Substrate Integrated Waveguide (SIW) to Microstrip Transition at X-Band

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***Abstract*— Substrate integrated waveguide (SIW) is a new form of transmission line. It facilitates the realization of non-planar (waveguide based) circuits into planar form for easy integration with other planar (microstrip) circuits and systems. This paper describes the design of an SIW to microstrip transition. The transition is broadband covering the frequency range of 8 – 12GHz. The measured in-band insertion loss is below 0.6dB while the return loss is less than 10dB. The circuit is simulated in HFSS and results are measured on vector network analyzer (VNA).**

***Keywords*— Microstrip; Substrate Integrated Waveguide; Transition**

I. INTRODUCTION

Substrate Integrated Waveguide (SIW) technology has provided a new approach in the design of microwave and millimeter-wave systems. It is replacing the traditional hybrid systems which are combination of both waveguides and stripline circuits. Using SIW, rectangular waveguide based non-planar circuits can be synthesized into planar form with a dielectric substrate having two parallel arrays of via-holes analogous to waveguide metallic side walls. The whole systems, combination of passive components (filters, couplers, diplexers, mixers etc), active elements (amplifiers, oscillators etc) and antennas can be made on same substrate. Two such systems, 24GHz radar and 60GHz active radio front-end are reported in [1]. The SIW based systems have several advantages: 1) Cost effective, 2) Easy to fabricate, 3) No bulky transitions between elements, thus reducing losses and parasitics, 4) Provide inherent shielding from outer environment, and 5) Considerably reduce packaging, EMC/EMI, interconnect and assembly problems that are of major concern in current microwave and millimeter equipment and systems.

In HMICs (hybrid microwave integrated circuits), the transition is an important bridge between non-planar and planar circuits. This transition is often very costly, bulky in size and often requires run-time tuning which is a cumbersome task. The synthesis of a non-planar waveguide in substrate permits the realization of efficient wideband transitions between the synthesized non-planar waveguide and planar circuits such as microstrip and coplanar waveguide (CPW) integrated circuits. With these transitions, the complexity and cost of interconnection between non-planar high-Q circuits and planar circuits are reduced to a minimum [2].

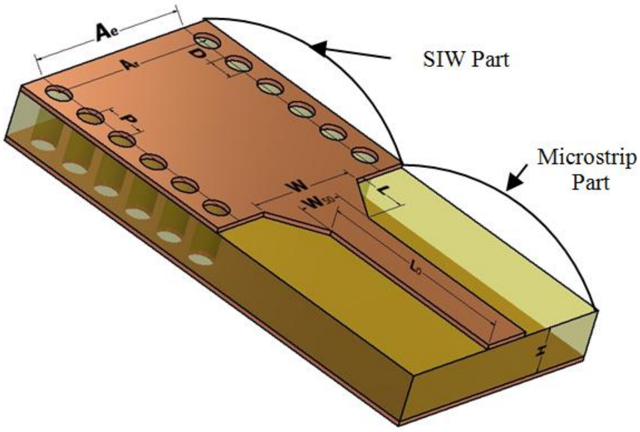

Fig. 1. SIW to Microstrip Transition Design Scheme

This paper presents the design of an SIW to microstrip transition. The desired band of frequencies is X-band. The taper line is utilized as impedance transformation between SIW and 50 ohm microstrip line. The effect of taper line length is observed on circuit performance. Rogers's 4350B substrate having relative permittivity of 3.48, loss tangent 0.0037 and 0.762 mm height is preferred because of its rigidity [8].

The remaining paper is organized as follows. The theoretical design of transition is discussed in section II. In section III modeling and simulation of transition is described while circuit fabrication and results are discussed in section IV. The work is finally concluded in section V.

II. DESIGN DESCRIPTION

The SIW to Microstrip transition consists of two parts; one is SIW part and the other is microstrip part as shown in Fig 1. The design of each part involves specific equations and design criteria which is briefly discussed in the subsequent paragraphs.

A. *SIW Design*

The substrate integrated waveguide (SIW) is sort of a guided transmission line just like a dielectric filled rectangular waveguide. Its dominant mode cut-off frequency is same as TE_{10} mode of rectangular waveguide. The only difference is that the metallic walls are replaced by two parallel arrays of conductive via holes. The key parameters of SIW design are spacing between the vias "P" also called pitch, diameter of

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vias “D”, central distance between via arrays “A_r” also called integrated waveguide width, and the equivalent SIW width “A_e”.

The SIW parameters should be designed carefully. The pitch “P” and diameter “D” control the radiation loss and return loss, while the integrated waveguide width “A_r” determine the cut-off frequency and propagation constant of the fundamental mode [3]. There are two design rules related to the pitch and via diameter as given by [4]:

$$D < \lambda_g / 5 \tag{1}$$

$$P \leq 2D \tag{2}$$

Where λ_g is the guide wavelength in the SIW.

The cut-off frequency of an SIW can be determined by [5]:

$$f_c = \frac{c}{2\sqrt{\varepsilon_r}}\left(A_r - \frac{D^2}{0.95P}\right)^{-1} \tag{3}$$

Where c is the speed of light in vacuum and ε_r is the relative permittivity of dielectric material.

The equivalent SIW width “Ae” is the width of rectangular waveguide whose modes exhibit the same propagation characteristics of the SIW modes [5]. It can be found by:

$$A_e = \frac{a}{\sqrt{\varepsilon_r}} \tag{4}$$

Where “a” is the broadside dimension of an air filled rectangular waveguide as shown in Fig.2.

Using (4), integrated waveguide width can be found by [6]

$$A_r = A_e + \frac{D^2}{0.95P} \tag{5}$$

After discussing the design details, next we move onto the design of an X-band SIW. The WR-90 is the standard X-band rectangular waveguide with dimensions:

a= 22.86 mm and b= 10.16mm.

From this using (4), the equivalent SIW width comes out to be 12.25mm on Roger’s 4350B substrate. The via diameter is chosen to be 0.61mm and pitch chosen as 1.5*D= 0.91mm following rules (1) & (2).

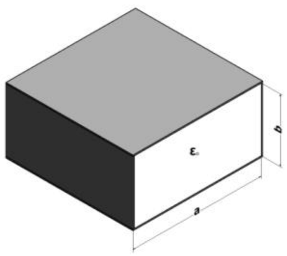

Fig. 2. Standard Rectangular Waveguide

B. Microstrip Part Design

The microstrip portion consists of series combination of quarter-wave tapered transformer and a 50 ohm track as shown in Fig 1. The transformer transforms the SIW impedance to the standard 50 ohm microstrip impedance. The 50 ohm track is added for interconnection of the I/O connectors. The key design parameters in this part are the length of tapered line “L” and width “W” of the taper at SIW end.

The width “W” of taper line can found by solving (6) [7]:

$$\frac{120\pi}{\eta H\left[\frac{W}{H}+1.393+0.667\ln\left(\frac{W}{H}+1.444\right)\right]} = \frac{4.38}{A_e} e^{-0.627\frac{\varepsilon_r}{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2\sqrt{1+\frac{12H}{W}}}}} \tag{6}$$

Where η is the free space intrinsic impedance having value 377 ohm.

The equation (6) is a complex equation and cannot be solved analytically. However, it can be solved numerically with the aid of some software e.g. Mathematica.

The taper length “L” is given by

$$L = \frac{n\lambda_g}{4}, n = 1, 2, 3, 4...... \tag{7}$$

and

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_r}} \tag{8}$$

Where f is the design frequency.

Using (6), the width of taper comes out be 3.51mm for 0.762mm height of the substrate while using (7) & (8), taper length is found to be 4.1mm for n=1 at 9.8GHz. The taper length is related to the return loss of the structure which will be discussed in the next section.

III. Modeling and Simulation

Due to un-availability of SIW probes currently, its not possible to test the SIW to microstrip transition. However, if two transitions are joined back to back then the structure can be tested with existing standard instruments. Due to symmetry, the total insertion loss can simply be halved to get insertion loss for one transition. Therefore, based on the calculations in the previous section, a back-back transitions structure is modeled in HFSS software as shown in Fig 3.

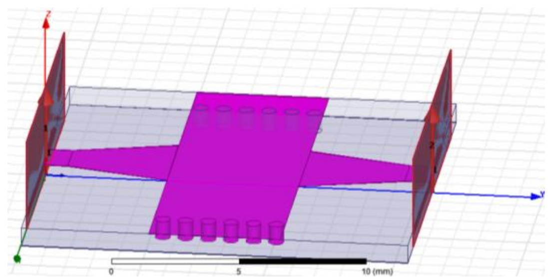

Fig. 3. Back to Back Transitions Simulation Model

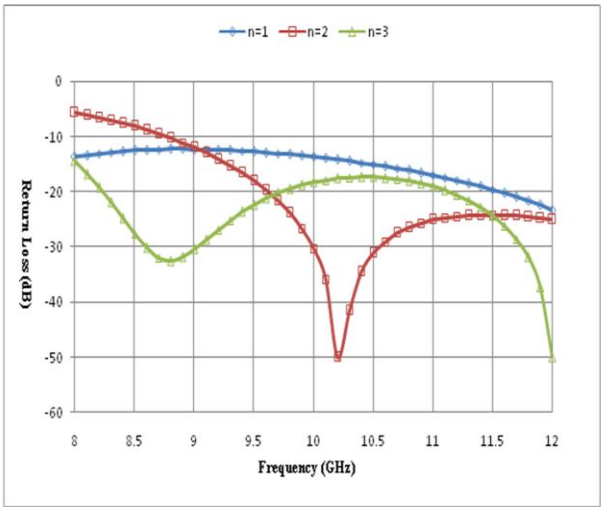

Fig. 4. Return Loss as a function of Taper Length

It is notable that the length of the taper line controls the return loss of the structure. It is already mentioned that the taper length is integer multiple of guided quarter wavelength λ_g. Fig. 4 analyzes the effect of taper length on return loss. It is seen that the return loss improves as the length is 2*quarter wavelength or 3* quarter wavelength. However, the band response becomes narrower for higher integer values, so an optimized value is to be selected according to the requirements.

IV. Fabrication and Results

Fig. 5 shows the picture of the fabricated back-back transitions structure. SMA connectors are used for the input and output ports. The vias are filled using Plated Through Hole (PTH) technique.

The circuit is tested using Vector Network Analyzer (VNA). The measured results are compared with the simulation results as shown in Fig. 6. Overall the measured results are acceptable. The simulated insertion loss for SIW-to- Microstrip transition is below 0.2dB while the measured value is below 0.6dB in the whole X-band i.e. 8 – 12GHz. The measured value of return loss is below 10dB as in simulation, although the two curves do not follow each other exactly.

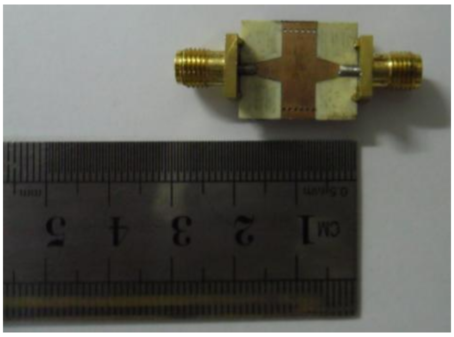

Fig. 5. Fabricated Circuit

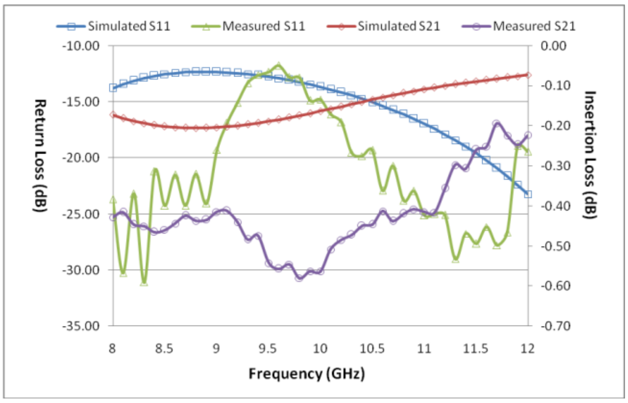

Fig. 6. Comparison of Simulated and Measured S_{11} and S_{21}

The discrepancy in the simulated and measured results can be attributed to the improper filling of via holes, deviation of dielectric loss tangent of the substrate, and, losses from SMA connectors and soldering (not considered in simulation).

V. Conclusions

This paper describes the design of an SIW-to-Microstrip transition at X-band. The tapered microstrip transmission line is utilized for matching purposes. The key design parameters are discussed along with the governing mathematical equations. The measured insertion loss of transition is below 0.6dB and return loss is below 10dB in the whole band. This transition is useful for X-band substrate integrated circuits and systems and also working band can be extended to millimeter wave frequencies as well.

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