A Transition Beween Single-Layer Substrate Integrated Image Guide and Coaxial Probe

Meng Tian Mu[1], Yu Jian Cheng[2]
EHF Key Laboratory of Fundamental Science, School of Electronic Science and Engineering, University of Electronic Science and Technology of China
Chengdu, China
mmtwswswws@163.com[1], chengyujian@uestc.edu.cn[2]

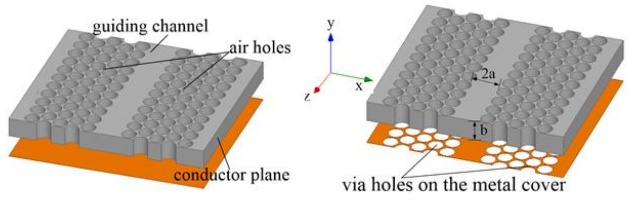
***Abstract*—The substrate integrated image guide (SIIG) is a planar transmission line with low-loss and high-Q properties. To reduce the fabrication complexity, the SIIG realized by the single-layer PCB technology is introduced. The differences between this type of SIIG and the conventional one are analyzed. A feasible method is proposed to minimize the additional leakage loss caused by the single-layer PCB process and achieve the similar performance compared with the conventional SIIG. A SIIG line working from 13.2GHz to 14.8GHz is designed utilizing this method. Then, a single-layer transition from a coaxial probe to the SIIG is presented. A 132.2 mm long single-layer PCB-based SIIG with such a transition is designed and fabricated. The measured results show that insertion loss is better than 4.25dB while the return loss is under –10dB from 13.2 GHz to 14.8 GHz.**

Keywords—PCB techonology, substrate integrated image line (SIIG), single-layer transition, co-axial probe feeding

I. Introduction

The substrate integrated image guide (SIIG) is a planar transmission line first proposed in 2005 [1]. It consists of a perforated dielectric substrate placed on a conductor plane. The periodically latticed air holes are set on both sides of the guiding channel to create effective low-permittivity zones to confine the electromagnetic wave propagating along the transmission line. As a synthesis version of dielectric image guide, SIIG not only exhibits low-loss and high-Q properties, but also is suitable for planar circuits integration [2]. These advantages enable the SIIG to be a good candidate for planar antenna feed lines.

However, the process complexity restricts the widely application of the structure. By far, traditional technologies employed to fabricate the SIIG encounters with potential air gaps between the dielectric substrate and the conductor plane [1-4] or needs complex fabrication and assembly process [5-6]. To overcome these shortages, a SIIG realized by the single-layer PCB technology is introduced in this paper. By drilling the holes directly on a single-layer metalized PCB board, the air gaps mentioned above can be effectively avoided. Meanwhile, the complexity of the fabrication can be reduced. However, the holes on the metallic cladding in the perforated region will cause leakage loss. To minimize the energy loss, a special method is employed to design this kind of SIIG and achieve a good performance.



(a) (b)

Fig. 1. (a) Configuration of the conventional SIIG. (b) Configuration of single-layer PCB-based SIIG.

The excitation of the SIIG has been investigated in several works. A transition from a rectangular waveguide to the SIIG is introduced in [1-4]. These transitions are not easily fabricated. Other planar excitation structures utilize the coplanar waveguide (CPW), which are multilayered [5-7]. As the SIIG transmission line presented here is realized in a single layer PCB board, the multilayer transition is no longer applicable. To avoid this problem, a transition from a coaxial probe to the SIIG through a substrate integrated waveguide (SIW) structure is designed.

II. Normal PCB-Based SIIG Transmission Line

The configuration of the conventional SIIG is shown in Fig. 1 (a). The configuration of the single-layer PCB-based SIIG is shown in Fig. 1 (b). The theory of the conventional SIIG transmission line has been introduced in detail in [1-2]. This section manly focuses on the unique characteristics of single-layer PCB-based SIIG.

A. Effects of Via-Holes on Metallic Cladding

Since the SIIG is relatively complex, an equivalent model is applied to simplify the analysis by replacing the perforated zones with effective permittivity regions. The effective permittivity of the substrate ε_e can be calculated as described in [1]. The electric current of the dominant mode in the perforated region on the metallic cladding of the PCB board can be described as follows:

$$\begin{aligned} |x| > a \qquad J_x &= \pm jA\omega\varepsilon_0 k_x \cos k_x a e^{\xi(a-|x|)} \\ J_z &= \pm A\omega\varepsilon_0 \beta \cos k_x a e^{\xi(a-|x|)} \end{aligned} \tag{1}$$

where ξ is the separation constant in x-direction in the perforated region. As shown in (1), there exist electrical currents on the metallic cladding in the perforated region, which decay with the distance from the guiding channel. The decay constant is ξ. The via holes on the metallic cladding will cut these currents, causing energy radiation and increasing the transmission loss.

B. Method to Reduce Leakage Loss

Because the currents on the metallic cladding in the perforated region is exponential attenuation with the increase of the distance from the guiding channel. Thus, the energy loss

can be reduced significantly if ξ is larger. According to [8], ξ can be approximated by:

$$\xi=\sqrt{(\varepsilon_r-\varepsilon_e)}k_0\sqrt{1-(\frac{\pi(\sqrt{(\varepsilon_r-\varepsilon_e)}k_0a+1)}{2a^2(\varepsilon_r-\varepsilon_e)k_0^{\,2}})^2} \tag{2}$$

This equation represents the inversely relationship between ξ and the guiding channel width $2a$. Thus, a practical way to reduce the additional attenuation causing by the via-holes is to increase the guiding channel width. For the conventional SIIG, the aspect ratio of the cross section is particularly chosen to be 2:1 ($2a$:b) to achieve a maximum single-mode bandwidth. When designing a single-layer PCB-based SIIG, a larger aspect ratio needs to be utilized. To validate the analysis, Fig. 2 shows the comparison of the attenuation constants of two SIIGs with different guiding channel widths.

C. Single-Layer PCB-Based SIIG Transmission Line Design Example

The SIIG is designed on a 2.54mm-thick Taconic RF-10 substrate. The dielectric loss tangent of the material is 0.0023 at 10 GHz. The guiding channel width is chosen to be 6 mm, wider than twice of the substrate thickness. The via holes in the perforated zones are five rows on both sides of the guiding channel, arranged in the equilateral triangular topology with a periodicity of 2 mm. The diameter of the hole is 1.8 mm.

III. SIIG Transition Design

A transition from the coaxial probe to the SIIG is proposed in this section. A SIW is employed to transform the energy from the probe to the SIIG. Thus, the whole transition can be divided into two parts, i. e. the probe to the SIW transition and

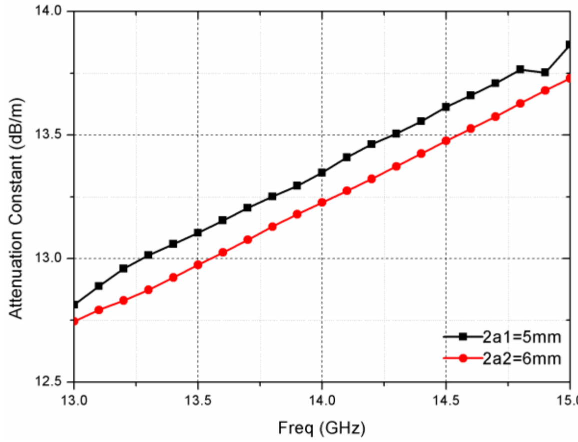


Fig. 2. Attenuation constants of two SIIG lines with different guiding channel widths

the SIW to the SIIG transition.

A. Coaxial Line to SIW Transition

The design theory of this part has been explained in [9]. A SIW cavity is designed to couple the energy from the coaxial probe. The probe is arranged on the center line of the cavity. The distance from the probe to the short circuited end is approximately a quarter wavelength, which can be optimized with HFSS. Two circular gaps with different radius are cut on the top and the bottom metallic layers of the SIW cavity, respectively. These gaps provide additional reactance for the structure. To reduce the effect of the protruding part of the probe, a metal cavity is added to cover this part.

B. SIW to SIIG Transtion

The dominant mode of the SIW is the TE_{10} mode, which owns similar electric field distribution with the dominant mode of the SIIG, E^y_{11} mode. A SIW horn combined with a triangular cut on the top metallic layer is utilized to match the impedance of SIIG [5]. The parameter optimization is conducted with Ansys HFSS. Two rows of metallized holes are arranged in the SIIG region to avoid the energy coupling into the perforated regions of the SIIG, causing additional leakage loss.

IV. Results

The SIIG transmission line with a back-to-back transition introduced above is fabricated as shown in Fig. 3 and measured. The whole configuration of this transition is shown in Fig. 4. The values of parameters are list in Table 1.

The results are demonstrated in Fig. 5. The length of the transmission line is 132.2 mm, which equals $6\lambda_0$ electrical length at 13.5 GHz. The measured insertion loss is less than 4.25 dB, meanwhile the measured return loss is under –10dB in 13.2~14.8 GHz range. The relative bandwidth is up to 11.5%. The mismatch between the simulated and measured results is mainly caused by the assembly tolerance of SMA connecters and the dielectric loss tangent tolerance. The comparison of the proposed transition and other works are demonstrated in Table II.

V. Conclusion

A single-layer PCB-based SIIG transmission line with a back-to-back transition between such a transmission line and a coaxial probe is designed in this paper. Good performance is obtained after careful design. Such a SIIG and corresponding transition present good candidates in integrated antenna and array design.

TABLE I. Design Parameters (mm)

Parameter	*Value*	*Parameter*	*Value*
l1	6.1	***w4***	7.6
l2	10	***w5***	8.6
l3	3.8	***d1***	2.6
w1	9.6	***d2***	2.2
w2	5.4	***d3***	4.2
w3	3.6		

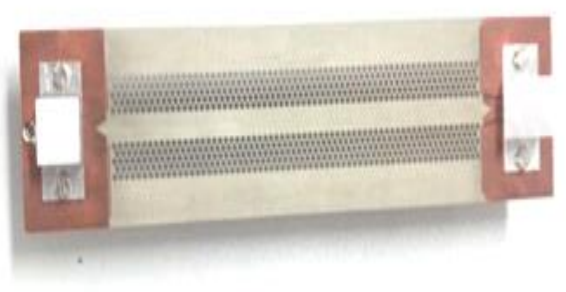


Fig. 3. Photograph of the fabricated single-layer PCB-based SIIG transmission line with a back-to-back transition.

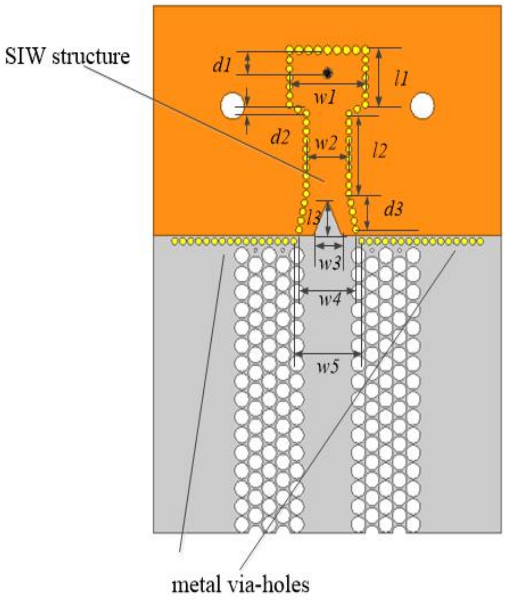


Fig. 4. Top view of the probe-SIW-SIIG transition

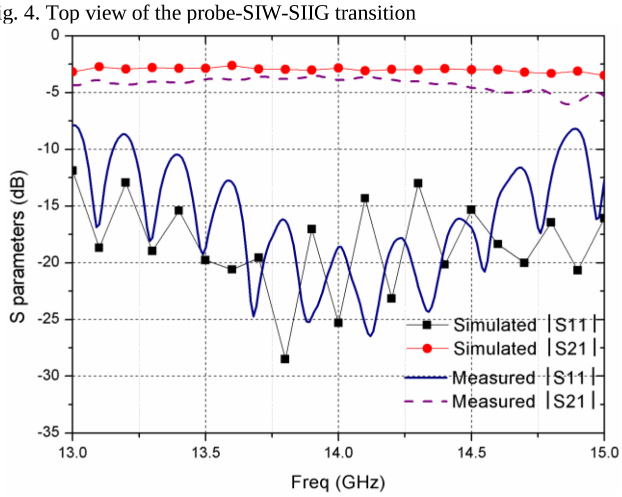


Fig. 5. Simulated and measured results for the 132.2 mm-length SIIG transmission line with a back-to-back transition.

TABLE II. COMPARISON OF DIFFERENT TRANSITION

	Port Type	*Layer*	*Length (mm)*	*Insertion Loss (dB)*	*-10dB Bandwidth*
[2]	Rectangular waveguide	2	40	2.3	26.5%
[5]	CPW	8	30	3.4	18%
[7]	CPW	2	--	2.8	16%
This work	Coaxial probe	1	132.2	4.25	11.5%

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