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Compact transition from CBCPW to substrate integrated suspended line (SISL) for operation up to 46 GHz

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Research Paper

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Abstract

A compact transition between conductor-backed coplanar waveguide (CBCPW) and substrate integrated suspended line (SISL) is presented. Compared to the reported transitions from CBCPW to SISL, performance and compactness are improved. For demonstration purpose, a multilayer transition is designed and fabricated for operation up to 46 GHz. Experimental results, based on an electronic calibration and thru–reflect–line calibration allowing measurement in the 0.01–50 GHz frequency range, demonstrate an insertion loss of 0.59 ± 0.51 dB with a return loss of better than 10 dB in the 10 MHz to 46 GHz frequency range.

Introduction

Emerging millimeter-wave applications require high-performance integrated components and circuits. For instance, the next generation payloads for satellite constellations [1], imaging systems [2], and automotive radars are in demand of highly integrated, low-cost, and high-performance alternative technologies to outperform existing systems.

Recently, novel integrated hollowed multilayer printed circuit board (PCB) technologies, using air as the main propagation medium, have been introduced. High-performance integrated components and circuits based on those promising technologies have been demonstrated. They achieve drastically reduced losses compared to their counterparts based on conventional PCB technologies. For instance, [3–6] reported the air-filled substrate integrated waveguide (AFSIW) technology. Al-Tarifi and Filipovic [7] presented a nearly-rectacoax hollowed transmission line technology. Li *et al.* [8] discussed the substrate integrated suspended line (SISL) technology. Those technologies are manufactured using standard PCB fabrication process including electroplating, milling, drilling, and laser cutting.

The design of high-performance millimeter-wave circuits based on those emerging technologies requires the development of novel transitions for interconnects, especially for operation at millimeter-waves. In [9], a broadband and low loss Ka-band transition between AFSIW and SISL was presented. It is based on a six-layer structure to avoid parasitic modes. In [8], a conductor-backed coplanar waveguide (CBCPW) to SISL transition operating from DC to 8 GHz was introduced. This transition consists of three sections: a tapered CBCPW, a tapered conventional stripline, and a tapered SISL segment. Instead, in this paper, a direct transition between CBCPW and SISL is presented for operation up to 46 GHz with an experimental validation in the 0.01–50 GHz frequency range.

Transition analysis and design

As described in [8] and [9], the SISL transmission line consists of five substrates of thickness h_i (Fig. 1). The top and bottom substrates (substrates 1 and 5 shown in Figs 1(a) and 1(e), respectively) are used to enclose the air cavities made within the milled inner substrates (substrates 2 and 4 shown in Figs 1(b) and 1(d), respectively). The middle substrate 3 (shown in Fig. 1(c)) sustains the strip conductor. The thinner the middle substrate is, the lower the dielectric loss becomes. Such SISL structure was studied in [9]. The mono-mode bandwidth is limited by the fc_{TE10} TE_{10} mode cut-off frequency given by:

$$f_{cTE10} = \frac{c}{2W_{channel}}\sqrt{1-\frac{h_3}{H}\left(\frac{\varepsilon_r-1}{\varepsilon_r}\right)}, \quad (1)$$

where $w_{channel}$ is the SISL channel width, H is the SISL channel total height ($H = h_2 + h_3 + h_4$), ε_r is the middle substrate dielectric relative permittivity, and c is the light velocity.

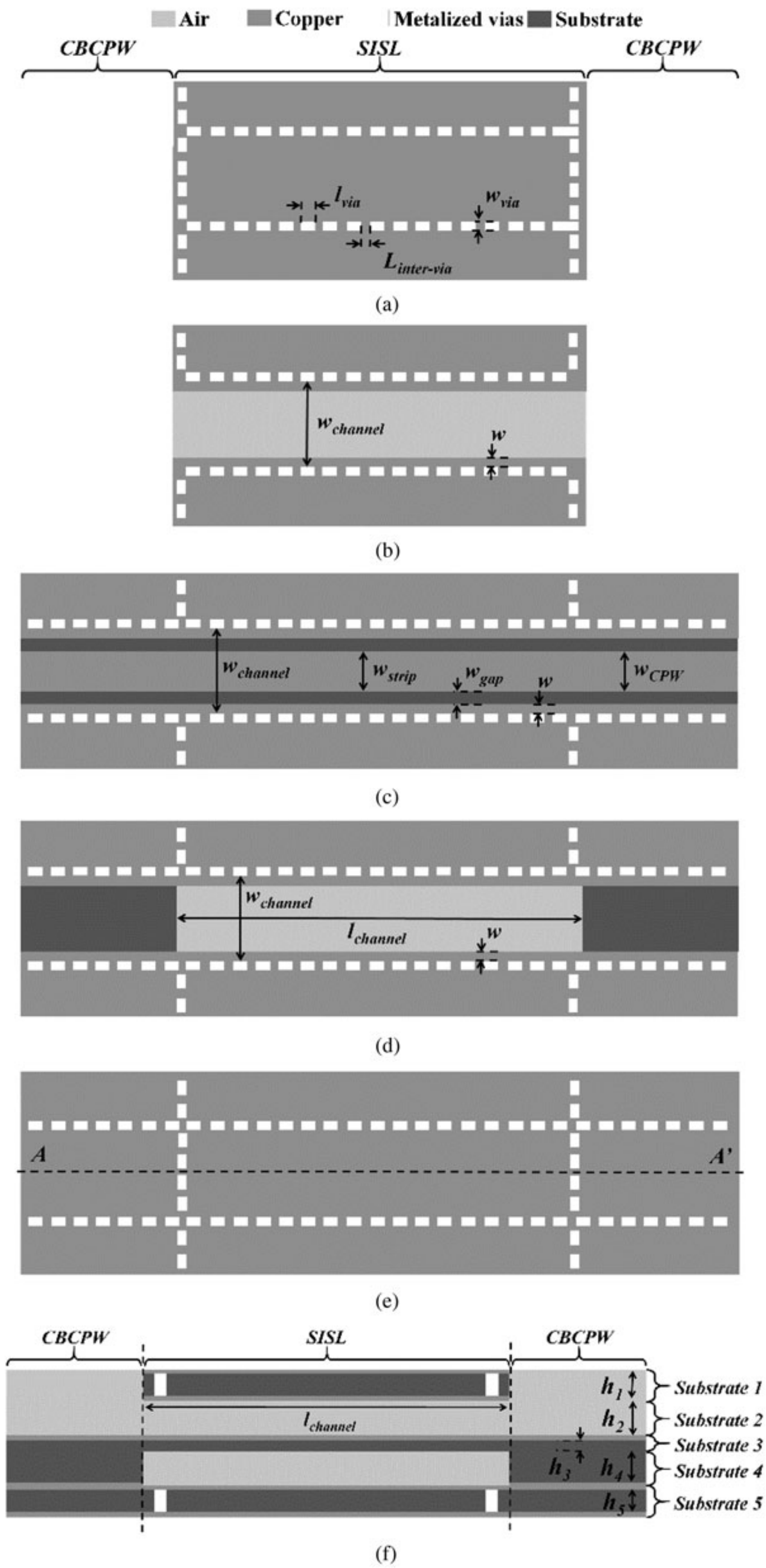

Fig. 1. Geometry of the back-to-back CBCPW to SISL transition: (a) top view of substrate 1, (b) top view of substrate 2, (c) top view of substrate 3, (d) top view of substrate 4, (e) top view of substrate 5, (f) cross-section view along the AA' cutting line.

The geometry of the proposed transition is illustrated in Fig. 1. As shown in Fig. 1, the CBCPW is designed using two layered substrates (substrates 3 and 4). This allows achieving a 50 Ω characteristic impedance CBCPW with the conductor strip width w_{strip} and gap width w_{gap} dimensions identical to a 50 Ω characteristic impedance SISL, as illustrated in Fig. 1(c). In Fig. 1(b), an opened air cavity with two dielectric slabs on side walls of total width $w_{channel}$ is realized in substrate 2. Beneath the conductor strip, another air cavity of the same width $w_{channel}$ is implemented in substrate 4 as shown in Fig. 1(d). To prevent coupling from a parallel plate mode in the top substrate (substrate 1), conductive via rows are implemented as shown in Fig. 1(a).

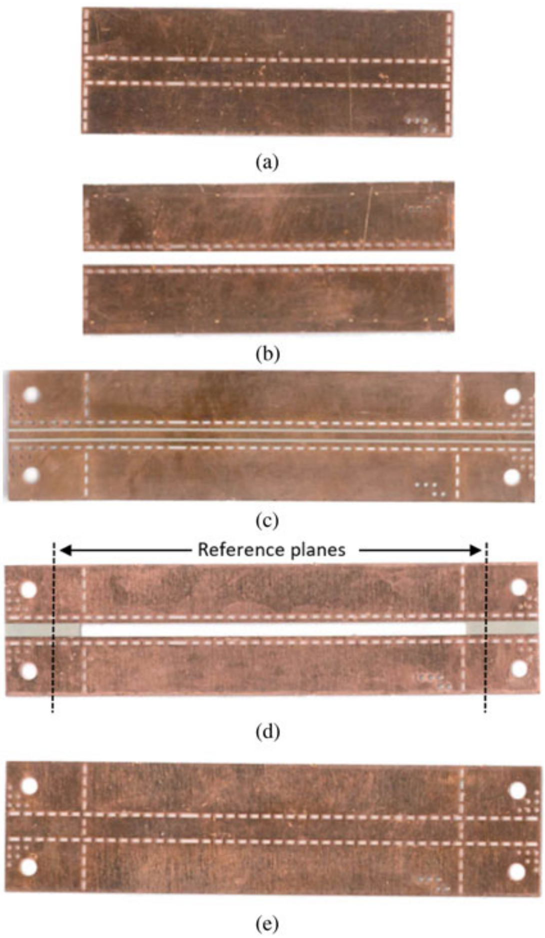

Fig. 2. Pictures of the fabricated prototype substrates before assembling: (a) substrate 1: top substrate enclosing the SISL structure, (b) substrate 2: SISL upper air cavity, (c) substrate 3: SISL and CBCPW conductor strip, (d) substrate 4: SISL lower air cavity, (e) substrate 5: bottom substrate enclosing the SISL structure.

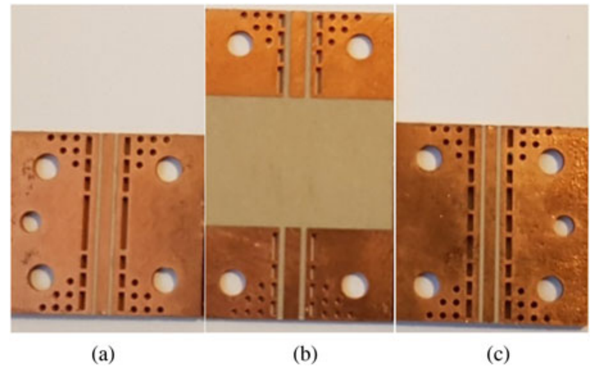

Fig. 3. Pictures of the fabricated TRL calibration kit : (a) thru, (b) reflect, and (c) line with a delay of 6.25 ps.

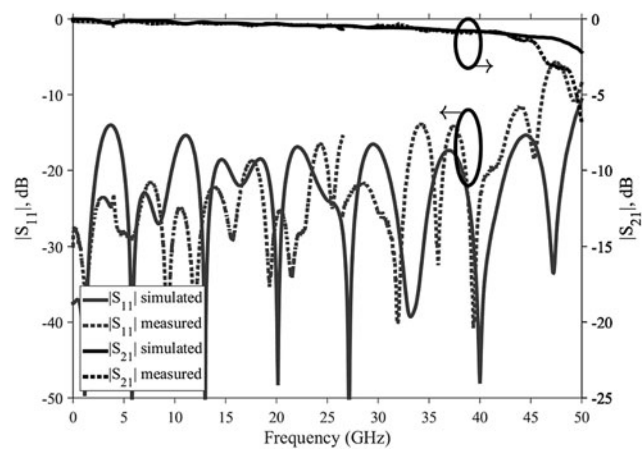

Fig. 4. Back-to-back transition *S*-parameters obtained in simulation and measurement.

Table 1. Performance comparison of the reported CBCPW to SISL transition

	Frequency range (GHz)	Length (mm)	Return loss (dB)	Insertion loss (dB)
[8]	0–8	4.278	>15	<0.6
This work	**0.01–46**	**0**	**>10**	**<1.1**

Bold is to highlight our results.

Experimental results

For demonstration purpose, a compact back-to-back transition between CBCPW and SISL has been fabricated with Rogers RT/Duroid 6002 having a relative permittivity of $\varepsilon_r = 2.98$ and a thickness of 0.254 mm for substrates 1, 2, 4, 5 and 0.128 mm for substrate 3. To obtain a fc_{TE10} above 50 GHz, an air-cavity width of $w_{channel} = 2.565$ mm is obtained using (1). To obtain a 50 Ω characteristic impedance SISL, w_{strip} is determined to be equal to 0.85 mm. After a preliminary design, the CST Microwave Studio 3D electromagnetic software has been used for simulation and fine tuning. The other prototype dimensions are $w = 0.508$ mm, $w_{gap} = 0.35$ mm, $w_{CPW} = 0.85$ mm, $l_{channel} = 26.7$ mm, $l_{via} = 1.016$ mm, $L_{inter\text{-}via} = 0.508$ mm, and $W_{via} = 0.508$ mm. Pictures of the fabricated prototype substrates are shown in Fig. 2 before assembly. The substrates 2 and 4 air cuts, shown in Figs 2(b) and 2(d), are made by a laser cutting process. For experimental validation, a 67 GHz E8391A vector network analyzer from Agilent and an SC5226 text fixture from Anritsu were used. An N7555A electronic calibration module from Keysight and a CBCPW thru–reflect–line (TRL) calibration kit, illustrated in Fig. 3, were used for calibration in the 0.01–26.5 and 26.5–50 GHz frequency range, respectively. The TRL calibration reference planes are shown in Fig. 2(d).

Simulated and measured results are compared in Fig. 4. A good agreement between simulation and measurement results is obtained.

A return loss of better than 10 dB is achieved up to 50 and 46 GHz in simulation and measurement, respectively. This difference is mainly due to fabrication uncertainties that may have resulted in a reduced TE_{10} mode cut-off frequency. From 0.01 to 46 GHz, the measured return loss is higher than 10 dB and the total insertion loss of the back-to-back transition prototype is 1.18 ± 1.02 dB. Considering the SISL transmission loss [9], it is determined that the proposed transition has 0.59 ± 0.51 dB of insertion loss in the 10 MHz to 46 GHz frequency range.

Table 1 compares the performance of the proposed multilayer transition with the CBCPW to SISL transition reported in [8]. The proposed topology allows operation up to 46 GHz while being more compact.

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Conclusion

A compact multilayer transition between CBCPW and SISL for operation up to 46 GHz has been reported with an experimental validation in the 10 MHz to 46 GHz frequency range. The proposed transition is of high interest for interconnecting within the future millimeter-wave radar and communication systems based on the high-performance hollowed multilayer SISL technology.

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