K-band Substrate Integrated Waveguide to Rectangular Waveguide Transition

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***Abstract*—In this paper, a K-band broadband in-line transition from a substrate integrated waveguide (SIW) to a rectangular waveguide (RWG) is proposed. The transition is realized by using a substrate taper inserted into a height-stepped impedance transformer in the RWG region. The transition is designed to cover the 18-26 GHz frequency band, showing a return loss of 20 dB. A back-to-back transition has been fabricated to verify the proposed transition. The measured results show good agreement with the simulation. The results show an insertion loss less than 0.65 dB and a return loss better than 16 dB in the designed frequency band.**

***Keywords*—K-band; substrate integrated waveguide; rectangular waveguide; transition**

I. INTRODUCTION

Solid state power amplifiers (SSPAs) using a monolithic microwave integrated circuit (MMIC) high power amplifiers (HPAs) [1-2] require a low loss and high power transmission line such as a rectangular waveguide (RWG). For this reason, the output power of each HPA is combined by using an RWG power combiner. Therefore, low loss and high power transition is required to connect between the planar circuit and the RWG. A substrate integrated waveguide (SIW) has low transmission loss and can be handling a high power due to use of the TE_{10} propagation mode such as RWG [3]. Also, the SIW is suitable for the planar circuit and easy to manufacture. For these reasons, the SIW has become a popular transmission structure in recent years. A number of papers have been published in relation with the SIW-to-RWG transition, for which there are two main geometrical configurations. One is a right angle configuration [4,5] in which the two axes are perpendicular, and another is an in-line configuration in which the main axes of both waveguides are collinear [6-9]. In the right angle configuration, there are one [4] or two [5] etched slots on the broad wall of the SIW to couple the waveguides. But this solution has narrow bandwidth and high transmission loss. In the in-line configuration, a fin-line [6] or quasi-Yagi antenna [7] is used to obtain the wide bandwidth. But these kinds of transitions are difficult to design, and the direction of a broad wall of SIW and RWG is perpendicular to each other. In [8] a radial probe is used to widen bandwidth. However, this solution has a greater transmission loss. In [9] the transition length becomes large because of the use of the multi-section stepped impedance transformer.

In this paper, we propose a novel transition structure, which is realized by using a substrate taper inserted into a height stepped transformer. It exhibits a broad bandwidth, low transmission loss, easy fabrication and good reproducibility. Also, it is suitable for hermetic packaging. Fig. 1 shows the structure of the proposed SIW-to-RWG transition. As shown in Fig. 1, the transition structure consists of an SIW, a substrate taper and a height stepped impedance transformer from an RWG to the reduced dimensions.

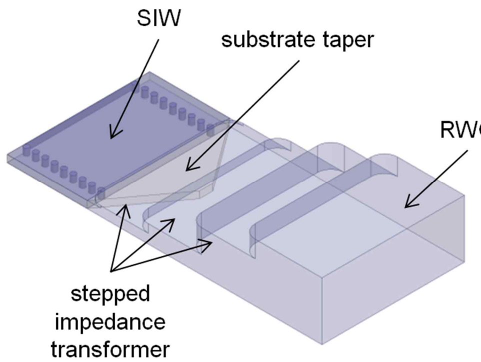

Fig. 1. SIW-to-RWG transition structure

II. TRANSITION DESIGN

Fig. 2 shows the design parameters of the proposed transition. The RT/Duroid 5880 substrate with relative dielectric constant of 2.2, loss tangent of 0.0009 at 10GHz, substrate thickness of 20mil and copper cladding thickness of 17um is used for the simulation and fabrication. The width of the SIW is simply calculated as follows:

$$w_{SIW} = \frac{1}{2f_{c10}\sqrt{\mu\varepsilon}} \quad (1)$$

Where f_{c10} is the cut-off frequency of the TE_{10} modes, and the SIW can be defined by the via holes. The substrate taper at the end of the SIW, which reduces the transmission loss, is not metallized. The three section height stepped impedance transformer, which widens the bandwidth, is between the SIW and the RWG. The simulation and the optimization are carried out using Ansys HFSS, a commercial software package. The optimized simulation results are presented in Fig. 3 and the design parameters are summarized in Table 1. The size of RWG is equal to the size of a standard WR-42 waveguide. As shown in Fig. 3, the insertion loss is less than 0.1 dB and the return loss is better than 20 dB in the entire K-band. Fig. 4 is a back-to-back model for verification of the designed transition. As shown in Fig. 4, the stepped impedance transformer is followed by the RWG. The end of the stepped impedance transformer is connected to the SIW by tightly sandwiching it. As a result, a hermetic packaging is realized between the SIW and the RWG. The length of the SIW is 12 mm and the total length of the back-to-back transition is 47.14 mm. The simulation results are shown in Fig. 5. Except the edge of pass band, the return loss is better than 20 dB.

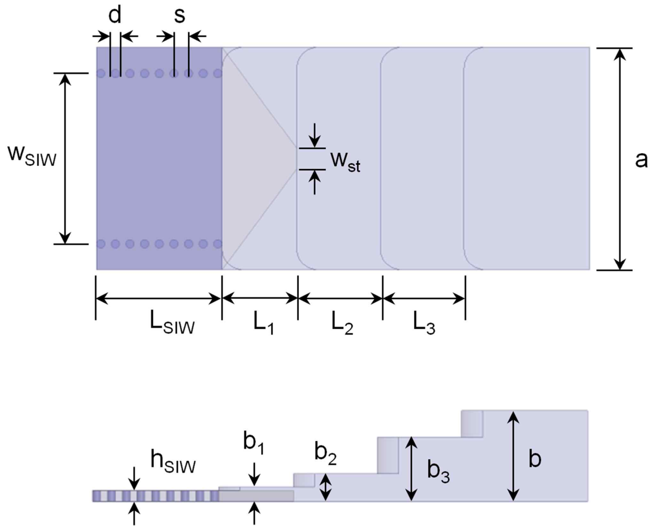

Fig. 2. Design parameters for the proposed transition: (a) top view and (b) cross section view

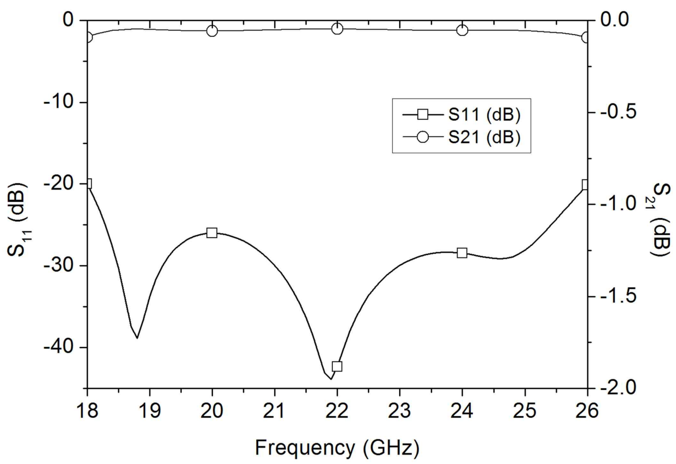

Fig. 3. Simulation result of the S-parameters for the proposed transition.

TABLE 1. Dimensions of optimized design parameters for the proposed SIW-to-RWG transition (dimensions in mm)

w_{SIW}	h_{SIW}	L_{SIW}	w_{st}	d	s	a
8.16	0.508	6.0	1.0	0.4	0.72	4.32
L_1	L_2	L_3	b_1	b_2	b_3	b
4.57	4.0	4.0	0.7	1.32	3.055	10.67

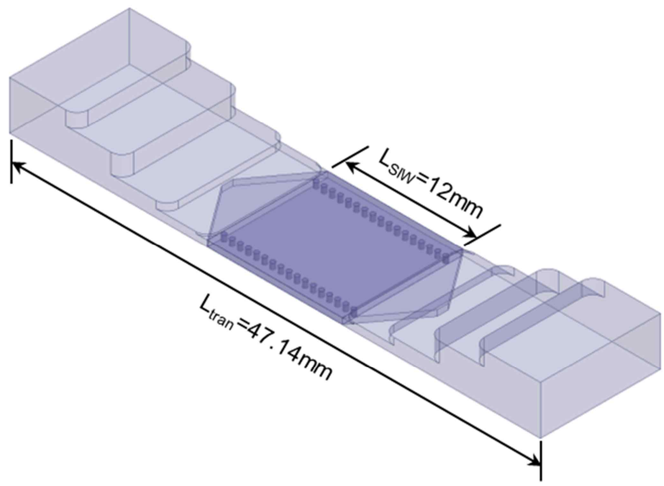

Fig. 4. Simulation model of the back-to-back SIW-to-RWG transition

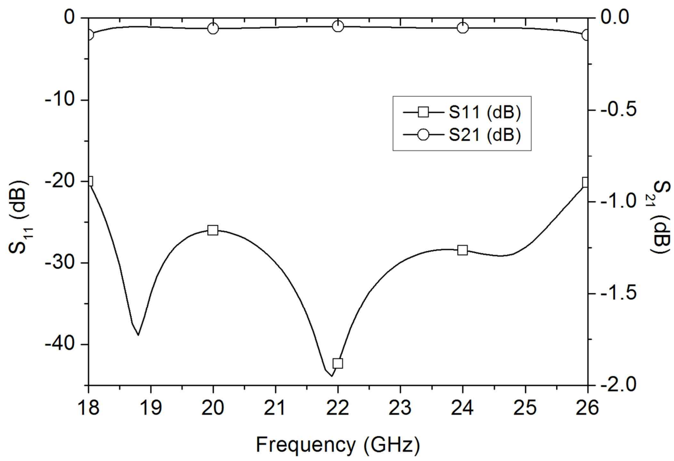

Fig. 5. Simulation result of the S-parameters for the back-to-back transition

III. EXPERIMENTAL RESULTS

A back-to-back transition was manufactured as shown in Fig. 6. The aluminum package was milled with three stepped impedance transformers, two WR-42 waveguides and a groove to align the SIW. The aluminum package is divided into two blocks and did not have any conductive plating. The corners at the stepped impedance transformers are rounded with a milling tool that has a diameter of 1mm. The SIW was made by a general PCB processor and both the upper and bottom side of the substrate tapers at the end of the SIW were etched to remove the metal layer. Fig. 7 shows the results of the measurement of the fabricated back-to-back transition. The measurements were made by an Agilent N5244A PNA-X network analyzer. As shown in Fig. 7, the insertion loss was less than 0.65dB and the return loss was better than 16dB in the designed frequency band of 18-26 GHz. Several samples of the transition were measured and all of the measured results showed good agreement with the simulation. In table 2, the values of transmission loss and frequency band width measured in this work are compared with other measurements. In comparison with the conventional transition, the proposed one has lower transmission. As such, the measured results have proved the design scheme, and we know that the proposed SIW-to-RWG transition has broad bandwidth, low transmission loss and good reproducibility.

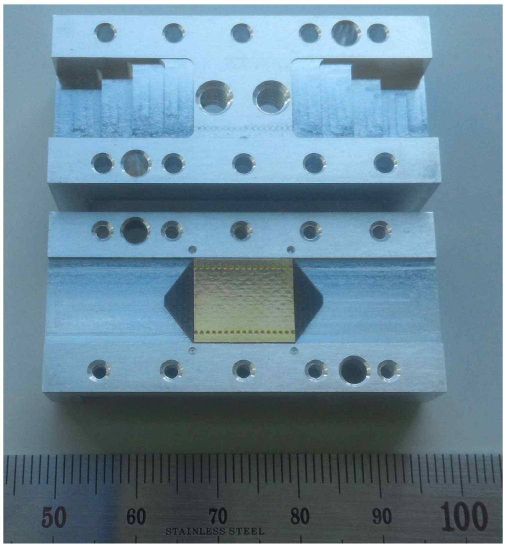

Fig. 6. Photograph of the manufactured back-to-back transition

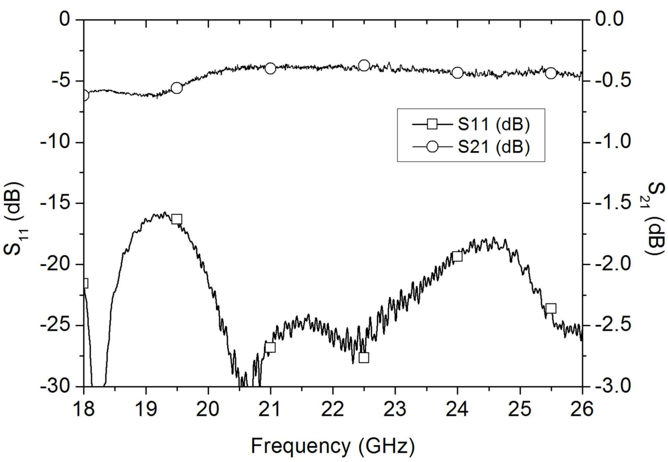

Fig. 7. Measured results of the manufactured back-to-back transition

TABLE 2. Comparison of proposed structure and conventional structures

Frequency (GHz)	Length of SIW (mm)	Transmission loss (dB max.)	Return loss (dB min.)	Ref.
18-26	12	0.65	16	This work
34.2-35.3	-	3.4	11	[4]
26	40	1.6	15	[5]
25-40	-	1.4	15	[6]
9.5-17.5	-	2.7	10	[7]
28.3-39.5	-	2.5	14	[8]
32-50	12	0.8	15	[9]

IV. Conclusions

K-band wide bandwidth, low loss SIW-to-RWG transition was designed and back-to-back transitions were fabricated to confirm the design scheme. The measured results show good agreement with the simulation results. Also, we know that there is excellent reproducibility through the several samples tests. The measured results show that the insertion loss is lower than 0.65 dB in the full K-band frequency band. Based on this result, an insertion loss lower than 0.33dB can be estimated for the stand-alone transition. This proposed transition could be used in the field of planar circuit to rectangular waveguide transitions that require low loss, wide bandwidth and hermetic packaging.

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