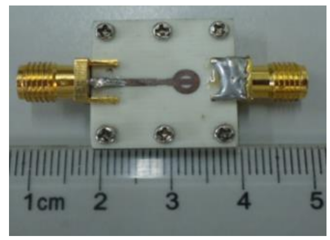

Fig. 6. Photograph of the proposed microstrip vertical transition.

Figure 7 shows the simulated and measured results of the proposed microstrip vertical transition. Measured results indicate that a broad transition bandwidth from 2.3 GHz to 14 GHz is achieved, referring to a criterion of better than 10 dB return loss. Inside the transition band, the maximum and minimum insertion losses are 2.0 dB and 0.3 dB, respectively, which ensures a good passband performance. There are some discrepancies between the simulated and measured results, which might be brought by the multiple reflections along the feed lines. The multiple reflections are due to the unexpected discontinuity effects between the SMA connectors and input/output terminals of the transition. For comparison, Table 1 summarizes the performance of some published microstrip-to-microstrip vertical transitions. It shows that the proposed transition has the property of wide bandwidth and good passband performance.

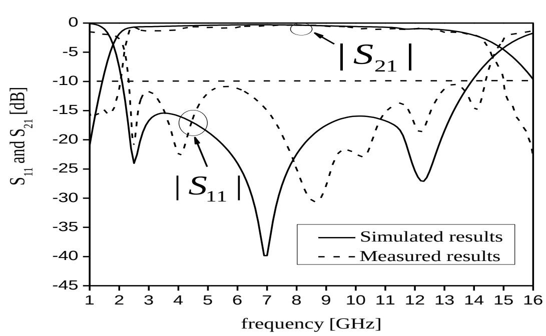

Fig. 7. Simulated and measured performance of the proposed transition.

Table 1: Performance comparisons among published microstrip-to-microstrip vertical transitions and proposed one

Ref.	Return Loss	Bandwidth	Insertion Loss
[3]	8 dB	4-12 GHz (100%)	≤2.7 dB
[4]	12.5 dB	3-11 GHz (114%)	≤1 dB
[6]	10 dB	3.1-11.56 GHz (115%)	≤2 dB
[7]	10 dB	2.6-7.8 GHz (100%)	≤1.5 dB
[8]	10 dB	18.3-22 GHz (18%)	≤2.5 dB
This work	10 dB	2.3-14 GHz (143%)	≤2 dB

IV. CONCLUSION

A broadband microstrip-to-microstrip vertical transition is presented in this letter. One prototype of transition with center frequency at 8 GHz has been demonstrated. The demonstrator exhibits the properties of compact size and broad bandwidth. With all these good features, the proposed transition could be widely applied in high-density multilayer integrated circuits.

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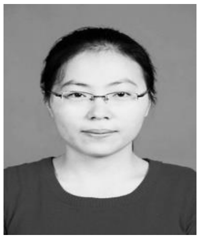

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