A Wideband Waveguide-to-Microstrip Transition via a Substrate Integrated Waveguide Transformer

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Abstract

In this paper, a novel Ka band waveguide-to-microstrip transition is proposed and designed, which transforms a waveguide port to a microstrip port via a substrate integrated waveguide (SIW) transformer. The operation frequency covers the full band of the WR-28 waveguide from 26.5 GHz to 40 GHz. The simulation results show that the insertion loss is less than 0.2 dB and the return loss is better than 17 dB. Another main feature is the novel configuration, where the SIW and the metal attachment separate the waveguide cavity and the microstrip circuits. Therefore, this transition is suitable for the hermetic sealing. The high performance and compact structure are most suitable for military and space applications.

1. Introduction

In most millimeter systems, the waveguide and microstrip are the two commonly used transmission lines. The waveguide is often used to connect the antenna and the millimeter receiver or transmitter owing to its low insertion loss. The microstrip is widely used in the receiver and transmitter to connect various active modules and passive components, such as the transistor, monolithic microwave integrated circuit (MMIC), filter and coupler, due to the small size, planar structure and easy integration. Since both the waveguide and the microstrip are used in practice, a waveguide-to-microstrip transition is often required as an important part of the millimeter receiver and transmitter to match the waveguide port with microstrip port. In most cases, the performance of the transition directly affects the system parameters, such as the noise figure of the receiver or the efficiency of the transmitter. Low insertion loss, wide operating bandwidth and low return coefficient are the main specifications of the waveguide-to-microstrip transition. In addition, for military and space applications, in order to ensure the quality and the long life of the receiver or the transmitter, the waveguide-to-microstrip transition should also play an important role to isolate the active circuit from the waveguide cavity, especially for MMICs, which should be packaged.

There are many waveguide-to-microstrip transition configurations proposed in the past, which can be classified into two categories according to the bandwidth: the wide band transition and the narrow band transition. [1and 2] are examples of wide bandwidth transitions where different kinds of probes as the transformer are inserted into the waveguide from either a sidewall or the end wall. They all have good performance, but the microstrip is located inside the cavity of the waveguide, thus they are not suitable for hermetic sealing. A slot-line antenna was used in broadband transition in [3], but it was not a sealing structure. For narrow-band waveguide-to-microstrip transitions, hermetic sealing configurations were reported in [4 and 5] and ceramic as the special microstrip substrate was selected for this purpose, but the bandwidths were all less than 16%.

The challenge of the transition design is not only to meet the technical specifications (wide bandwidth, low insertion loss and return loss), but also to allow for the packaging procedures and the respective manufacturing tolerances.

2. Configuration of the Transition

Figure 1 shows the proposed configuration of the waveguide-to-microstrip transition. According to the discontinuous structure, the proposed transition can be divided into three parts to design, which are microstrip to SIW transformer, SIW to non-standard waveguide transformer and non-standard waveguide to WR-28 waveguide transformer.

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Al2O3 ceramic with relative permittivity of 9.9, loss tangent of 0.0006 and thickness 0.38 mm is used as the substrate for the microstrip and SIW, owing to the thermal expansion coefficient close to the hermetic sealing metal-invar.

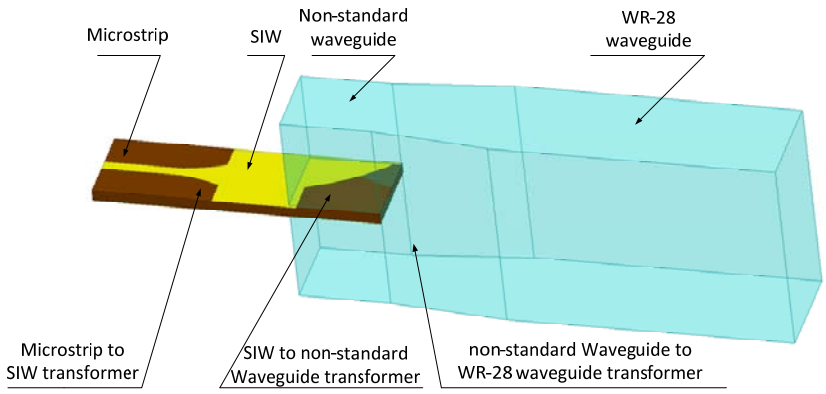


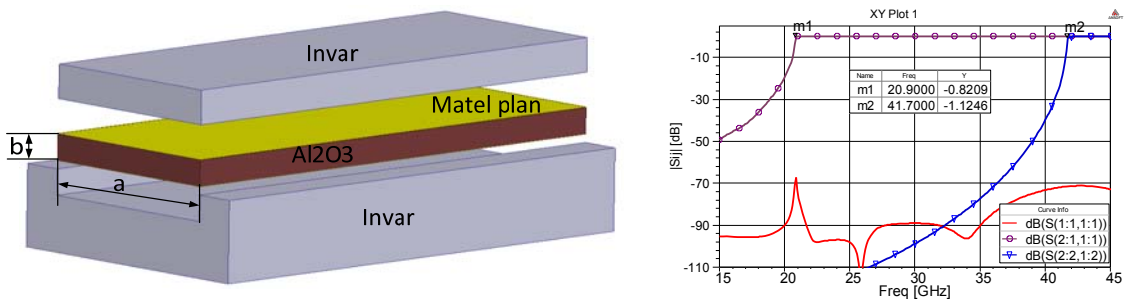
Figure 1. Configuration of the waveguide-to- microstrip transition.

2.1 Microstrip to SIW

Figure 2(a) shows the structure of the SIW. The double metal planes of substrate are welded with invar shell by $Au_{80}Sn_{20}$ solder to realize the SIW structure. In the microstrip to SIW transformer, the quasi-TEM mode of the microstrip is transformed into the TE_{10}-like mode of the SIW. The SIW is used to transmit the TE_{10} mode and to restrain the high modes, and whose sizes can be calculated using the cutoff frequency of its equivalent waveguide. The TE_{mn} mode cutoff frequency of the SIW is given as,

$$f_{mn}^{c} = \frac{1}{2\pi\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m\pi}{a}\right)^{2}+\left(\frac{n\pi}{b}\right)^{2}} \tag{1}$$

Where a and b are the broad and the narrow edge widths of the SIW. Obviously, the basic mode of SIW is TE_{10} mode, and the first high model is TE_{20} mode, because size b is far less than a. In order to reduce the influence of manufacturing errors, the size a is selected as large as possible and in this design, it is 2.3 mm while b is 0.38 mm. Using equation (1), the cutoff frequency of TE_{10} mode is found to be about 21.73 GHz and the cut-off frequency for TE_{20} mode is about 41.45 GHz. The structure is also simulated using HFSS software and the results are shown in Figure 2(b), which are in good agreement with the calculated results.

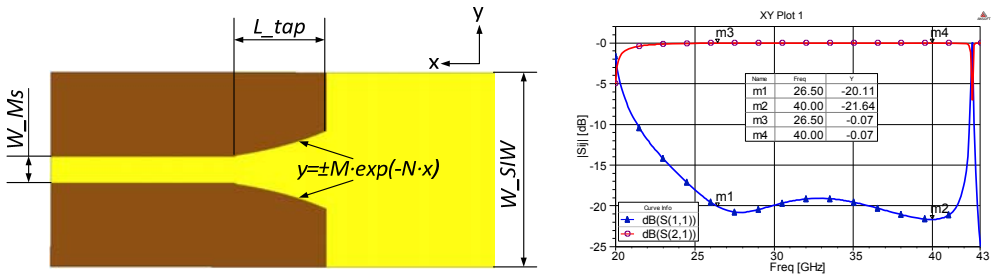


(a) (b)

Figure 2. (a) Configuration of the SIW, (b) Cutoff frequencies of TE_{10} mode and TE_{20} mode in the SIW

A tapered line is used to match the microstrip with the SIW over a wide bandwidth as shown in Figure 3(a). The optimized variables are tapered line length *L_tap* and the parameters *M*, *N*, of the exponentially tapered profile which is defined by the function $y = \pm M\cdot\exp(-N\cdot x)$. The optimization has been undertaken and resulted in the optimized values for *L_tap* = 1.36 mm, *M* = 0.65 and *N* = 1.01.

The insertion loss and return loss were obtained using HFSS software and depicted in Figure 3(b). The matching is better than -20 dB (reflection coefficient) over the band from 26.5 GHz to 40 GHz, and the insertion loss is less than 0.1 dB.



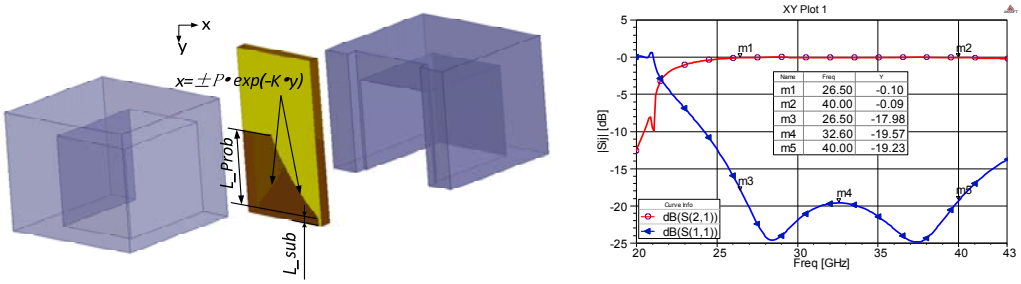
(a) (b)

Figure 3. (a) Configuration of the microstrip to SIW transformer, (b) S21 and S11 parameters

2.2 SIW to Non-standard Waveguide

In order to achieve wideband performance, a non-standard waveguide was used to match SIW. Figure 4(a) gives the configuration of a SIW to non-standard waveguide transformer, the radiation probe is also designed to an exponentially tapered profile, which is defined by the function $y = \pm P\cdot\exp(-K\cdot x)$. After optimized, the tapered line length *L_prob* is found to be 3 mm, the parameter *K* 0.35, and *P* 1.68. At the tip of the probe, the substrate is extended for matching the SIW with the waveguide to minimize the reflection over the frequency band, the optimized length of the substrate *L_sub* is 0.33 mm.

Figure 4(b) shows the simulation results. The insertion loss is less than 0.2 dB and the reflection coefficient is less than -17 dB over the frequency band from 26.5 GHz to 40 GHz.

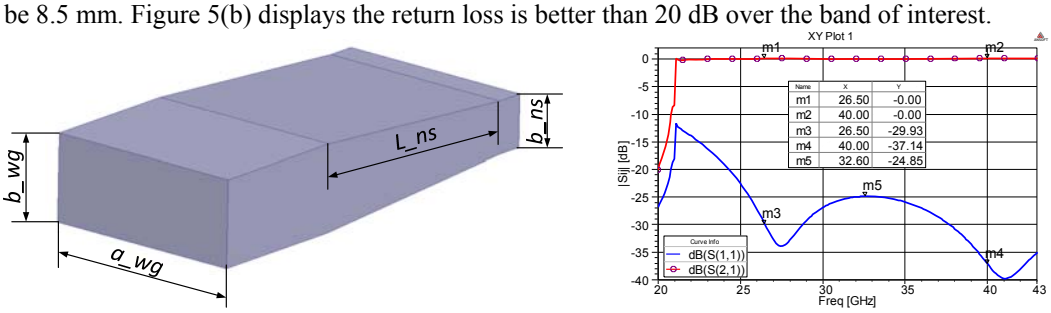


(a) (b)

Figure 4. (a) Configuration of the SIW to non-standard waveguide, (b) S21 and S11 parameters

2.3 Non-standard Waveguide to WR-28 Waveguide

This part is the last section of the transformer which is used to connect non-standard waveguide and WR-28 waveguide with a low reflection coefficient over the full band of WR-28. Figure 5(a) shows the structure of the non-standard waveguide to WR-28 waveguide transformer. The edge length *a_wg* and *b_wg* of WR-28 are 7.112 mm and 3.556 mm, respectively. The broad edge length of non-standard waveguide is same as WR-28, but the narrow edge length *b_ns* different from WR-28 is 1.81mm. After optimized using HFSS software, the length of the transformer *L_ns* is found to be 8.5 mm. Figure 5(b) displays the return loss is better than 20 dB over the band of interest.



(a) (b)

Figure 5. (a) Configuration of the non-standard waveguide to WR-28 transformer, (b) S21 and S11 parameters

3. Simulation Results

After the three parts of the transition were simulated respectively, the whole transition was assembled and simulated using the HFSS software. The final structure needs slight tuning to accommodate the higher order mode effect. The initial and the final values of the transition are given in Table I.

Table I. Values of the transition

Variables	Initial	Final	Variables	Initial	Final	Variables	Initial	Final	Variables	Initial	Final
W_Ms	0.49	0.49	*M*	0.65	0.58	*L_sub*	0.33	0.33	*a_wg*	7.112	7.112
W_SIW	2.3	2.3	*N*	1.01	0.99	*P*	1.68	1.34	*b_wg*	3.556	3.556
L_tap	1.36	2.01	*L_prob*	3.00	2.77	*K*	0.35	0.32	*b_ns*	1.81	1.81
L_ns	8.5	9.56									

Note: *M, N, P* and *K* are constants; others are dimensions with unit mm.

Figure 6 shows the optimized S-parameters of the transition which cover the full bandwidth of WR-28 waveguide from 26.5 GHz to 40 GHz. The maximum reflection coefficient is lower than -17 dB and the insertion loss less than 0.2 dB.

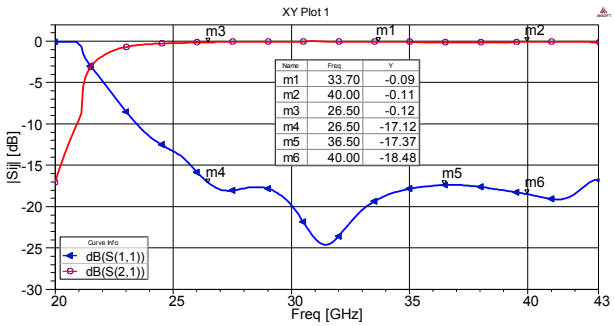


Figure 6. Simulation results of the proposed waveguide-to-microstrip transition

4. Conclusion

In this paper, a waveguide-to-microstrip transition has been studied in details. The SIW was first used as a broadband transformer to connect microstrip with waveguide. The cavity to install active circuits and MMICs is fully isolated from waveguide cavity, and thus this hermetic sealing configuration is better for special applications in such as military or space. The exponentially tapered probe and taper line are used to match microstrip, SIW and waveguide over a wide bandwidth. After simulated and optimized with industrial standard software, it has demonstrated that the proposed transition covers the full bandwidth of WR-28 with good performance.

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