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A DC-40 GHz Substrate Integrated Suspended Line (SISL) to GCPW Transition

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***Abstract*-In this paper, an ultra-wideband self-packaged SISL to GCPW transition is studied and designed. A new structure from stepped impedance to two-stage gradient is proposed to solve the problems of impedance mismatch and parasitic mode caused by structural discontinuity between SISL and GCPW direct interconnection. Compared with the direct interconnection structure, the proposed SISL to GCPW transition has the advantages of wideband and lower insertion loss. The final simulation results show that the return loss $|S_{11}|$ of the transition structure achieves better than 20 dB and the average insertion loss $|S_{21}|$ is 0.35 dB over DC to 40 GHz.**

Index Terms—SISL, Transition, Self-packaged, MM-Wave

I. INTRODUCTION

Nowadays, the modern wireless communication system has put forward higher requirements for microwave and millimeter wave circuits. Substrate integrated suspended line (SISL) has been widely used in the design of microwave millimeter wave circuit filters [1]-[2], power divider [3], antenna [4] and other components due to its advantages of low loss, high quality factor, high integration and self-packaged characteristics [5].

In order for SISL with multi-layer PCB characteristics to integrate with other planar transmission line structures (such as GCPW, microstrip, etc.), wideband and high performance transition structures need to be designed, especially when the frequency rises up to mm-wave band. A novel ultra-wideband suspended stripline to shielded microstrip transition is presented in [6], which is better than 15 dB return loss over DC to 40 GHz. However, the heavy metal casing limits its application. A novel transition from SISL to conductor backed coplanar waveguide (CBCPW) is proposed in [7]. The transition uses SISL structure based on multi-layer PCB technology and obtain compact size, but it only realizes DC to 8 GHz bandwidth so that it is not suitable for mm-wave wideband circuits. Reference [8] introduces a vertical transition structure from GCPW to SISL in the design of SISL-based filter, which realizes the working bandwidth of DC to 18 GHz, but this structure has relatively high requirements for processing technology so that it is not suitable for mass production.

In this study, a DC to 40 GHz SISL to GCPW transition with self-packaged characteristics is designed based on multi-player PCB technology, which realized compact size and low loss. It provides a new scheme for the design of mm-wave self-packaged circuits in the future.

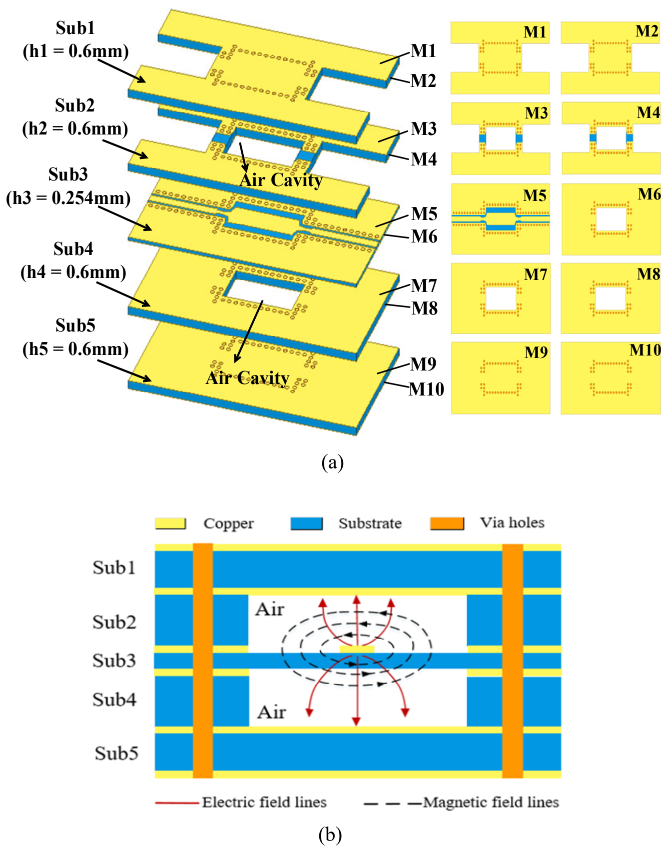

Fig.1 SISL to GCPW transition structure. (a) 3-D view. (b) Cross section view and the circuit electromagnetic field.

II. TRANSITION CONFIGURATION AND DESIGN

As shown in Fig. 1(a), it is the 3-D view of the SISL to GCPW transition structure. It consists of five layers of substrates labeled as Sub1-Sub5, respectively. Sub1 and Sub6 are low cost substrates of FR-4 ($h_1 = h_5 = 0.6$ mm, $\varepsilon_r = 4.4$, $\tan\delta_d = 0.02$), which are used to realize good electro-magnetic shielding. Sub2 and Sub4 with cut part of the medium are used to form air cavities, which is also FR-4 ($h_2 = h4 = 0.6$ mm, $\varepsilon_r = 4.4$, $\tan\delta_d = 0.02$). And Sub3 is the main circuit layer in the middle of the whole structure, which is Rogers 5880 ($h_3 = 0.254$ mm, $\varepsilon_r = 2.2$, $\tan\delta_d = 0.0012$). M1-M10 represent the top and bottom metal layers of the substrates, respectively. The transmission line is distributed on the metal layer M5, and the bottom of the GCPW is grounded on the metal layer M6. The stripline (SL) has ground metal layers M2 and M6. The suspended line (SSL) has ground metal layers M2 and M9. Fig. 1(b) illustrates the cross-view and electromagnetic field of the circuit, it can be seen that the electromagnetic field is concentrated in the air cavities through the suspended line to obtain lower insertion loss. Moreover, metallic via holes around the air cavities are used to suppress high frequency harmonics while preventing leakage of electromagnetic waves.

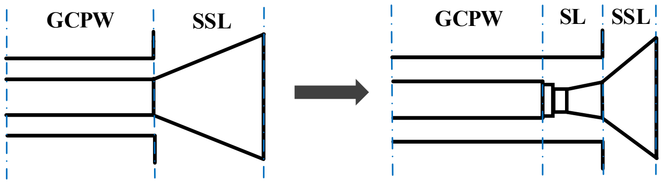

Fig. 2 Diagram of SISL to GCPW transition structure. (a) Traditional structure. (b) Improved Structure.

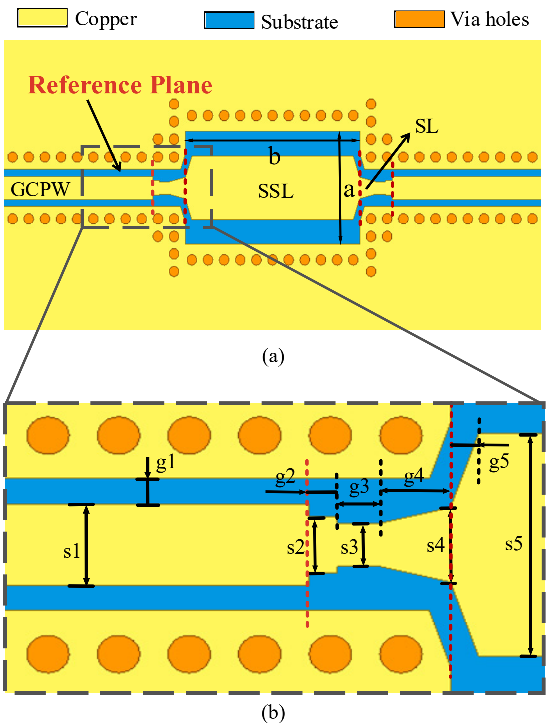

Fig. 3 Structure of Sub3. (a) Top view of SISL to GCPW transition. (b) Details of SISL to GCPW transition.

The traditional transition structure of GCPW to SISL is demonstrated in Fig. 2(a). However, this direct transition from GCPW to SISL results in considerable transition loss due to structural discontinuities, especially when the frequency moves up to the mm-wave band. So an improved SISL to GCPW transition structure is proposed as shown in Fig. 2(b). The whole transition structure is composed of three parts: GCPW, SL, and SSL. Accounting the different linewidths of each part of the proposed transition structure and the discontinuity of electromagnetic field caused by dielectric mutation when energy is transferred from the plane to the cavity, we designed a new transition structure from stepped impedance to a two-stage gradient structure, as shown in Figure 2(b). By adjusting the dimensions of SL and SSL, impedance matching can be more flexibly adjusted while at the same time improving electromagnetic discontinuity due to structural mutations.

Fig. 3(a) presents the top view of layer Sub3, and Fig. 3(b) shows the details of the proposed transition structure. The impedance of each part of the transmission line is 50 ohms. Through the transmission line calculation control can be calculated that $s1$ = 0.65 mm, $g1$ = 0.2 mm, $s2$ = 0.35 mm, $s5$ = 1.9 mm. However, in the simulation design process, the energy transition from a planar substrate to a 3-D air cavity may excite higher order modes. On the one hand, this is caused by the discontinuity of the transitional structure. Interestingly, it is found that the two-stage gradient structure has great effect on the suppression of higher harmonics. The final parameters obtained by simulation and optimization in Ansys High Frequency Simulation Software are: $s1$ = 0.66 mm, $g1$ = 0.2 mm, $s2$ = 0.4 mm, $g2$ = 0.2 mm, $s3$ = 0.35 mm, $g3$ = 0.3 mm, $s4$ = 0.6 mm, $g4$ = 0.5 mm, $s5$ = 1.8 mm, $g5$ = 0.2 mm.

On the other hand, it's worth noting that the parasitic modes in air cavities are also major factors. Therefore, during the design process, the size of the air cavities should be considered clearly to inhibit the generation of parasitic mode. The cut-off frequency f_c of the cavity can be approximately expressed as follows [9]:

$$f_c = \frac{c}{2a}\sqrt{1-\frac{h}{H}\left(\frac{\varepsilon_r-1}{\varepsilon_r}\right)} \quad (1)$$

where c represents the velocity of the light, a is the width of the air cavity as shown in Fig. 2(a), h represents the thickness of Sub3, H is the sum height of the cavity ($H = h_2 + h_3 + h_4$), ε_r is the dielectric constant of Sub3. From (1), when the cut-off frequency f_c = 40 GHz, the calculated value of air cavity width a = 3.5 mm, and the final optimization value a = 3.2 mm.

III. Simulation and Analysis

The proposed from stepped impedance to a two-stage gradient structure can flexibly adjust impedance matching by adjusting parameters $s4$ and $s5$ as shown in Fig. 4 (a) and (b), respectively. It can be seen from Fig. 4(a) that when $s4$ changes from 0.4 to 0.6 mm, $|S_{11}|$ in the band above 20 GHz has obvious changes. From Fig.4(b), when $s5$ changes from 1.8 to 2 mm, $|S_{11}|$ was significantly affected during the whole working band.

In order to see the performance of the proposed transition structure more directly, we compared it with the traditional

GCPW to SSL transition structure. The comparison results are illustrated in Fig. 5. It can be seen that as the frequency rises up, the impedance of the traditional GCPW to SISL transition structure no longer matches and is affected by the parasitic mode due to the discontinuity of the structure. However, the return loss $|S_{11}|$ of the new transition structure proposed in this work is better than 20 dB over DC to 40 GHz, and the average insertion loss $|S_{21}|$ in the band is 0.35 dB as shown in Fig. 5.

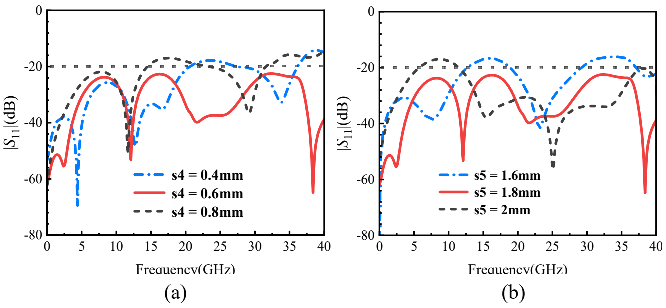

Fig. 4 Simulated S_{11} variations versus physical parameters of SISL to GCPW transition. (a) Simulated $|S_{11}|$ variations versus $s4$. (b) Simulated $|S_{11}|$ variations versus $s5$.

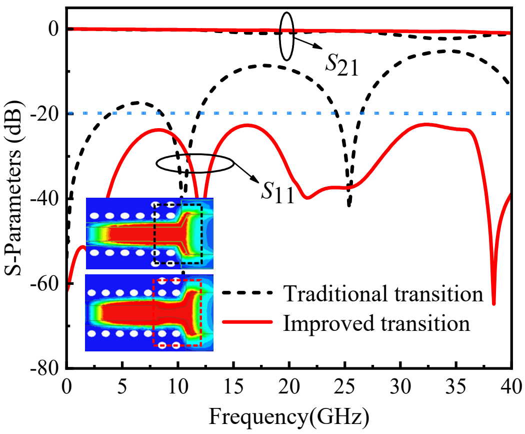

Fig. 5 Comparison of S-parameters between improved GCPW to SISL transition and traditional transition.

TABLE I
COMPARISON OF SISL TO GCPW TRANSITION

Ref.	Techn.	Self-packaged	Weight	f_c (GHz)	I.L. (dB)	R.L. (dB)
[6]	Shielded microstrip	No	Heavy	DC-40	<0.4	>15
[7]	SISL	Yes	Light	DC-8	<0.6	>15
[8]	SISL	Yes	Light	DC-18	<0.64	>19
This Work	SISL	Yes	Light	DC-40	0.35 (Average)	>20

Moreover, compared with some reported papers, as shown in Table I, the SISL to GCPW transition structure proposed in this paper has advantages of self-packaged characteristics, ultra-wideband and high performance, which is suitable for future wideband mm-wave circuit applications.

IV. CONCLUSION

In this study, an ultra-wideband transition structure of SISL to GCPW suitable for mm-wave frequency band is proposed. The proposed design has advantages of low loss, compact size and highly ease of integration with other planar circuits compared to traditional metal shell suspension circuits. Firstly, the proposed transition structure is theoretical and numerical analyzed. Simulation results show that the return loss of the transition structure achieves better than 20 dB and the average insertion loss is 0.35 dB in the range of DC to 40 GHz, which shows that the proposed transition structure has significant performance advantages and the advantages of suppressing parasitic modes. It provides a new design scheme for mm-wave self-packaged circuits with higher requirements in the future.

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