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Analysis and Design of Compact Bandpass Filter using SIW and CSRR

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***Abstract*— Recently, substrate integrated waveguide (SIW) based devices have attracted the attention of many researches due to low loss, low cost, lightweight, small size. The Substrate Integrated waveguide technology takes the advantages of both waveguides and planar transmission lines. The substrate integrated waveguides are fabricated in planar form using a standard printed circuit board or other planar processing techniques. In this paper SIW is analyzed using commercially available low cost FR4 material with thickness h=0.8mm to operate at 8GHz. The simulation results show that there is a good agreement between the response of SIW and conventional metallic waveguide. This paper also gives the analysis of bandpass filter using SIW and complimentary split ring resonators to operate at 6GHz. The simulated results show bandpass around 6GHz with very low insertion loss.**

Keywords*— Substrate Integrated Waveguide (SIW), Microstrip Transition, Reflection Parameter, Rectangular waveguide, microwave components, via.

I. INTRODUCTION

Classical metallic waveguide can be used to design high Q and low loss components but difficult to integrate with planar circuits. Several studies of integration of microstrip line and rectangular waveguide have been reported in [1]–[4]. Typical integration schemes for rectangular waveguide with planar structure are bulky and usually require a precision machining process, which is difficult to achieve at millimeter-wave frequencies. Conventional metallic rectangular waveguide and related components have been widely used in microwave and millimeter wave systems due to its merits of low insertion loss and high power handling capacity. However, it is nonplanar, which makes it difficult for integration with planar circuits. In order to combine the advantages of rectangular waveguide and microstrip circuits, substrate integrated waveguide (SIW) technologies that can be synthesized within printed circuit boards, were recently proposed [5]–[9]. Using standard planar fabrication techniques, the waveguide is integrated into the substrate using the rows of metal vias as electric walls. SIWs combine the benefits of rectangular waveguides, such as good power handling and high quality factor, with the low cost and low profile. In most of the previous studies thickness of the substrate is equal to or less than 0.5mm. A lot of microwave components have been developed based on the SIW technique because of easy schemes for integration with other planar circuits [13]. Substrate integrated waveguide loaded by complementary split-ring resonators and its applications to miniaturized waveguide filters are proposed in [13]. Combination of SIW and complementary split-ring resonators (CSRRs) have been attracted interest of microwave engineers to develop various structures [13]-[15].

In this study commercially available low cost FR4 material is used for the analysis of SIW. It is designed to operate at different cut off frequencies 8GHz. This paper also gives the analysis of bandpass filter using SIW to operate at 6GHz.

II. GEOMETRY OF THE SIW AND DESIGN EQUATIONS

The geometrical parameters of a substrate integrated waveguide are shown in Fig.1.SIWs are integrated waveguide like structures fabricated on a dielectric material with top and bottoms are conductors, whose lateral walls are formed through rows of vias sufficiently close to each other. The SIW has a width (center-to-center distance between the rows of vias) as, each via has a diameter d and is separated from its neighboring via by a center-to-center spacing p. The SIW is embedded in a dielectric layer with thickness h and loss tangent tanδ. The behavior of a SIW is similar to that one of a conventional rectangular waveguide (RWG) [10].

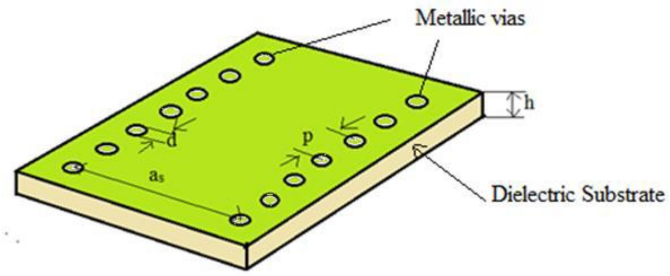

Fig. 1. Geometry of the SIW structure.

Let a and b denote the width and height of the conventional RWG, respectively, Fig.2. Assuming a the propagating mode with the lowest cutoff frequency is the TE10 (dominant mode), calculate the width a using [11]

$$a = \frac{c}{2 f_{c10}\sqrt{\varepsilon_r}} \qquad (1)$$

Where, $fc10$ is the cutoff frequency of the TE10 mode, and c is the speed of light in free space. The cutoff frequencies of each propagating mode on the waveguide are given by [11]

$$f_{cmn} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \qquad (2)$$

Where, m and n are the mode indexes.

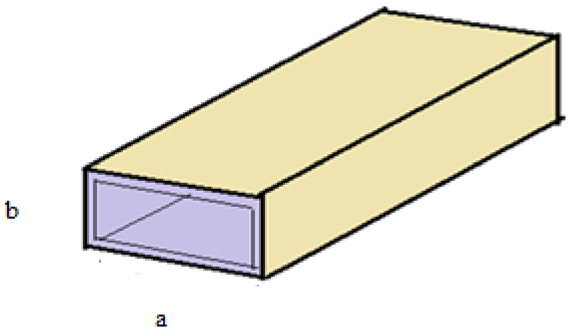

Fig. 2. Geometry of the conventional waveguide.

Where c is the speed of light in free space, m and n are mode numbers, a is the longer dimension and b is the shorter dimension of the waveguide. It is desired to work at the dominant TE10 mode, is simplified to [12]

$$f_{c10} = \frac{c}{2a} \qquad (3)$$

The $fc10$, for a dielectric filled waveguide can be obtained when a is replaced by [12]

$$a_d = \frac{a}{\sqrt{\varepsilon_r}} \qquad (4)$$

where εr is the relative dielectric constant of the dielectric that fills the waveguide. The first empirical design equation of a SIW is related to its width as, and is given by [12]

$$a_s = a_d + \frac{d^2}{0.95p} \qquad (5)$$

Where 'as' is the separation between the vias in transverse direction, ad is the width of the dielectric filled waveguide, d is the diameter of the vias, and p is the centre to centre separation between the vias along the longitudinal direction as shown in Fig. 1. If the separation p between vias is too large, radiation losses occur due to EM field leakage in the SIW. The via diameter d may affect the return loss of the SIW transition. The upper bounds for p and d are p≤ 2d and d≤ λg/5, where λg is the guided wavelength, which for the dominant mode is given by [12]

$$\lambda_g = \frac{2\pi}{\sqrt{\left(\frac{\varepsilon_r (2\pi f)^2}{c^2}\right) - \left(\frac{\pi}{a}\right)^2}} \qquad (6)$$

III. ANALYSIS OF SIW

Apply the equations given in previous section to design a single-layer SIW with tapered microstrip transition feed is as shown in Fig. 3. The SIW is implemented on a commercially available low cost FR4 substrate with □r=4.3 and tan δ=0.02 and the substrate height is 0.8mm. The desired cutoff frequency for the dominant mode is fc= 8GHz.

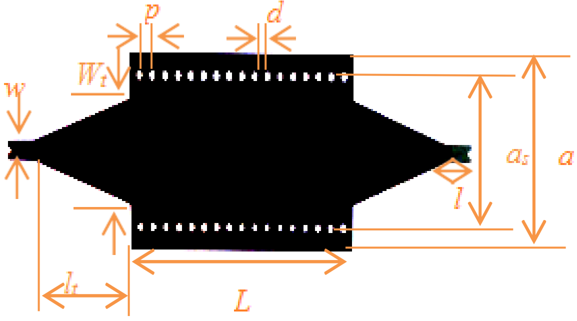

Fig. 3. Geometry of the SIW with feed and physical parameters.

Using design equations given in previous section SIW is designed to operate at cut off frequencies 8GHz, 16GHz and 32GHz. Geometrical parameters for three cutoff frequencies are given in TABLE 1. The SIW (including the microstrip transitions and ground plane) uses copper with a conductivity 5.8 x107Sim.

TABLE I. GEOMETRICAL PARAMETERS OF SIW FOR DIFFERENT CUTOFF FREQUENCIES

Parameter (mm)	f_c=8GHz	f_c=16GHz	f_c=32GHz
a	18.75mm	9.375mm	4.6875mm
a_d	8.938mm	4.521mm	2.2605
a_s	14.4mm	5.04mm	2.634mm
h	0.8mm	0.8mm	0.8mm
d	1mm	0.8mm	0.8mm
p	2mm	1.8mm	1.8mm
L	35mm	25 mm	15 mm
l_t	14.5mm	17.5mm	5.5mm
W_t	5mm	3.2mm	1.9mm
Feedline	1mm	0.8mm	0.6mm
Feedlinelength(l)	4mm	5mm	4mm

This structure is analyzed using full wave simulation tool IE3D. Fig. 4 shows the Transmission (S21) and reflection coefficient (S11) of the SIW structure using the dimensions given in TABLE 1 for 8GHz.Fig. (5) and Fig (6) shows the reflection and transmission coefficients of 16GHz and 32GHz respectively. It is observed from the plots that no transmission is observed below cutoff frequency.

Transmission is constant above cutoff frequency and is similar to the conventional waveguide. So SIW structures can be used as planar version of conventional waveguides. The transmission loss in the results may be due to substrate losses (tanδ=0.025) and small mismatch losses.

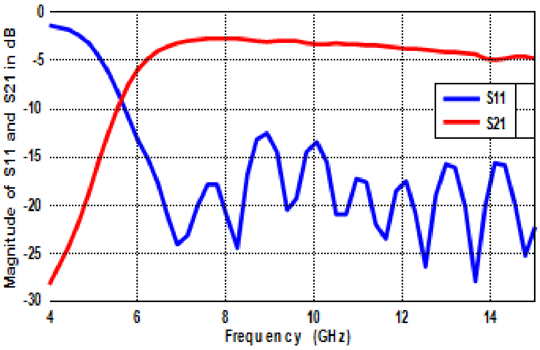

Fig. 4. Transmission(S_{21}) and reflection coefficient (S_{11}) for 8 GHz SIW structure.

IV. SIW BANDPASS FILTER

Fig. 5 shows the CSRR and its geometrical parameters. The geometry of the CSRR on the SIW is shown In Fig. 6,. The conventional CSRR SIW filter is implemented by patterning only a single side while the other side is remained as a solid ground. The transfer characteristics of the SIW filter employing the CSRRs have bandpass properties at the resonance frequency. The resonance frequency can be adjusted by changing the dimensions of the CSRRs. The waveguide structure is synthesized by the incorporation of arrays of metallic via holes through the substrate with the patterned top and bottom plates. The propagation constant and the waveguide cutoff frequency are function of the width of w.

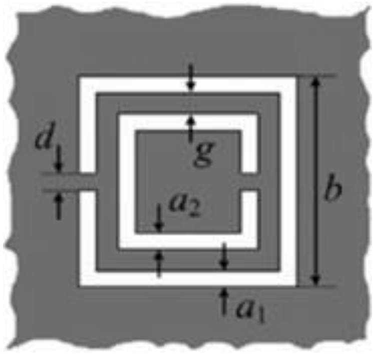

Fig. 5. CSRR structure and its geometrical parameters

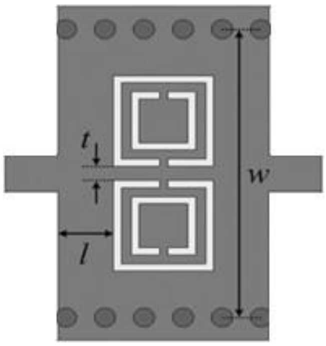

Fig. 6. Geometry of SIW bandpass filter using CSRR

The Geometrical parameters for the unit cells are a1 = 0.32mm, a2= 0.32mm, d = 0.18mm, g = 0.26mm, b = 3.92mm, s = 1.53mm, t= 0.54mm, l = 2.04mm, and w = 12.3mm. In the third case, part of the parameters are revised as a1 = a2 = 0.34mm, d = 0.17mm, b = 3.93mm, t = 0.5mm, and w = 12.1mm.

The structure is analyzed using EM simulation tool. The transmission and reflection characteristics of the structure are shown in Fig. 7.The pass is around center frequecny 4GHz. The structure exhibits very low loss in the passband and reflection is below -10dB.

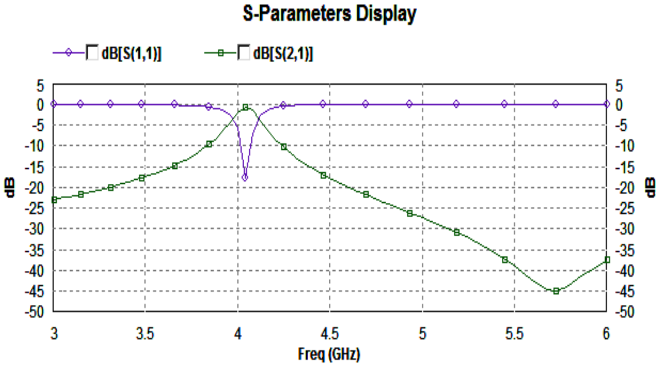

Fig. 7. Transmission and reflection characteristics of bandpass filter

V NEW PROPOSED CSRRS STRUCTURE

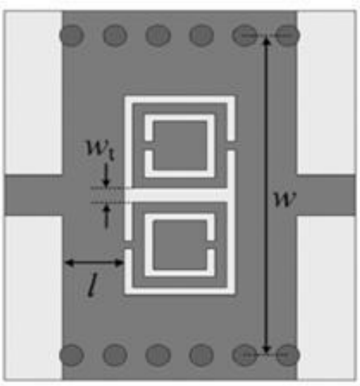

Fig. 8. Geometry of the New Proposed SIW using CSRR

The Geometrical Parameters of this Proposed new Structure are a1= 0.36mm, a2 = 0.36mm, d = 0.17mm, g = 0.24mm, b = 3.96mm, wt = 0.62mm, l = 2.02mm, and w = 12.1mm. In this proposed new structure we obtain the filter design with improved stopband rejection.

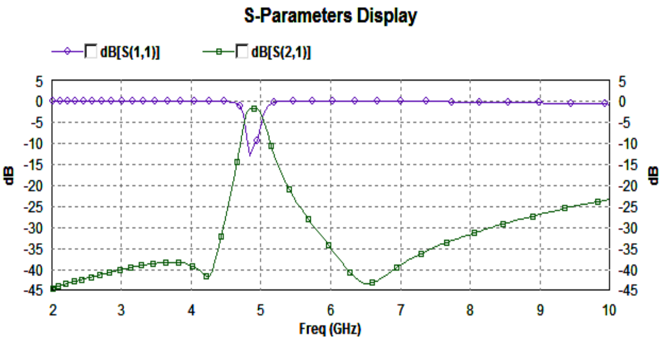

Fig. 9. Transmission response of the proposed new structure

V. CONCLUSION

SIW structure is designed to operate at 8GHz using low cost commercially available substrate. The analysis of band pass filter using SIW and CSRR shows the pass band around center frequency 4GHz. The structure exhibits very low loss in the pass band and reflection is below -10dB.

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