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Design and Analysis of Substrate Integrated Waveguide Wideband Filter for X-Band Frequency Applications

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Abstract- **A Novel Substrate Integrated waveguide(SIW) for Wideband Filter is presented. The proposed filter operates at X-Band frequency applications. Microstrip tapered transistion provides the compatibility with the planar circuits. Complementary Split Ring Resonator is etched on the surface of the SIW cavity. This structure is designed with NumericMethodusing Advanced Design System(ADS) software and the substrate used is FR4.S-parametersare presented to show the characteristics and obtained reults are discussed.**

Keywords: **Substrate integrated waveguide(SIW), Wideband Filter, Microstrip tapered transition Complementary Split Ring Resonator(CSRR).**

I.INTRODUCTION

Microwave passive components which has high performance such as waveguide filters, can have high manufacturing costs. A way to reduce these costs is to realize substrate integrated waveguide components, where the waveguide structure is embedded in the same substrate which is used to implement the active part of a microwave system. The conductor layers form the top and bottom walls of the waveguide. An array of vias forms the side walls of the waveguide.Substrate Integrated Waveguide has much interest in the design of microwave and millimeter-wave integrated circuits. The basic concept of the SIW is that it merges waveguide cavities with planar structures on a single dielectric high frequency material.The Substrate Integrated Waveguide is also called as Post-wall waveguide or Laminated waveguide. SIW is generally the synthetic rectangular electromagnetic waveguide which is formed in a dielectric substrate by densely arraying a via-holes which will connect the upper and lower metal plates of the substrate. The distribution of field in an SIW is similar to that in a conventional rectangular waveguide.SIW is a transition between dielectric-filled waveguide (DFW) and microstrip. The Microstrip tapered transition is compatibility to the planar circuits. The microstrip energy to the SIW can be easily transformed by the plane taper transition. The microstrip tapered transition regions are then placed between the planar structure and the top metal layer of each cavity, which constitutes the complete structure of SIW. For high frequency applications SIW devices are preferred. The SIW waveguide propagation Characteristics are similar to classical rectangular waveguide. SIW structure has high Quality factor, high power handling capacity with self consistent electrical shielding and these are the advantages of SIW with that of the conventional waveguides. Complementary Split Ring Resonator(CSRR)The Complementary Split Ring Resonator CSRR is the complementary of Split Ring Resonator(SRR) .The CSRR the rings are etched on a metallic surface of the SIW Cavities. CSRR is used to improve the resonance frequency. CSRR are significantly smaller in size and compatible. CSRR is a type of metamaterial structure. CSRR produces a filter that has ni ripples in the passband and the performance of the filter can be improved by the use of the CSRR. Introduction of the CSRR in the ground plane is the promising technique for the miniaturisation and multiband operation.The advantage of the CSRR structure is that it produces low radiative losses and very high quality factors.

II.DESIGN OF SIW CAVITY AND MICROSTRIP TRANSISTION

The structure of the SIW consists of the conductor layers form the top and bottom walls of the waveguide. An array of vias forms the side walls of the waveguide. The SIW structure consists of the SIW cavities and the Microstrip TaperedTransition.The Microstrip tapered transition is compatibility to the planar circuits. The microstrip energy to the SIW can be easily transformed by the plane taper transition. A Microstrip tapered transition is used to interconnect

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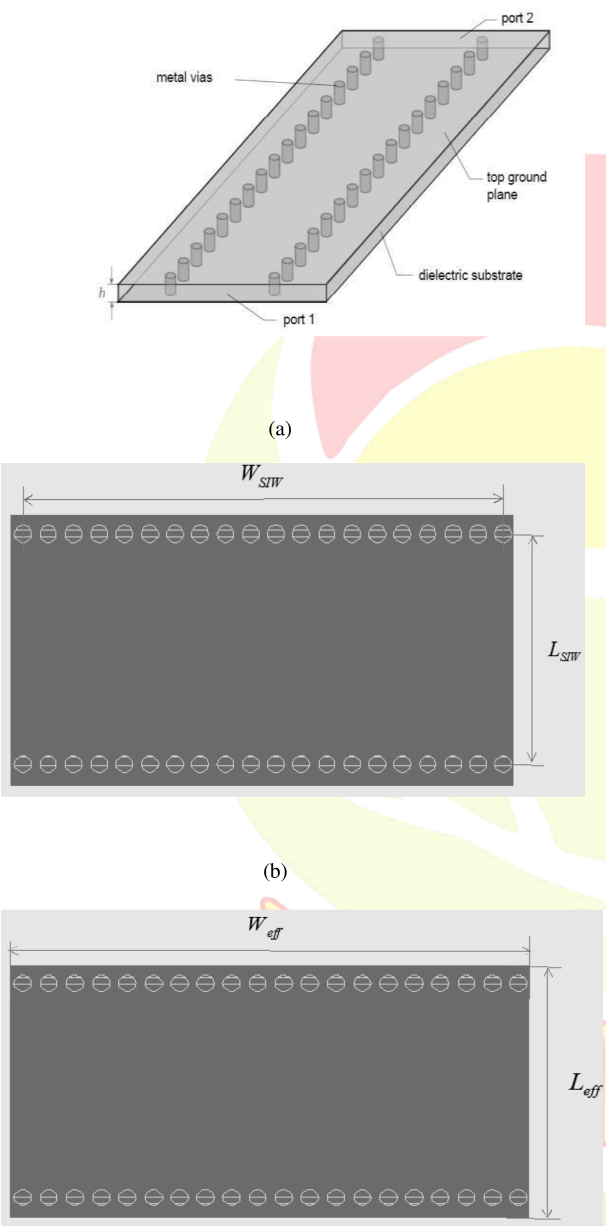
Substrate integrated waveguide (SIW) cavity to the planar transmission lines.



(c)

Fig.1 (a), (b) and (c) Structure of the Substrate Integrated Waveguide

Fig.1 shows the structure of the Substrate Integrateed Waveguide, since it is a filter it consists of two ports namely port1 and port2 , it consists of the metal vias , top ground plane and the dielectric substrate.

p is the distance between two metallic posts, d is the diameter of the metallic vias.Where W_{SIW} is the width of the SIW and L_{SIW} is the length of the SIW. W_{eff} is the effective width of the SIW is also defined as W_{equi} is the equivalent width of the SIW. L_{eff} is the effective length of the SIW is also can also be defined as L_{equi} is the equivalent length of the SIW.In order to design SIW filter, the first step begins with the designing of the vias. The value of the d and p are chosen in such a way that it should satisfy the following condition ,

$$d / p \geq 0.5 \qquad (1)$$

where d is the diameter of the metal vias, p is the spacing between two metal vias. d and p are the most important geometrical parameters. These rules are as

$$d < \lambda g / 5 \qquad (2)$$

$$b \leq 4d \qquad (3)$$

where d is the diameter of the metal vias, b is the via post spacing. The above two are considered as an important conidtion . Without satisfying this condition can if the dimensions are which results in creating too much leakage loss for the via post in SIW cavity side walls. λ_g is the guided wavelength. The guided wavelength is given by

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\varepsilon_R (2\pi f)^2}{c^2} - (\frac{\pi}{a})^2}} \qquad (4)$$

Where ε_R is the dielectric constant, f is the resonant frequency, c is the speed of the electromagnetic wave in free space, a is the width of the waveguide. The Mathematical equations for the calculation of the cavities of the Substrate integrated waveguide (SIW). The cutoff frequency for the SIW can be defined as

$$f_c = \frac{C}{2\varepsilon_R} . a_{equi} \qquad (5)$$

The mathematical equation for the calculation of the effective width and the effective length is given below,

$$W_{eff} = W_{SIW} - \frac{D^2}{0.95p} \qquad (6)$$

$$L_{eff} = L_{SIW} - \frac{D^2}{0.95p} \qquad (7)$$

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$$a_{SIW} = W_{equi} + p\left(0.766e^{0.4882\frac{d}{p}} - 1.176e^{-1.176\frac{d}{p}}\right) \quad (8)$$

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A Microstrip transition is used to interconnect SIW to the planar transmission lines.The Microstrip tapered transition is compatibility to the planar circuits. The microstrip energy to the SIW can be easily transformed by the plane taper transition. The microstrip tapered transition regions are then placed between the planar structure and the top metal layer of each cavity, which constitutes the complete structure of SIW.

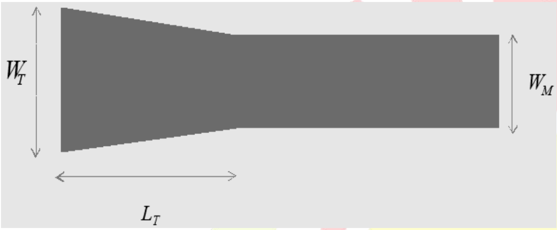

Fig.2 Structure of the microstrip tapered transition

The above fig.4 shows the structure of the Microstrip transition. Where W_T is the microstrip transition width, L_T is the microstrip transition length , L_M is the length of the microtrip line, Length should be chosen in such as a multiple of a quarter wavelength in order to minimize reflection loss. The mathematical equation for calculating the Microstrip tapered transition width is given below,

$$W_T = 0.4 \times (W_{SIW} - D) \qquad (9)$$

Length should be chosen in such as a multiple of a quarter wavelength. By using the equation (9) the microstrip tapered transition is calculated. It provides the compatibility with the planar circuits.

III COMPLEMENTARY SPLIT RING RESONATOR

CSRR produces a filter that has no ripples in the passband and the performance of the filter can be improved by the use of the CSRR. CSRR is a type of metamaterial which are artificially engineered materials which display negative permeability and permittivity over a certain range of frequency. Introduction of the CSRR in the ground plane is the promising technique for the miniaturisation and multiband operation.The advantage of the CSRR structure is that it produces low radiative losses and very high quality factors. There are many shapes in the CSRR design they are rectangular, square and the circular shaped CSRR. Here we used Rectangular shaped CSRR. The structure of the CSRR is given below in Fig.3

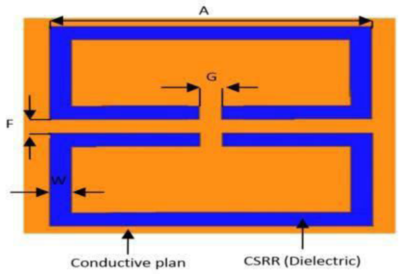

Fig.3 structure of the CSRR

Figure 3 shows the Rectangular CSRR where, W is the ring length of CSRR,G is the gap length, A is the width of CSRR and F is the width which separates two rings. It consists of two square shaped rings with gaps in between them on the opposite side of both the rings. The CSRR consists of two parts one is the conductive part and the other one is the dielectri part. When 2 resonators with 2 different frequencies f1 and f2 are coupled , the coupling changes both resonances by f_m . The frequency drift depends on the coupling vales between the two rings.

$$L_1 = 4xl_1 - s - 4xw \qquad (10)$$

$$L_2 = 4xl_2 - s - 4xw \qquad (11)$$

$$f_1 = \frac{c}{2L_1\sqrt{\varepsilon_{eff}}} \qquad (12)$$

$$f_2 = \frac{c}{2L_2\sqrt{\varepsilon_{eff}}} \qquad (13)$$

The following above four formulas are used to calculate the dimensions of the complementary split ring resonator. The formula for calculating the resonance frequency of the CSRR i given below in equation (14),

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (14)$$

IV DESIGN AND ANALYSIS

Based on the conditions and based on the mathematical equation the SIW cavity and the Microstrip transition is designed.The work is carried out using the Advance Design System(ADS) software.The software used is ADS(Advanced Design System)It is an electronic design automation software system and provides an integrated design environment to designers RF

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electronic products such as mobile phones, wireless networks, satellite communication, radar system and high speed data links. The SIW Cavity and the Microstrip transistion is designed seperately and them it is joined using merge position provided by the ADS software.The dimensions of the SIW Cavity is given below as,the value of the d and p are chosen in such a way that it should satisfy the following condition ,

$$d / p \geq 0.5 \qquad (15)$$

The diameter of the via is 1mm and the spacing between the two metal vias is 1.5. Here the value of d is chosen to be 1mm and the value of the p is chosen to be 1.5 mm . So that 1/1.5 = 0.66 which is greater than 0.5 .The number of vias used are 20 on the top and above the SIW cavity.

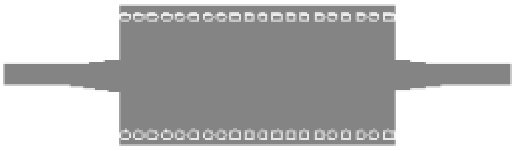

Fig.4 Structure of the SIW with Microstrip tapered transistions

Based on the conditions and based on the mathematical equation the SIW cavity and the Microstrip transition is designed. The work is carried out using the Advance Design System(ADS) software is an electronic design automation software system. Relative dielectric constant of 4.6. The Substrate used is FR4 its Relative dielectric constant of 4.6 , Loss tangent of 0.01 and its Thickness of 1.6mm. The SIW Cavity and the Microstrip transition is designed separately and them it is joined using the merge position in edit provided by the ADS software.

V. RESULTS AND DISCUSSION

Based on the calculated dimensions the design is simulated using the ADS software, since filter is a 2 port network two ports are given , P1 is given as the input to the filter which is also called as RF In and the pin P2 is given at the output which is also called as RF Out. In the substrate editor map the conductor via and select the layer as via, then select the substrate and give its thickness. The substrate used is FR4 ($\mathcal{E}_R$=4.4, tan δ=0.02, h=1.6mm)and its thickness is 1.6mm. In the EM setup the frequency plan is assigned and the simulation is done. Since it is a filter Return loss and Insertion loss is only considered. Since it is a filter the results are plotted for the scattering parameters S(1,1) and S(2,1).The S(1,1) represents the return loss or input inflection coefficient and S(2,1) represents the insertion loss or forward transmission gain. The insertion loss in dB is given by,

$$\text{IL(dB)}=10\log_{10}\frac{P_T}{P_R} \qquad (16)$$

P_T isthe power transmitted to the load before insertion and P_R is the power received by the load after insertion is

And the return loss is dB is given by,

$$\text{RL(dB)}=10\log_{10}\frac{P_i}{P_r} \qquad (17)$$

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Where P_i is the incident power and P_r is the reflected power. . Two simulations are done first the simulation is done without the CSRR and then the simulation is done by etching the CSRR on the surface of the SIW cavity. The dimensions of the SIW with microstrip tapered transistions is given below as, the diameter of the metal via is 1mm, spacing between two metal vias is 1.5mm, the width of the SIW is 28.5mm, and the effective width of the SIW is 29.84mm, the length of the SIW is 13.4mm and thethe effective length of the SIW is 15.75mm. The dimensions of the Microstrip Tapered Transistion is given below as, width of the taper is 3.61mm, length of the taper is 4.98mm , width of microstrip is 2.37mm and length of the microstrip is 7.63mm. The structure is given below as,

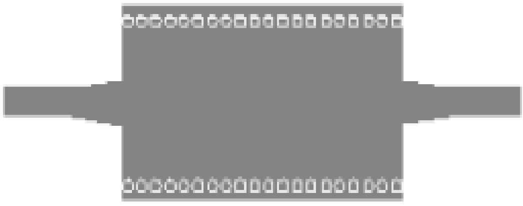

Fig.5 SIW structure without CSRR

and the simulated result for the above dimensions is givenbelow

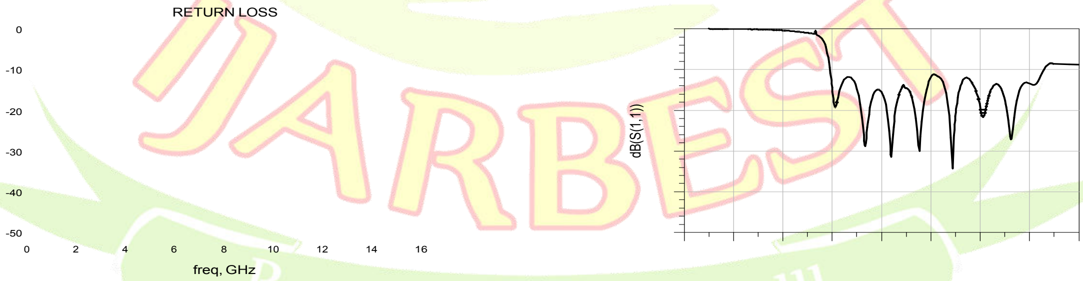

fig.6 simulated Return Loss

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Fig.7 Simulated Insertion Loss

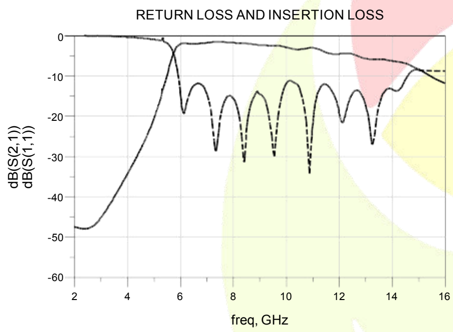

Fig.8 Simulated Return loss and Insertion Loss

With the same structure and dimensions the CSRR is etched and the simulation is done. The dimensions of the CSRR is given below , Length of CSRR Ring W =4.6mm , the gap lengthG =0.3, the side-length of CSRR A =0.3 ,F is the width which separates two ring F =0.3. The structure of the SIW with CSRR is given below,

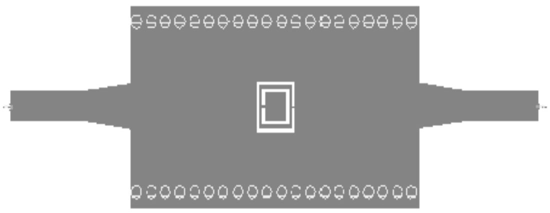

Fig.9 Structure of the SIW with CSRR

The simulated results for the above dimensions is given below as follows,

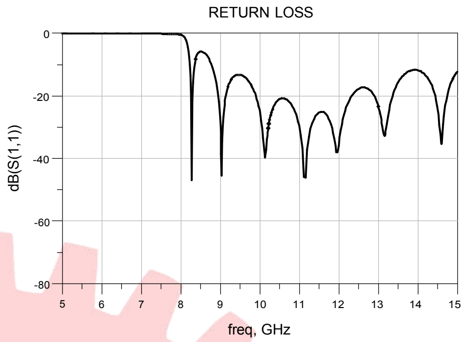

Fig.10 Simulated Return Loss

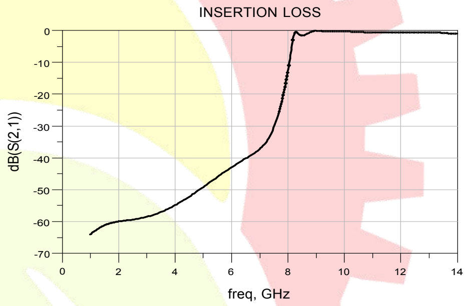

Fig.11 Simulated Insertion Loss

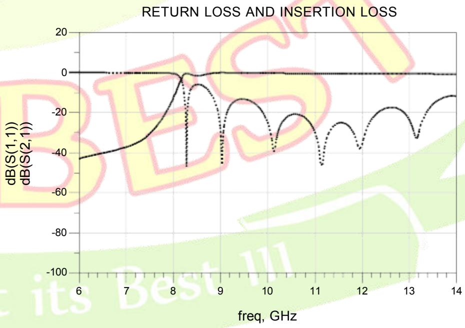

Fig.12 Simulated Return Loss and Insertion Loss

The performance is improved with the use of the CSRR. The return loss obtained is below -25dB.

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VI CONCLUSION

A Novel Substrate Integrated waveguide Wideband filter For X-Band Frequency applications is designed using ADS and the simulated results is obtained. The design is carried out using the FR4 substrate. The overall dimensions of the designed Filter is 29.84mm X 15.75mm. It is analysed that the performance is improved with the use of the CSRR. The obtained Results shows that the better insertion loss and return loss. In future the results will be further optimised to satisfy the required application. And the structure is fabricated and tested using the netwok analyser.

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