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Half - Mode Substrate Integrated Waveguide Bandpass Filter with Split Ring Resonators

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ABSTRACT

A half- mode substrate integrated waveguide (HMSIW) band pass filter is presented. Split ring resonator (SRR) introduced as a series element provides the required bandpass while edge coupled SRRs produce well defined transmission zeros on either side of the passband. The filter is analysed using the LC equivalent circuit and also using the surface current distribution for better understanding of its behavior. The simulated values of the insertion loss and return loss are 1 dB and 30 dB respectively. Slight deviation is observed in the measured values due to fabrication errors.

Key words: Bandpass Filter, half-mode substrate integrated waveguide (HMSIW), split ring resonator (SRR).

INTRODUCTION

In the modern microwave and millimeterwave communication systems printed filters play key role. The popular transmission line structures like microstrip, coplanar and the substrate integrated waveguide (SIW) meet most of the challenging issues of the passive component design. Among these, SIW combines the advantages of the planar structure as well as the waveguide to emerge as the new candidate for high frequency applications [1]. The substrate integrated waveguide (SIW) and its derivatives like half-mode substrate integrated waveguide (HMSIW), quarter-mode substrate integrated waveguide (QMSIW) etc. being used as transmission lines while HMSIW occupy half the size compared to SIW, QMSIW occupy still smaller size. Passive components derived out of these transmission lines are compact, with large power handling capability, low loss, high Q-factor and easy integration with planar circuits. SIW components can be fabricated using simple PCB process [2 -3].

The artificial structures showing negative permittivity and permeability known as meta materials have been widely used with SIW structures to design different microwave components [4].The split ring resonators (SRRs), proposed by Pendry and Compementary Split Ring Resonators (CSRRs) are promising candidates to be used with HMSIW to achieve component size reduction, evanescent mode, narrow band nature etc. [5- 6].

This paper deals with a bandpass filter design in HMSIW using SRRs for realising bandpass and notch characteristics. In this proposed design, a small cut is introduced in the HMSIW structure and SRR is introduced in the gap to act as a series component to couple a desired frequency. Two more SRRs are edge coupled to the HMSIW to get sharp stopband and thus good transmission zeros on either side. A narrow passband from 9.13 GHz- 9.26 GHz (130MHz) is obtained with this simple structure.

HMSIW FILTER DESIGN AND SIMULATION

The SIW filters meet the specifications of the modern day communication systems. HMSIW filters can reduce the structure size to half with the same electrical properties of SIW with change in mode from TE1, 0 to TE0.5, 0. This also eliminates the use of side wall vias with introduction of magnetic wall in one side [7]. The equation for cut off frequency of a rectangular waveguide is given by [8 - 9]

$$fc_{m,n} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\frac{(m\pi)^2}{a^2}+\frac{(n\pi)^2}{b^2}} \tag{1}$$

The conventional rectangular waveguide is converted to the planar dielectric filled waveguide by using the following relations

$$W_{siw} = \mathrm{w} - 1.08\frac{\mathrm{d}^2}{\mathrm{p}} + 0.1\frac{\mathrm{d}^2}{\mathrm{w}} \quad (2)$$

Where d is the diameter of the vias, p is the via pitch (centre to centre distance), w is the conventional rectangular waveguide width.

For the selection of via diameter and pitch to get the desired cut off frequency the following relations can be used

$$\mathrm{p} \leq 2\mathrm{d} \quad (3)$$

$$\mathrm{d} < 0.2\lambda_{\mathrm{gsiw}} \quad (4)$$

$$\lambda_{\mathrm{gsiw}} = \frac{\lambda_d}{\sqrt{1-\left(\frac{\lambda_d}{2\mathrm{Wsiw}}\right)^2}} \quad (5)$$

$$\lambda_d = \frac{\lambda_c}{\sqrt{\varepsilon_r}} \quad (6)$$

Where λ_c is the wavelength corresponding to f_c.
Now, the width of HMSIW, $W_a = W_{siw}/2$

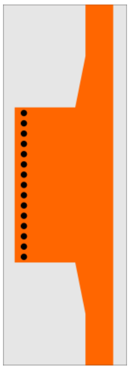


Fig.1(a) HMSIW

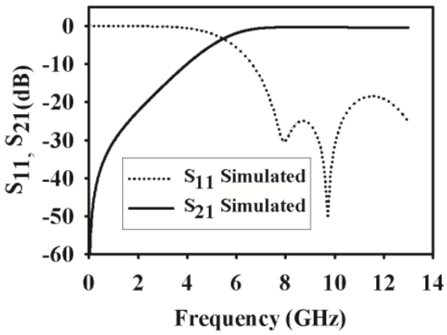


Fig.1(b) Simulated S-Parameters

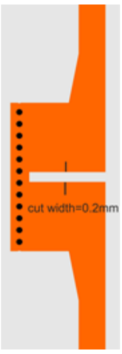


Fig.2(a) HMSIW with cut

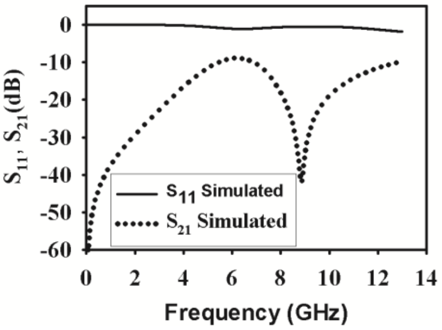


Fig.2(b) Simulated S-Parameters

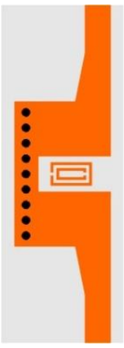


Fig.3(a) HMSIW with centre SRR

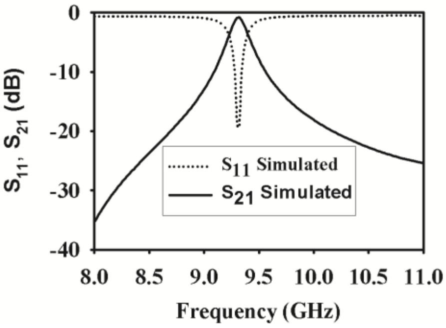


Fig.3(b) Simulated S-Parameters

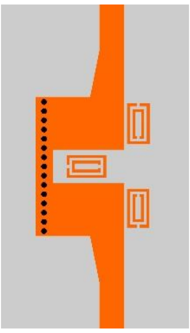


Fig.4(a) HMSIW

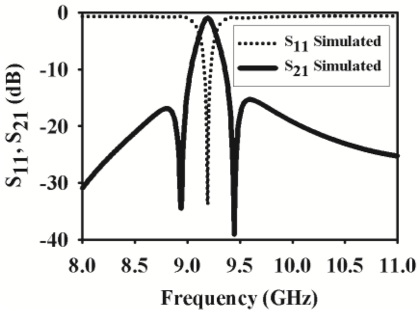


Fig.4(b) Simulated S-Parameters Filter

The evolution of the filter structure is shown in Fig.1- 4. The HMSIW with a cut off frequency of 6 GHz is designed and simulated in CST MW Studio as shown in Fig.1 (a) and (b). The input and output lines are tapered to match with 50Ω line. A small gap is introduced in it as shown in Fig. 2(a) and the response is shown in Fig. 2(b). SRR is inserted in the gap to get a desired narrow pass band as shown in Fig. 3(a) and (b). To sharpen the stopband edges we need more resonating elements. As shown in Fig. 4(a) and (b) two SRRs are introduced into the structure near the virtual magnetic wall of the HMSIW so that the fields of both the structures can interact well. These two SRRs are resonating at different frequencies which act as notch filters giving transmission zeros on either side of the pass-band.

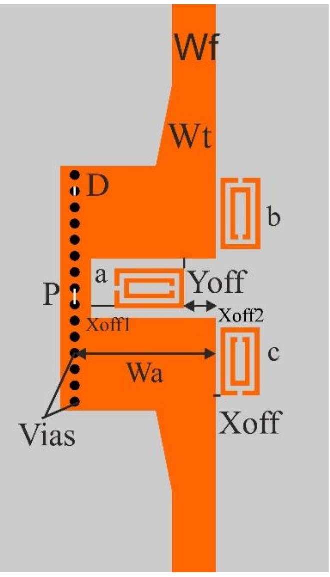


Fig.5 Filter structure (top view)

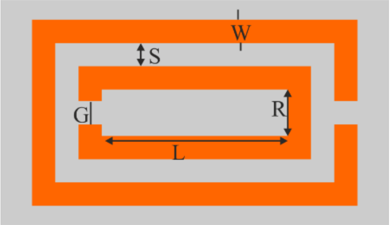


Fig.6 Enlarged view of SRR

Table -1 Parameters of the designed filter

Parameters of the Filter (mm)								
Wf	Wt	Wa	Xoff	Xoff1	Xoff2	Yoff	D	P
2.7	3.7	8.4	0.3	1.25	1.95	0.6	0.8	1.2

Table -2 Prameters of SRRs

SRR Dimensions (mm)					
SRR name	W	S	G	Ra,Rb,Rc	La,Lb,Lc
(a) Passband	0.3	0.3	0.3	0.65	2.5
(b) Transmission zero1	0.3	0.3	0.3	0.65	2.6
(c) Transmission zero2	0.3	0.3	0.3	0.6	2.4

The final structure of the filter is shown in Fig.5 and enlarged view of SRR in Fig.6 with the optimized parameters given in table1 and 2.The behaviour of the filter is explained using the equivalent circuit [10] given in Fig.7 and the EM simulation verus LC circuit simulation charcteristics is shown in Fig.8. The three parallel LC circuits (LS1&CS1,LS2&CS2,LS3&CS3) represent the three SRRs in the filter structure.The inductors L1 and L2 represent the HMSIW sections,the capacitor C1 indicates gap capacitance to the edge coupled SRRs and capacitor C2 gap capacitance to the series coupled SRR.

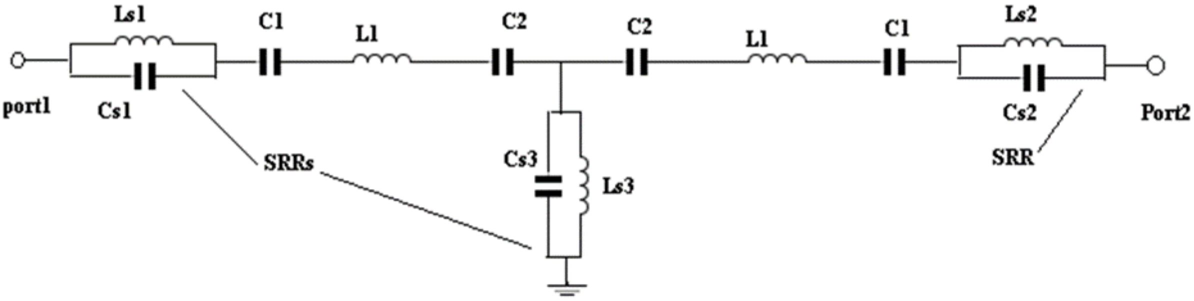


Fig.7 Equivalent Circuit Model

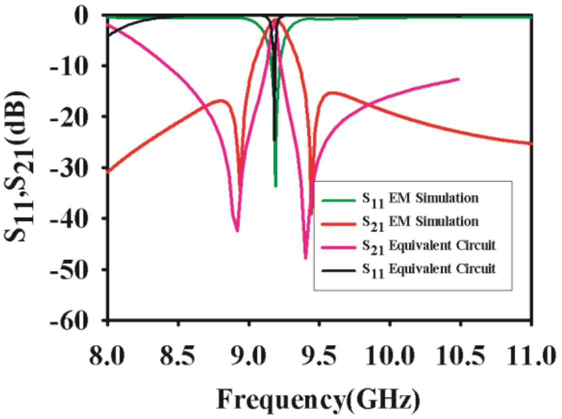


Fig.8 EM Simulation and LC Circuit Characteristics

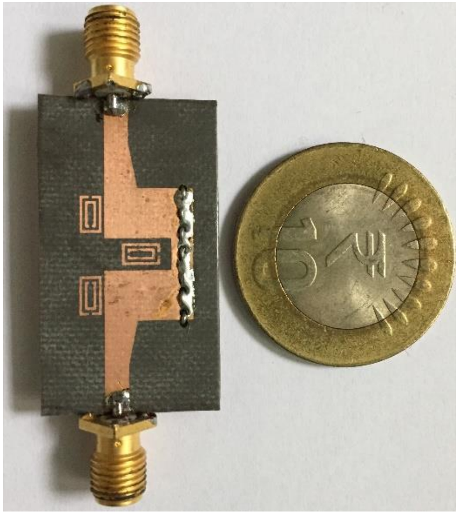


Fig.9 Photograph of fabricated filter

EXPERIMENTAL RESULTS AND DISCUSSION

The proposed structure is fabricated on Rogers RT/Duroid 5880 substarte with relative permittivity of 2.2 and loss tangent of 0.0009 and a thickness of (0.79mm) using the standard PCB process. Photograph of the fabricated structure is shown in Fig.9.The measured S-parameters using Rohde &Schwarz ZVB-20 vector network analyzer are shown in Fig.10.The measured values show a small shift from simulated value which may be due to fabrication tolerance.

The resonant frequencies of the SRR named (a) ,(b) , (c) are given by the relations

$$fa = \frac{1}{2\pi\sqrt{Ls3Cs3}} \quad \text{(passband-center frequency)} \tag{7}$$

$$fb = \frac{1}{2\pi\sqrt{Ls1Cs1}} \quad \text{(transmission zero1)} \tag{8}$$

$$fc = \frac{1}{2\pi\sqrt{Ls2Cs2}} \quad \text{(transmission zero2)} \tag{9}$$

The insertion loss of the designed filter is directly proportional to the number of resonators used in the circuit[11].In the proposed filter it reaches upto a maximum of 3dB.The measured and simulated group delay of the filter is shown in Fig.10.The in-band variation of the group delay in this case is large due to its narrowband nature[12].

The parametric analysis of Xoff and Yoff is shown in Fig.12 (a) and (b). From the LC equivalent circuit, it is clear that Xoff represents capacitor C1 and Yoff capacitor C2. For the given filter the variation of Xoff shows an upward frequency shift on transmission zeros and a downward shift after a certain value. As Yoff increases the out of band rejection on both side improves. Both the cases show a passband frequency shift also.

The surface current distribution for the lower transmission zero (8.93GHz), and upper transmission zero (9.44GHz) are Shown in Fig.13(a) and (b) respectively. From the figure it is clear that the curresponding SRRs are excited for the designed frequency.The surface current distribution and electric field distribution at center frequency 9.19GHz is ahown in Fig.14 (a) and (b) It shows excitation of all the SRRs in the filter structure.

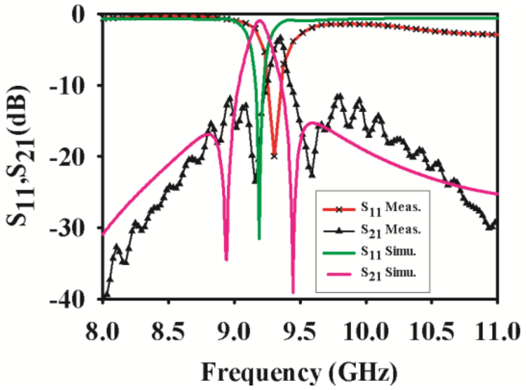


Fig.10 Simulated and Measured Insertion and Return losses

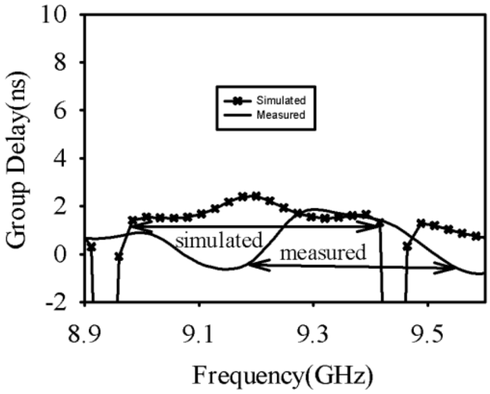


Fig.11 Simulated and Measured Group Delay Characteristics

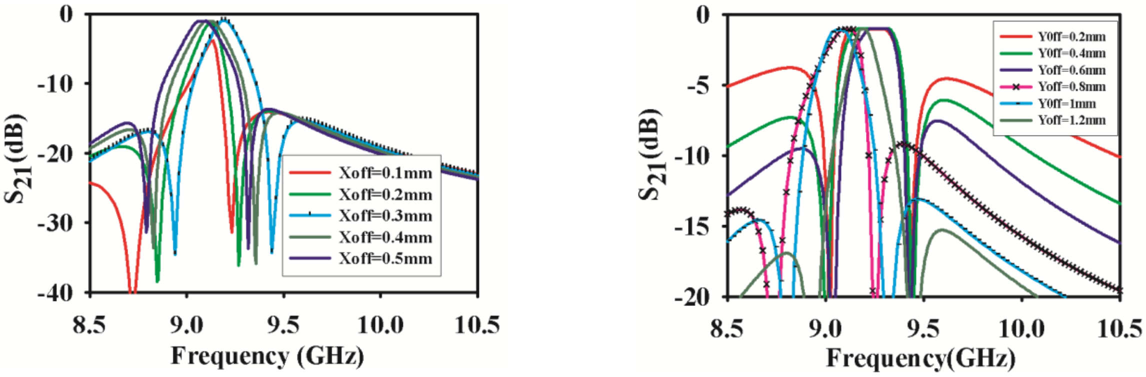


Fig. 12 Variation Studies on Parameter (a) Xoff **(b) Yoff**

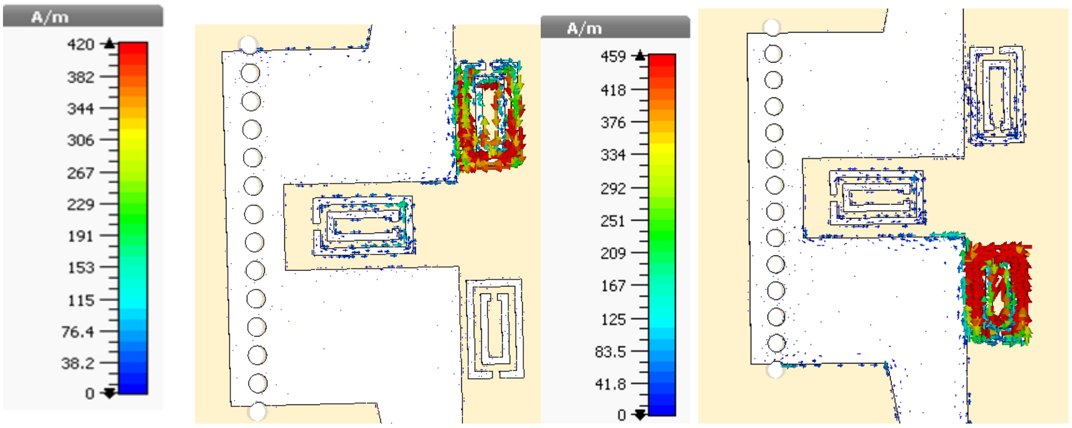
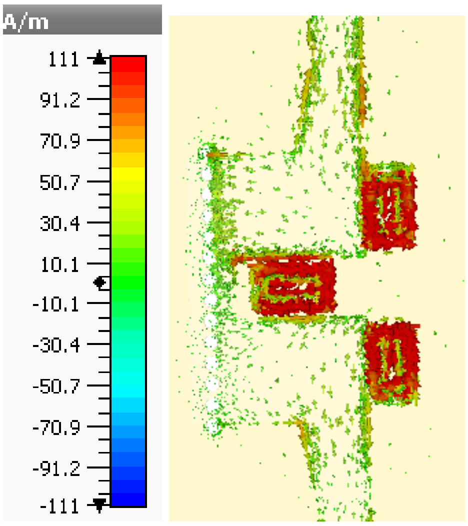
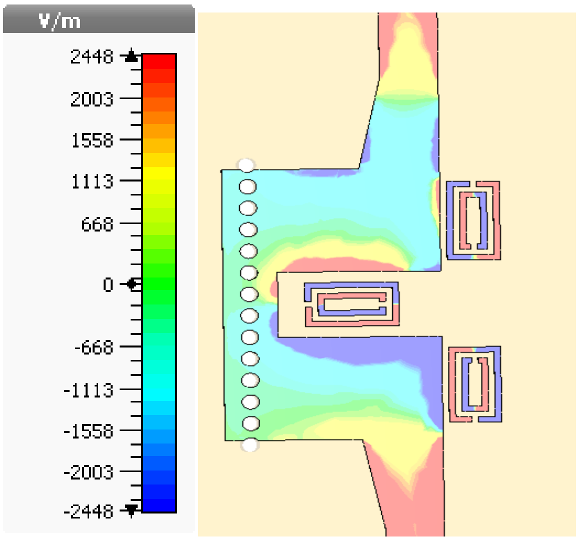


Fig. 13 Surface Current distribution at (a) 8.93GHz **(b) 9.44GHz**





(b) Electric field distributions at 9.19GHz

Fig.14 Surface Current distribution at (a) 9.19GHz

CONCLUSION

A HMSIW bandpass filter with narrow passband with transmission zeros on either side is proposed. The proposed structure has got a simple design with insertion and return loss values in the acceptable range. The filter makes use of SRR as the resonant structure to get the required response.By changing the dimensions of the resonant structures,the passband and stopband can be shifted to a desired range.

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