Design of Substrat Integerated Waveguide Bandpass Filter of SCRRs in the Microstrip Line

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Abstract— In this paper A novel band-pass Substrate Integrated Waveguide (SIW) filter based on complementary Split ring Resonators (CSRRs) is presented in this work.a X-band wideband bandpass filter based on a novel substrate integrated waveguide-to-Complementary split ring resonators (SIW-CSSRs) cell is presented. In the cell, the (CSRRs) is etched on the top plane of the SIW with high accuracy, so that the performance of the filter can be kept as good as possible. Finally, the filter, consisting of three cascaded cells, is designed meet compact size, Three different CSRRs cells are etched in the top plane of the SIW for transmission zero control. A demonstration band-pass filter is designed, It agreed with the simulated results well. This structure is designed with Numeric Method (MOM) using CST on a single substrate of RT/Duroid 5880. Simulated results are presented and discussed..

Index Terms— Substrate Integrated Waveguide, Complementary split ring resonators CSRRs, band-pass, via, SIW, simulation

Introduction : very recently, Complementary split ring resonators (CSSRs) elements have been proposed for the synthesis of negative permittivity and left-handed (LH) metamaterials in planar configuration [1] (see Fig 1). As explained in [2], CSRRs are the dual counterparts of split ring resonators (SRRs), also depicted in Fig. 1, which were proposed by pendry in 1999. It has been demonstrated that CSRRs etched in the ground plane or in the conductor strip of planar transmission media (microstrip or CPW) provide a negative effective permittivity to the structure, and signal propagation is precluded (stopband behavior) in the vicinity of their resonant frequency [2]. CSSRs have been applied to the design of compact band-pass filters with high performance and controllable characteristics [3]. Recently, a new concept "Substrate Integrated Waveguide (SIW)" has already attracted much interest in the design of microwave and millimeter-wave integrated circuits. The SIW is synthesized by placing two rows of metallic via-holes in a substrate. The field distribution in an SIW is similar to that in a conventional rectangular waveguide. Hence, it takes the advantages of low cost, high Q-factor etc., and can easily be integrated into microwave and millimeter wave integrated circuits [4]. This technology is also feasible for waveguides in lowtemperature co-fired ceramic (LTCC). The SIW components such as filter, multiplexers, and power dividers have been studied by researchers in [5]. In this paper, a band-pass SIW filter based on CSRRs is proposed for the first time. The filter is consisted of the input and output coupling line with the CSRRs loaded SIW. Using the high-pass characteristic of SIW and band-stop characteristic of CSSRs, a bandpass SIW filter is designed. In this paper, we will do a detailed investigation of CSRR based stop band filters: starting with a single CSRR etching in the microstrip line, finding its stop band characteristics and quality factor. Then the effect of number of CSRRs etching and periodicity on the stop band filter performance will be investigated.

ANALYSIS OF SIW-CSRRs CELL

The proposed SIW-CSRRs cell is shown in Fig 1. Since the CSRRs is etched into the top metal cover of SIW, it is quite convenient to do system integration. For this proposed SIW-CSRRs cell, its bandpass function is the composite high-low (Hi-Lo) type, i.e., it is a combination of the highpass guided wave function of SIW and the bandgap function of CSRRs.

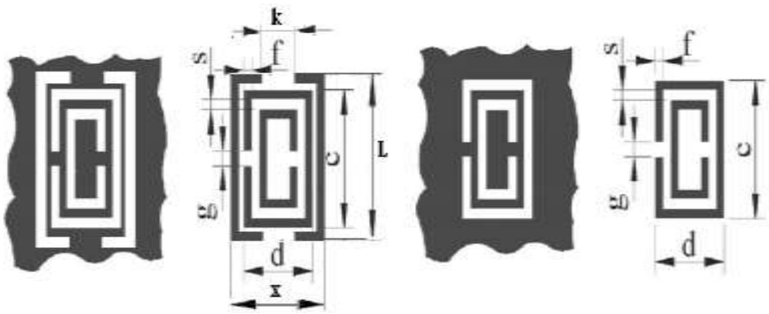


Fig1. Geometries of the CSRRs and the SRRs, grey zones represent the metallization.

filters: starting with a single CSRR etching in the microstrip line, finding its stop band characteristics and quality factor. Then the effect of number of CSRRs etching and periodicity on the stop band filter performance will be investigated.

PARAMETER DESIGN OF SIW

The SIW was constructed from top and bottom metal planes of substrate and having two arrays of via holes in the both side walls as shown in Fig. 2. Via hole must be shorted to both planes in order to provide vertical current paths, otherwise the propagation characteristics of SIW will be significantly degraded. Since the vertical metal walls are replaced by via holes, propagating modes of SIW are very close to, but not exactly the same as in rectangular waveguide [6].

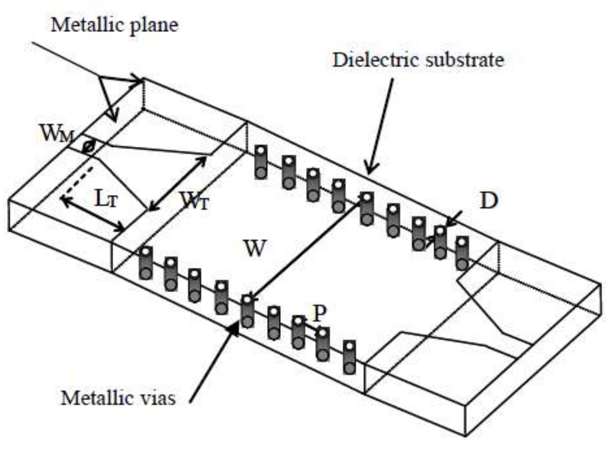


Fig. 2 Topology of the substrate Integrated Waveguide

By using equivalence resonance frequency, the size of SIW cavity is determined from [7]:

$$f_{101} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}}\sqrt{\left(\frac{\pi}{w_{eff}}\right) + \left(\frac{\pi}{l_{eff}}\right)}$$

This is to ensure that the SIW filter be able to support TE_{10} mode in the operating frequency range. The T*E*-field distribution in SIW is just like in the conventional ectangular waveguide. The effective length of SIW cavity can be determined from:

$$l_{eff} = l - \frac{d^2}{0.95p}$$

Where *w* and *l* are the real width and length of SIW cavity. However *D* is the diameter and *P* is the pitch, also known as distance between center to center of adjacent via hole shown in Fig. 3.

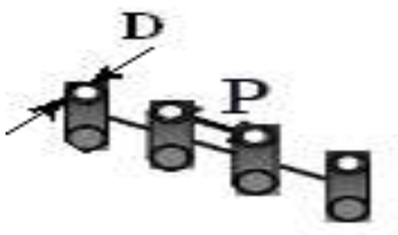


Figure 3: Via hole

Via holes form a main part of SIW in order to realize the bilateral edge walls, the reduction and huge scale combination of electronic devices place a remarkable request on multilayer geometries and also important for discontinuities in multilayered circuits. The diameter and pitch is given by:

$d < \lambda g/$ (3)

$p \leq 2d$ (4)

In order to minimize the leakage loss between nearby hole, pitch needs to be kept as small as possible based on (3) and (4) above. The diameter of via hole also contributes to the losses. As consequences, the ratio *d/p* reflected to become more critical than pitch size of via hole. This is because the pitch and diameter are interconnected and it might distract the return loss of the waveguide section in view of its input port [21, 11]. The SIW components can be initially designed by using the equivalent rectangular waveguide model in order to diminish design complexity. The effective width of SIW can be defined by:

$$w_{eff} = w_{siw} - 1.08\left(\frac{D_{via}^2}{S_{vp}}\right) + 0.1\left(\frac{D_{via}^2}{w_{siw}}\right)$$

Substrate Integrated Waveguide

The SIW features high-pass characteristics, it was demonstrated in [8] that a *TE*10-like mode in the SIW has dispersion characteristics that are almost identical with the mode of a dielectric filled rectangular waveguide with an equivalent width. This equivalent width is the effective width of the SIW, namely, can be approximated as follows:

$$a_{eqv} = a - \frac{d^2}{0.95.b}$$

Then, the cutoff frequency for the SIW can be defined as $fc = (c/2\varepsilon r \cdot aeqv)$, in which C is the light velocity in vacuum. Based on this property, existing design techniques for rectangular waveguide can be used in a straightforward way to analyze and design various components just knowing *aeqv* of the SIW. In this case, the SIW geometry size can be initially designed by

CSSR Loaded SIW

Fig 4 shows the Layout of a SIW with CSSRs etched in the top substrate.

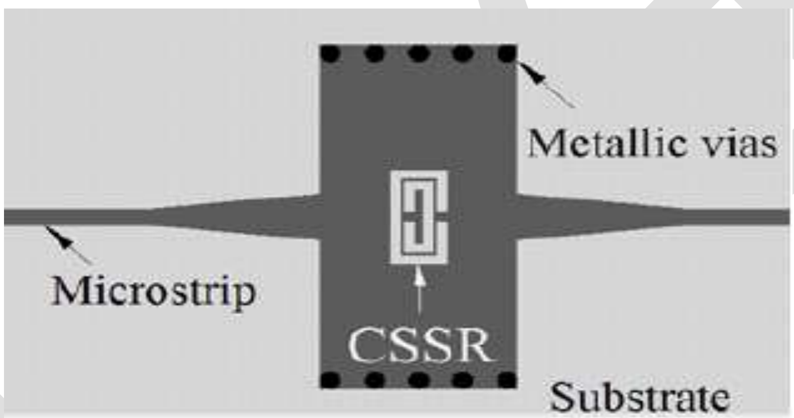


Figure 4. Layout of a SIW with CSSR etched in the top substrate side, (a) top layer

Let us now analyze the CSSRs loaded SIW. Since CSRRs are etched in centre of the top layer, and they are mainly excited by the electric field induced by the SIW, this coupling can be modeled by connecting the SIW capacitance to the CSRRs. According to this, the proposed lumped-element equivalent circuit for the CSRR loaded SIW is that depicted in Fig. 4. As long as the electrical size of the CSRRs is small, the structure can be described by means of lumped elements. In these models, L is the SIW inductance, C is the coupling capacitance between the SIW and the CSRR. The resonator is described by means of a parallel tank [9], Lc and Cc being the reactive elements and R accounting for losses.

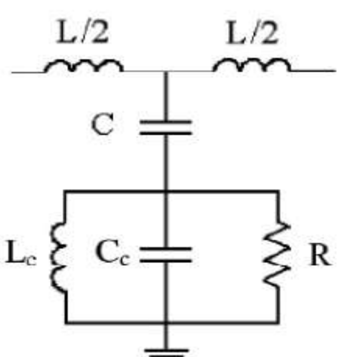


Fig. 5 The depicted equivalent circuit models

In order to demonstrate the viability of the proposed technique, we have applied it to the determination of the electrical parameters of the single cell CSSRs loaded SIW.

First Design Example

The specifications for the design example are:

• Frequency Band : 2 to 15 GHz

• Substrate : Duroid (cr = 2.2, h = 0.254 mrn)

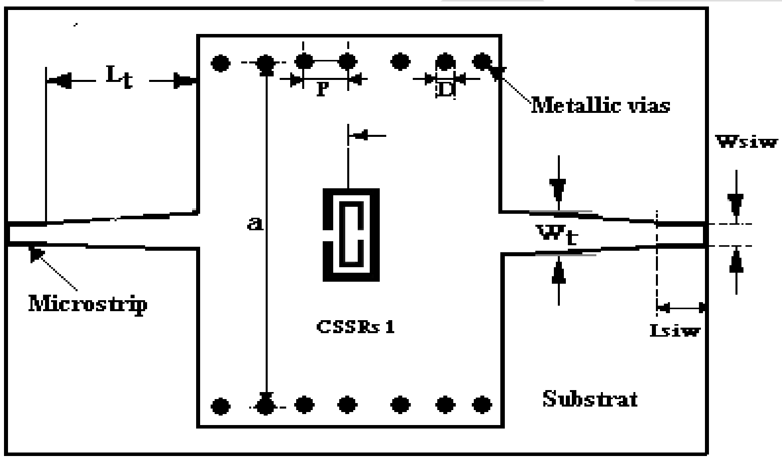


Fig. 6 Topology of the substrate Integrated Waveguide

The dimensions to the SIW are: a = 14 mm. The equivalent width of microstrip line w = 0.8 mm. The taper of microstrip line of length equal to 5.5 mrn. and SIW dimensions are *a* = 14mm, *D* = 0.8mm and *P* = 1.6 mm, respectively. The width of the access lines is 0.76 mm. The simulated (using CST Microwave Studio) S-parameters of Figure. 5 are shown in Fig. 6. It can be clearly found that these structures exhibit similar characteristics except Figure. 6 Excellent results are also obtained for this transition, as shown in fig. 7

RESULTS AND DISCUSSION

A CSRR structure is designed to resonate at 9.17 GHz of the X-band microwave frequency region. The dimensions of the CSRR structure are *c* = 4mm, *d* = 2 mm, *f* = 0.3 mm, *s* = 0.2mm and *g* = 0.4mm. The dependence on dimensions of the CSRR structure for the resonant frequency is observed as follows: with the increase of the ring width (*c*) and gap width (*d*) resonant frequency increases. The CSRR structure is placed in the microstrip line exactly below the center of a ground plane of width 2.89mm for a RT/Duroid 5880 substrate (dielectric constant εr = 2.22, thickness *h* = 0.254mm and tan δ = 0.002) as shown in Fig. 6. Same substrate is used for all other later designs. All the designs are simulated using Microwave CST software [8]. The simulation results for a single CSRR etching in a microstrip line are shown in Fig 7.

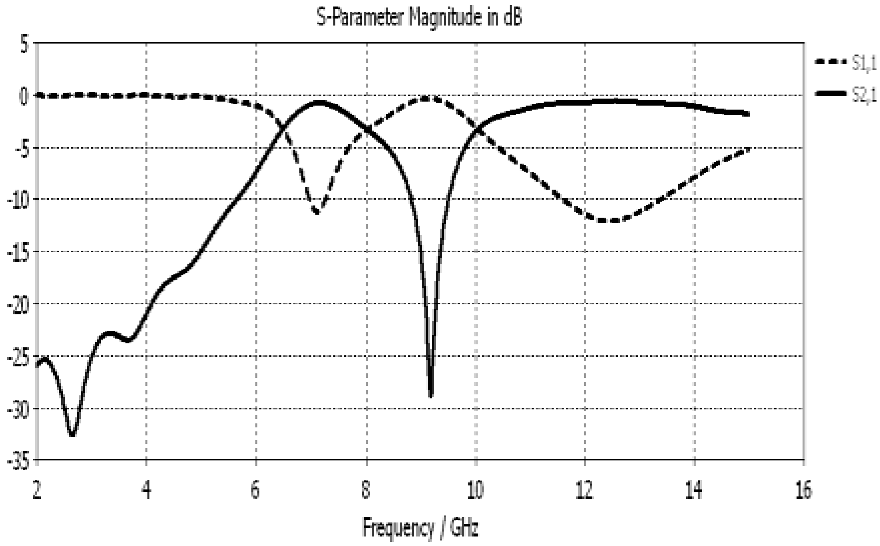


Fig 7. Simulate frequency response corresponding to the basic cell

The results of scattering parameters versus frequency (GHz) show narrow stop band characteristics at the resonant frequency of CSRR at 8.3 GHz. By placing a single CSRR structure in the strip line, we can obtain a narrow stop band with a very low insertion loss level, which is not possible with conventional microstrip resonators. It is difficult to achieve such a good narrowband stop band response with a single element of conventional resonators. Stop bandwidth of the above single CRRR loaded microstrip line filter is approximately 456 MHz at the resonant frequency of 9.17 GHz.

Design of proposed transition

In order to combine SIW and microstrip technologies, SIW-microstrip transitions are very required [10]-[11]. SIW filter and tapered transition shown in Fig. 8 has been studied. This structure is simulated on a The substrate used in the filter is RT/Duroid 5880 which has permittivity of 2.22, height of 0.254mm, the distance between the rows of the centres of via is w = 15 mm, the diameter of the metallic via is D = 0.8 mm and the period of the vias P = 1.6 mm. The width of tapered Wt is 1.72 mm, its length is Lt = 5.5 mm, and thickness t = 0.035mm of the ground plane and microstrip line.

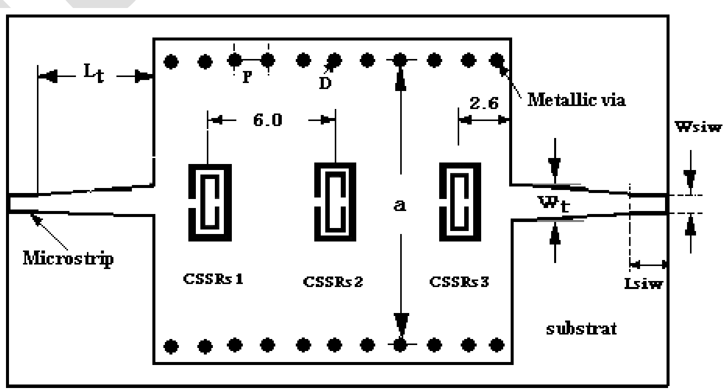


Fig 8. Configuration for the proposed SIW Filter.

Table 1: The simulated performance of this structure

CSSRs1 dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
c	3.7	*f*	0.3
d	1.85	*s*	0.2
f	0.3	*g*	0.4
CSSRs2 dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
c	4	*f*	0.3
d	2	*s*	0.2
f	0.3	*g*	0.4
CSSRs3 dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
c	3.8	*f*	0.3
d	1.9	*s*	0.2
f	0.3	*g*	0.4
SIW dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
Lt	5.5	*Wt*	1.72
W_{SIW}	0.8	L_{SIW}	1.9
D	0.8	*P*	1.6
a	14	*L*	32

Here our concern is to enhance the stop band filter characteristics by increasing the number of CSRR structures in the ground plane. This is achieved by placing more CSRRs with the same resonant frequencies periodically. Such a stop band filter structure is shown in Fig.8, which has three CSRR structures in the strip line and all the CSRRs are resonating at the same frequency of 8.3245 GHz. The distance between the centers of any two adjacent CSRRs is known as period and it is 6 mm for this filter. The simulation results are shown in Fig. 8.

The simulation results depicted in Fig. 9 shows a stop band at 8.3245 GHz with a stop bandwidth of approximately 1.75GHz (1750Mhz) .

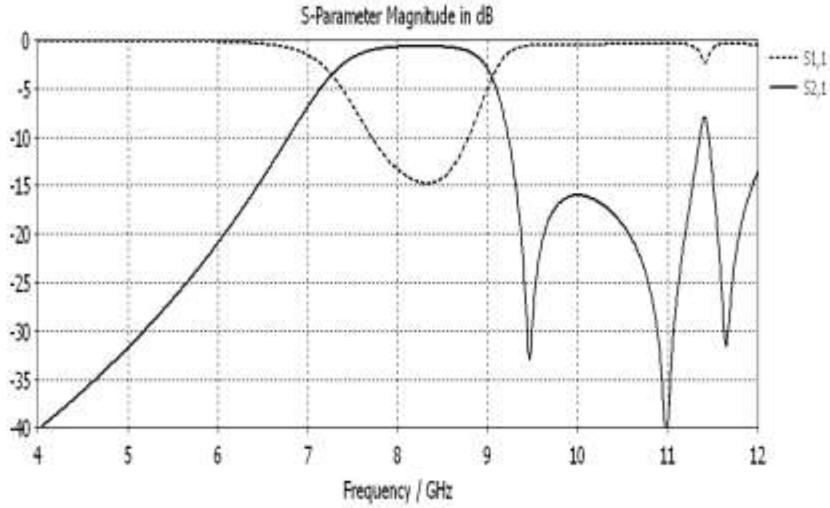


Fig 9. Simulation results for the proposed filter SIW-CSRRs cell with different values

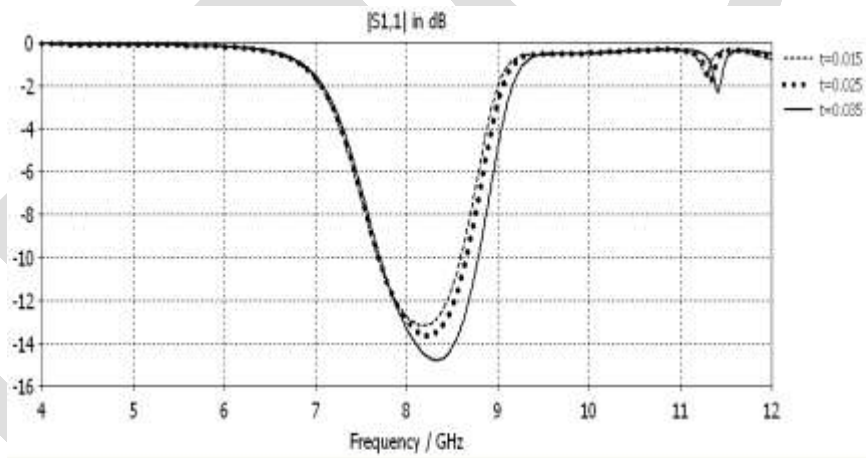


Fig 10. Simulation results S11 for the proposed filter SIW-CSRRs cell with different values for t=0.015,t=0.025 and t=0.035

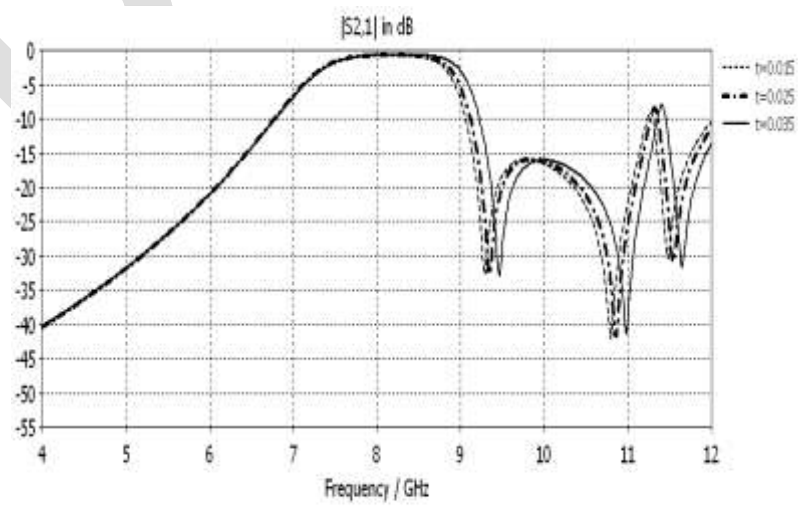
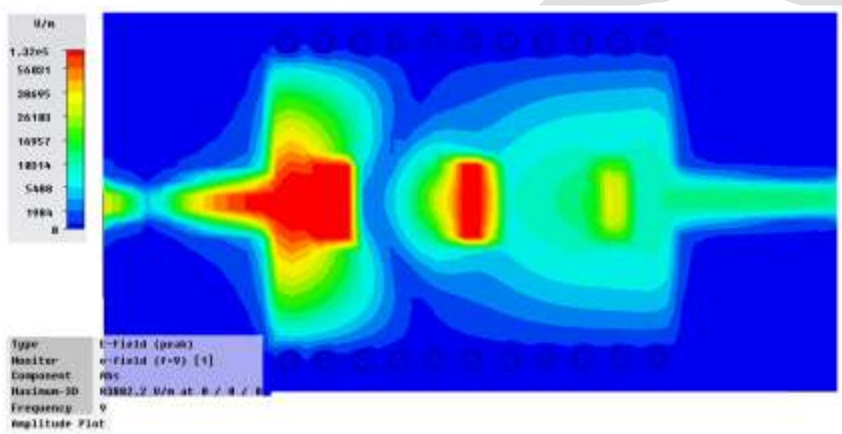


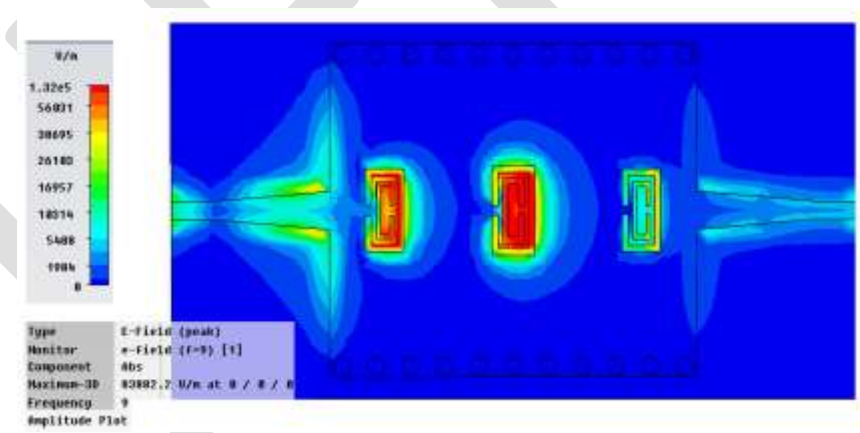
Fig 11. Simulation results S21 for the proposed filter SIW-CSRRs cell with different values for t=0.015,t=0.025 and t=0.035

In order to achieve a low-loss broadband response, the transition is designed by simultaneously considering both impedance matching and field matching. Thus, due to the electric field distribution in the SIW, each transition is connected to the center of the width of the SIW, since the electric field of the fundamental mode is maximum in this place [8]. The optimization of the transition is performed by means of electromagnetic simulations by varying the dimensions (Lt, Wt) of the stepped geometry. After optimization, the dimensions retained are Wt = 1.72 mm and Lt = 5.5 mm.

The distribution of the electric field is given in Fig12.



a



b

Fig 12. Electric field distribution of proposed filter with three cascaded SIW-CSRRs cells (a) bottom layer, (b) top layer.

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DESIGN OF SIW FILTER

Filter Configuration

Fig.13 Shows the proposed design of filter, this filter includes two microstrip tapered transitions and four SIW resonators cavities.

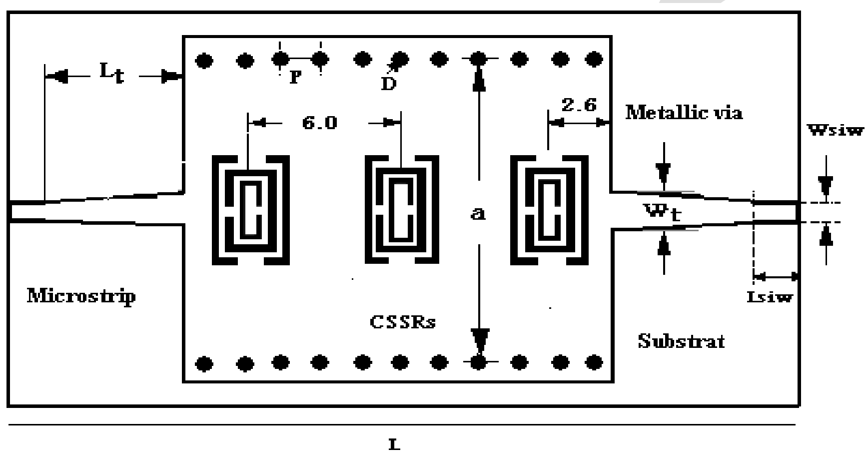


Fig. 13. Configuration for the proposed SIW Filter

d = 2 mm, *s* = 0.2 mm, *g* = 0.4mm, *a* = 14mm, *d* = 0.8mm and *b* = 1.6 mm.

Table 2: The simulated performance of this structure

CSSRs dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
c	*1.5*	*f*	*0.3*
d	*1*	*s*	*0.1*
f	*0.15*	*g*	*0.2*
L	*4*	*x*	*2*
SIW dimensions			
Symbol	*Quality (mm)*	*Symbol*	*Quality (mm)*
Lt	*5.5*	*Wt*	*1.72*
W_{SIW}	*0.8*	*L_{SIW}*	*1.9*
D	*0.8*	*P*	*1.6*
a	*14*	*L*	*32*

Since the field distribution of mode in SIW has dispersion characteristics similar to the mode of the conventional dielectric waveguide, the design of the proposed SIW band-pass filter, makes use of the same design method for a dielectric waveguide filter. The filter can be designed according to the specifications [9]-[10]. Fig. 14 shows the simulation results of the opasse band filter structure shown in Fig. 13. The results are plotted for the scattering parameters (S11 and S12) against frequency from 1GHz to 3GHz. These results show a stop band mid band frequency of 1.9GHz, stop bandwidth ranges from 8 GHz to 12 GHz approximately 4 GHz. The period of the CSRRs based stop band filter is changed to 6 mm. The number of CSRRs in the ground plane is same as in the previous design.

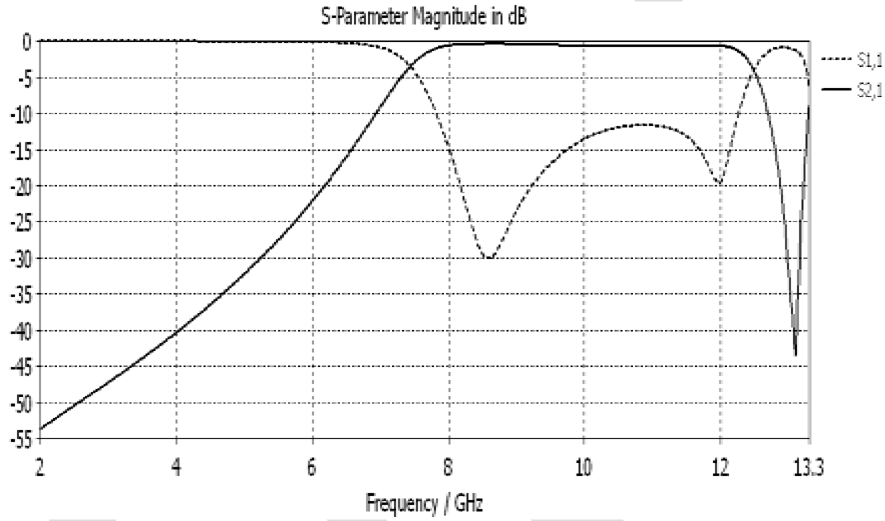


Fig.14. Stop band filter having 3 CSSRs in the stripline

Scattering parameters

Its simulated *S*-parameters in Fig14 . From the simulated results, the filter has a central frequency of 10 GHz, a fractional bandwidth of 72% and return loss better than 20 dB in the whole passband.

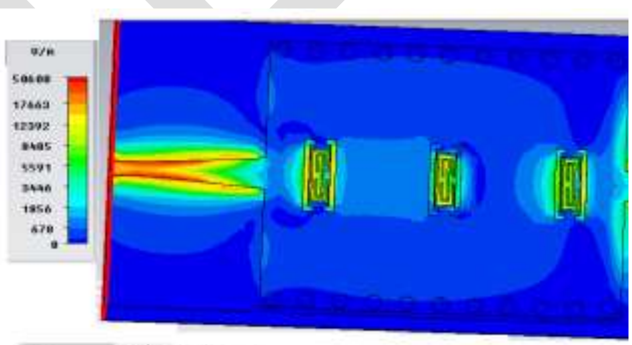
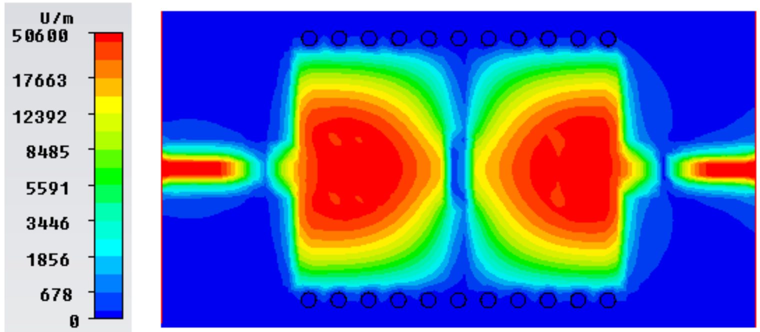


Fig 15. Electric field distribution of proposed filter with three cascaded SIW-CSRRs cells(a) top layer, (b) bottom layer.



CONCLUSION

Using the sub-wavelength resonator components of left handed metamaterials namely CSRR, more compact planar microstrip stop band filtersIn this paper, Substrate Integrated Waveguide (SIW) filter based on complementary Split ring Resonators (CSRRs) is presented in this work for X-band applications has been designed. The simulation process of the structure is done by using CST software. This type of filter is suitable for highdensity integrated microwave and millimeter wave applications. The design method is discussed; the effect of the aperture width of coupling and isolation is studied. By using SIW techniques, the compact size of the CSSRs is produced and easy to integrate with other planar circuit compared by using conventional waveguide. Single CSSR particle in the microstrp line gives a very narrow stop band at its resonant frequency with an extremely high Q factor but periodically placing these CSRR structures gives wide stop bands. This is especially of benefit for the growing numbers of microwave circuits required for the compact integrated circuits (ICs) for wireless communications.

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