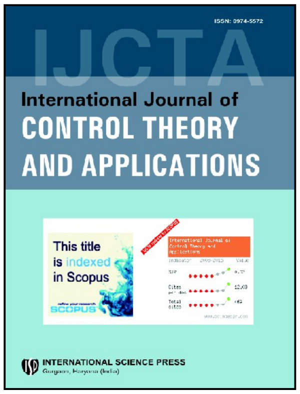

International Journal of Control Theory and Applications

ISSN : 0974-5572

© International Science Press

Volume 10 • Number 21 • 2017

Wide Band High Resonance Band Stop Filter Using Tapered Split Ring Resonator (SRR)

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Abstract: This article presents a customized edge-coupled split ring resonator (SRR). The proposed structure consists of four square SRRs with non-uniform strip width (Tapered width SRR) used to provide proper electrical and magnetic coupling with transmission line. In uniform SRR miniaturization methods, only the equivalent capacitance is increased where as in the proposed SRR, both the capacitance and inductance is increased. This structure preserves wider band width and high resonance in stop band. The electrical size of uniform and non-uniform SRR is same and it provides a high resonance with 90% wider bandwidth than uniform SRR. The transmission coefficient of S_{12}= -32dB and bandwidth of BW = 130MHz are simulated using Ansoft HFSS. Finally, various electrical and magnetic coupling of SRR are analyzed using parametric study.

Keywords :Tapered split ring resonator, microstrip line, narrow band stop filter

1. INTRODUCTION

Metamaterials are artificial materials with unusual properties, which are not directly available in nature. They have negative permeability (μ_r) and permittivity (ε_r) over a microwave frequency band. There are two main methods for realizing the metamaterials. They are right/left-handed transmission line which is established by loading the conventional transmission line (TL) with series capacitors and shunt inductors [2] and the conventional TL is loaded with split ring resonators [3], [4].

Recently, there has been growing interest in using split ring resonator (SRR) and complementary split ring resonator (CSRR) in the design of novel planar microwave components and radiating systems, especially it has the property of band pass and band reject filter response over a microwave frequency band. Split ring resonator (square, triangular, circular shapes) consists of an inner square with a split on one side embedded in an outer square with a split on the other side. The advantage of this type of resonators is high resonance over a wider bandwidth of frequencies in filter design either pass band or stop band. It also provides miniaturization of the structure compared to the conventional resonator structure, enabling the filter design to be compact. Many researches have been done at achieving SRRs with strong resonance and wider bandwidth. By using the equivalent circuit model of SRR, it is inferred that the fractional area occupied by the interior of resonators ring within the unit cell can be extended in order to achieve wider bandwidth resonance [5], [6]. For instance, compared to the edge-coupled SRR proposed by Pendry [3], the broad-side coupled split ring resonator (BC-SRR) has smaller electrical size [5]. But due to the increased capacitance, the resonator provides narrow bandwidth. Moreover, the structure is technologically more complex and difficult to fabricate due to the multilayer substrate. The spiral structure resonators are compact and uniplanar, but compared to edge-coupled SRRs, they are less efficient and provide weak resonance. Alternatively, the resonance bandwidth can be controlled by using single split ring resonator with a semi-lumped LC resonator, but this result in narrow bandwidth with weaker resonance and also has a larger electrical size. A sharp and narrow rejection band at resonant frequency is obtained by aligning SRRs with the slots in a Coplanar Waveguide (CPW) and the SRR dimensions are much smaller than signal wavelength, so the proposed filters are extremely compact and can be used to reject microwave frequency in CPW structure [7].

In this paper two pairs of tapered edge-coupled SRR with transmission line were used to provide sharp band stop filter. The proposed SRR has same electrical size of uniform SRR is used to provide proper distribution of current and voltage to the structure. It also compares the resonance between uniform SRRs and tapered SRRs. Finally a tapered SRR provides a wider bandwidth and high resonance than conventional SRR.

2. EQUIVALENT CIRCUIT CHARACTERISTICS OF TAPERED SRR LOADED WITH TRANSMISSION LINE

Fig. 1(a) shows an equivalent circuit model for unit cell tapered SRR with transmission line where L_{eq} and C_{eq} are equivalent inductance and capacitance of the SRR respectively and R_{eq} is resistive loss in SRRs. The magnetic coupling between SRR and the transmission line is represented by M and approximated by

$$M = L_{eq}\gamma G \tag{1}$$

Where G is the cell area occupied by the SRR and γ is the fitting parameter. The resonant frequency is obtained from

$$\Omega_o = \frac{1}{\sqrt{L_r C_r}} = \frac{1}{\sqrt{L_{eq} C_{eq}}} \tag{2}$$

The transmission line with SRRs coupling factor is defined as the ratio of resonator resistance (at the resonance frequency) to the sum of the external resistances [8]. Approximate value of L_{eq} is 2nH and the C_{eq} is 0.3pf are obtained by manual calculation. The coupling factor β is expressed as

$$\beta = \frac{R}{R_{eq}} = \frac{R}{2Z_o} = \frac{1}{2Z_o R_{eq}} = \frac{L_{eq}}{C_{eq}}(\gamma G)^2 \tag{3}$$

The coupling factor is also defined as the ratio of magnitude of reflection coefficient to the transmission coefficient and it is taken from simulated result.

$$\beta = \frac{|S_{11_0}|}{|S_{21_0}|} \tag{4}$$

Where S_{11} is reflection co-efficient and S_{21} is transmission co-efficient at the resonant frequency f_0. Equation (3) shows that increasing the equivalent inductance not only decreases the electrical size but also increases coupling co-efficient and it leads to stronger resonance. Using the simplified bandwidth equation for the structure [9],

$$BW_L \approx \sqrt{\frac{L_{eq}}{C_{eq}} \cdot \frac{(\gamma G)^2}{2Z_0}} \tag{5}$$

From this equation, it is very clear that when capacitance C_{eq} increases, bandwidth at resonant frequency is reduced. Similarly when L_{eq} increases bandwidth also increases which is useful in wideband filter design application.

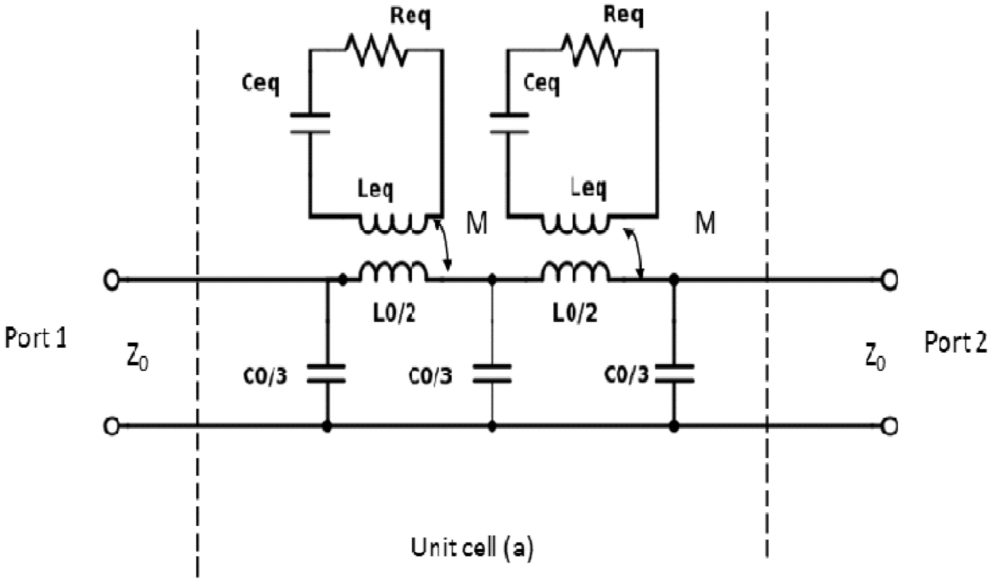

Figure 1(a): Tapered SRR with transmission line equivalent circuit model including SRR losses

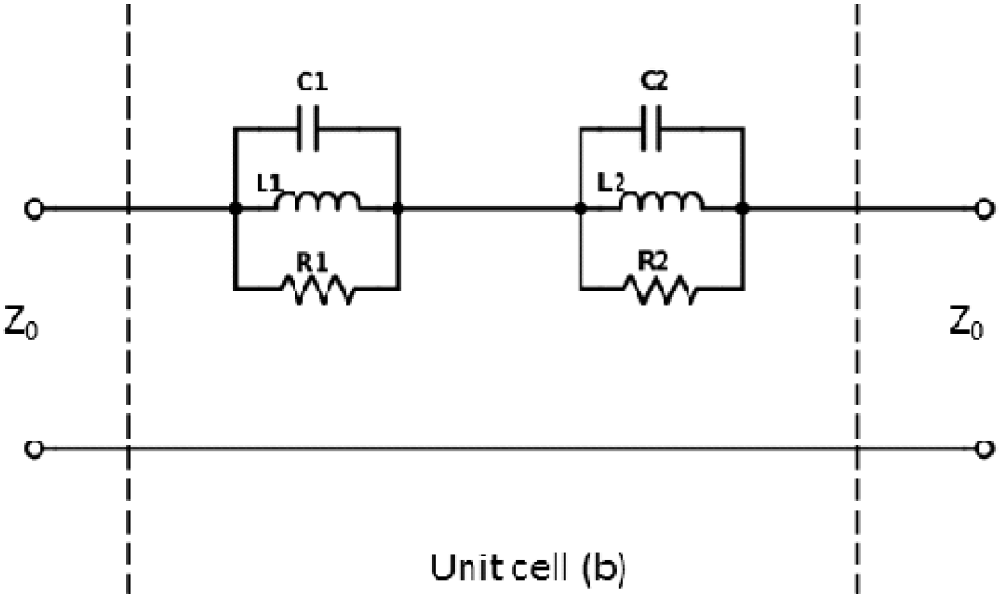

Figure 1(b): Simplified equivalent circuit model

3. STRUCTURE OF TRANSMISSION LINE WITH UNIFORM AND TAPERED SRR

The increase in the equivalent capacitance and inductance of the SRR leads to achieve high miniaturization level, wider bandwidth and high resonance. However, there is a conflict in this structure because of the increase in inductance and capacitance in the equivalent circuit. The space between narrow rings gets wider and results in smaller equivalent capacitance and vice versa.

The equivalent inductance and capacitance of an SRR structure is increased simultaneously. The concept of tapering the SRR is used to provide maximum voltage and current distribution along the transmission line and that improves the quality factor, especially in high quality factor resonators [10], [11].

The structure of uniform SRR and tapered SRR with transmission line is shown in fig 2(a) and 2(b). The two pairs of SRRs and transmission line are presented at power plane with respect to ground and they are separated by substrate, whose thickness is h=0.78mm (in this structure Duroid (tm) material is used) with relative permittivity $\varepsilon_r = 2.2$ and loss tangent $\tan(\delta) = 0.009$.

In order to verify the theory, two pairs of tapered SRRs with a transmission line between them were simulated and compared with uniform SRR. The design values of the structure are transmission line width w=2.3mm with coupling to 50Ù impedance, SRR outer edge length a=10mm, split ring gap g=1mm, uniform ring width c_c=1.5mm and tapered ring width c_l=0.5mm and d = 1mm.

Fig. 3 shows the comparative results of transmission coefficient between TL loaded with uniform and non-uniform SRRs. The transmission coefficient S_{12} for uniform SRR is -16dB at 6.5GHz. Similarly the transmission coefficient S_{12} for tapered SRR is -32dB at 6.6GHz. This graph shows the difference in resonance between uniform and tapered SRR response and moreover the fractional bandwidth is increased from 1.8% to 2.7%.

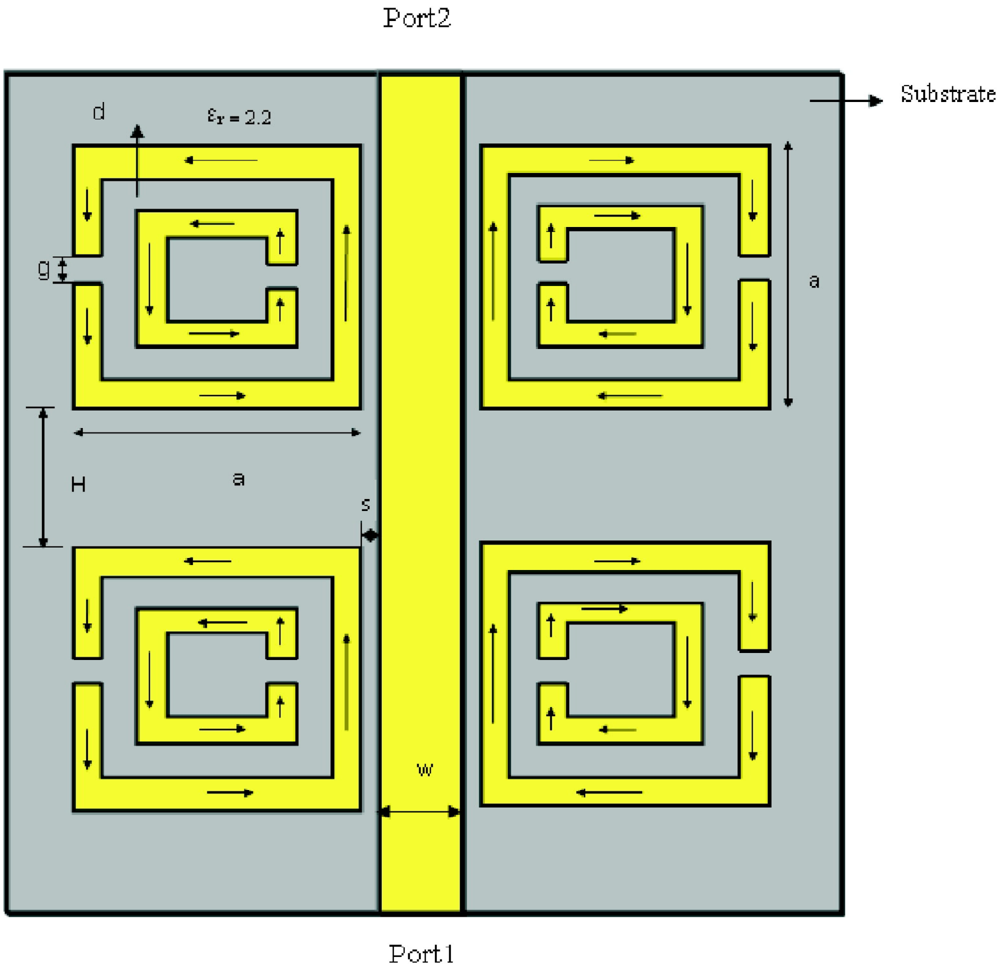

Figure 2(a): Microstrip line loaded with two pair of uniform SRR

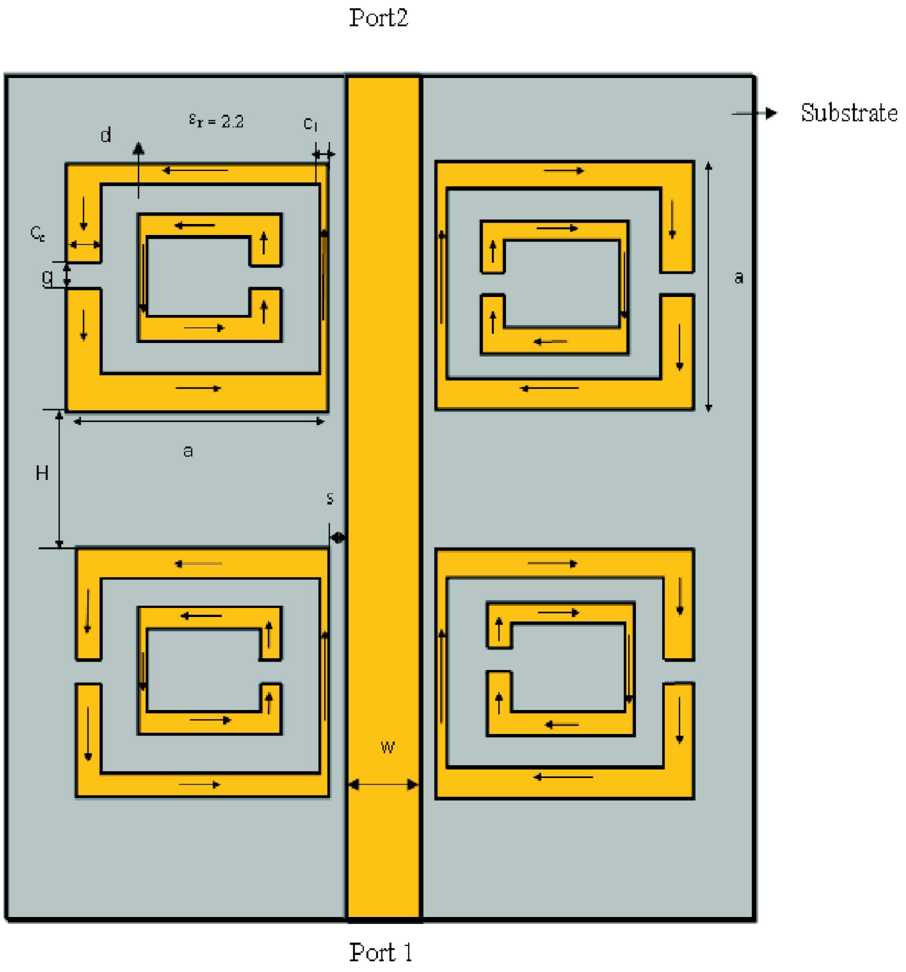

Figure 2(b): Microstrip line loaded with two pair of tapered SRRs

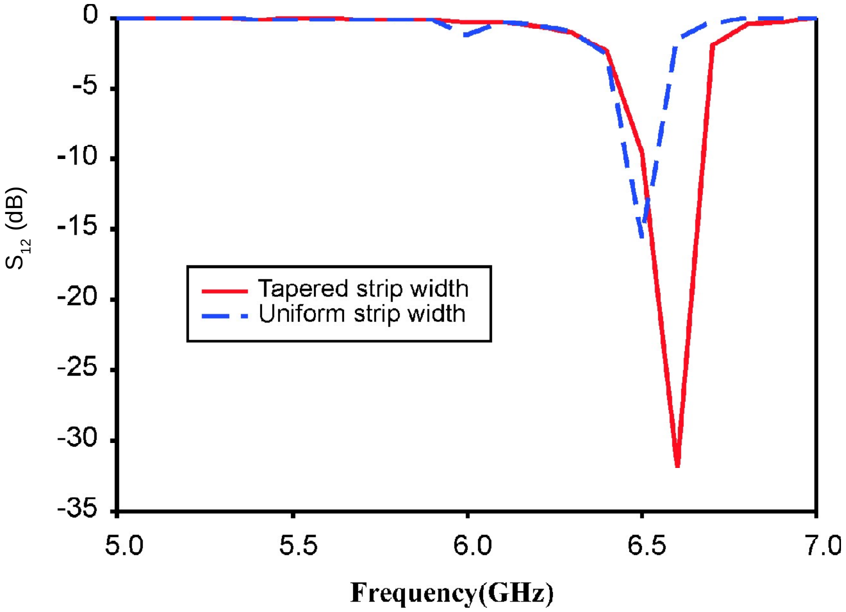

Figure 3: Simulated result of transmission coefficients of TLs loaded with two pair of uniform SRRs and tapered SRRs

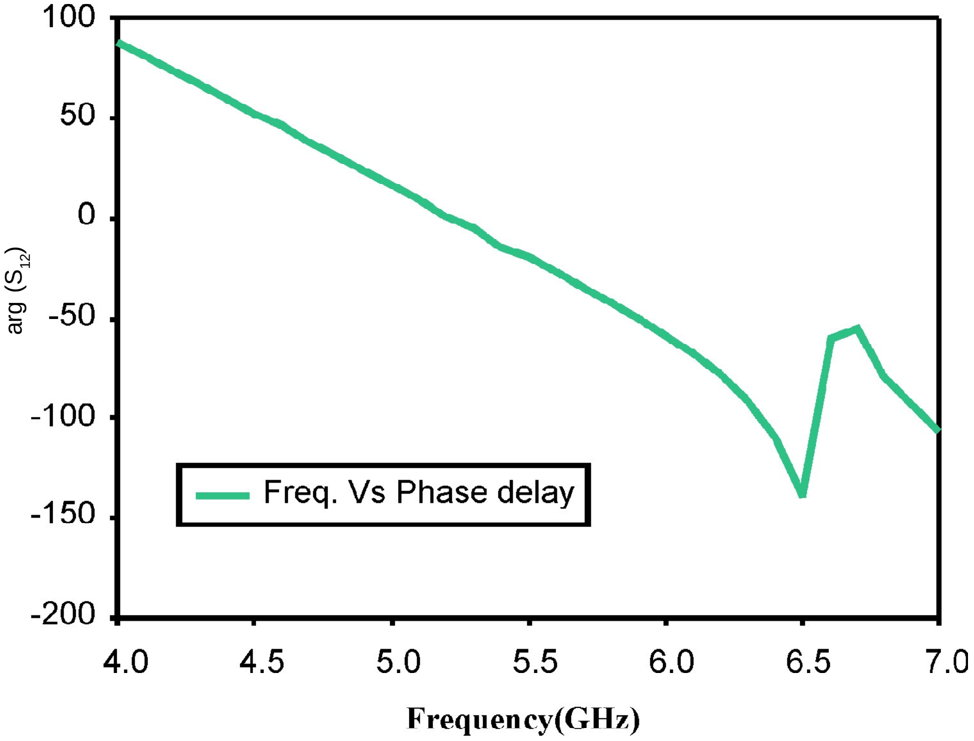

Figure 4: Phase delay variation with respect to over a wide range of frequency

Fig. 4 shows the linear phase variation in the pass band frequency over a wide band. And it shows the filter performance is linear with respect to frequency, so it is also called linear time invariant filter. And it also shows the sharp change in phase delay above 6.5 GHz that indicates the narrow stop band filter. This phase delay is measured at port 2 and it is represented by τ_d.

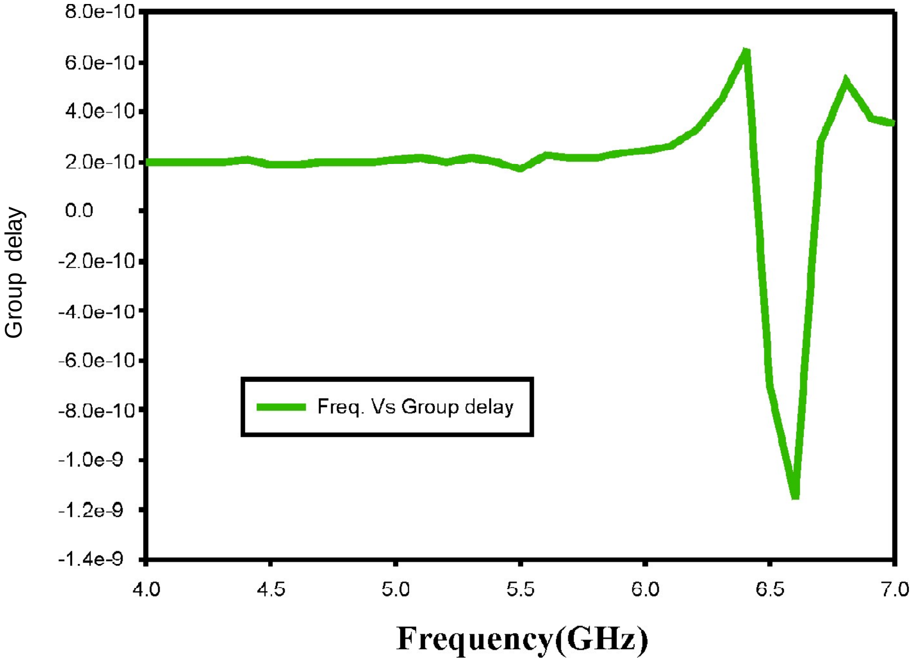

Figure 5: Group delay with respect to over a wide range frequency

Fig. 5 shows the group delay in the pass band frequency over a wide range. And the group delay is almost constant in the pass band. From this result observe that group delay is minimum in the pass band and it shows filter performance is good. For the case of above 6.5 GHz the group delay is high and it indicates narrow stop band frequency. The slope of group delay is high at resonant frequency. In theoretical definition group delay represent the true signal and also referred to as the envelope delay. Mathematically group delay is obtained by differentiation of phase delay.

$$\tau_d = \frac{-d\phi_{21}}{d\omega} \text{ Seconds} \tag{6}$$

4. PARAMETRIC ANALYSIS

Parametric analysis is done by varying two different parameter of the structure. They are (i) varying distance between microstrip line and tapered SRRs and (ii) the distance between adjacent tapered SRRs as shown in fig 2(a) and 2(b).

These variations are represented by s and H in this graph showing different resonances. The difference in values indicates the electrical and magnetic coupling response. The transmission line loaded uniform and tapered structure is simulated in Ansoft HFSS. Both the parametric study values are listed in the below table 1 and 2.

Table 1
Parametric Analysis of Fig 1(b) by Varying the Parameter s

S.No.	*s (mm)*	*S_{12} (dB)*
1	0.8	-10.5
2	0.6	-17
3	0.4	-9
4	0.45	-23

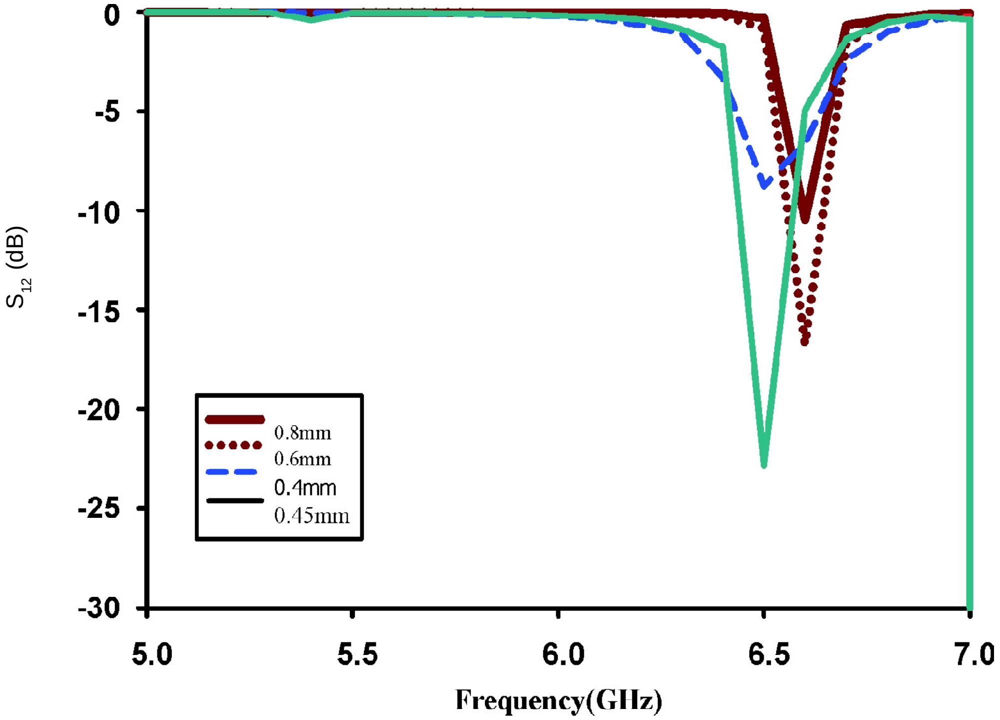

Figure 6(a): Optimization results by varying the distance between the microstrip line and tapered SRRs (s)

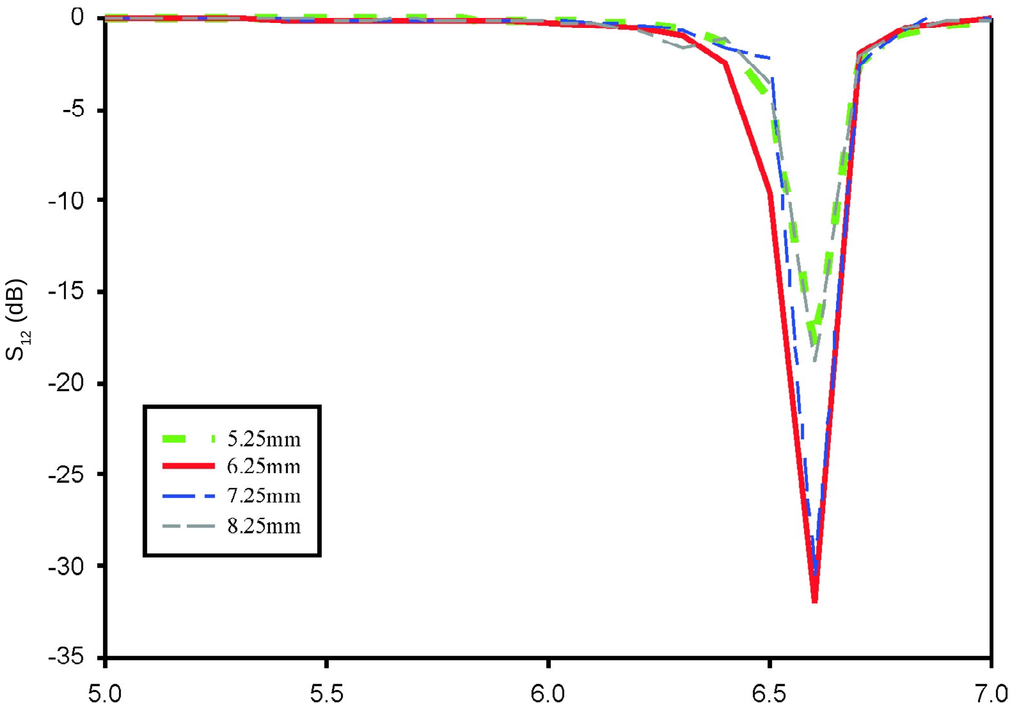

Figure 6(b): Optimization results by varying the position between adjacent SRRs (H)

Table 2
Parametric Analysis of Fig 1(b) by Varying the Parameter H

S.No.	*H(mm)*	*S_{12}(dB)*
1	5.25	-18
2	6.25	-32
3	7.25	-30.5
4	8.25	-19

The transmission co-efficient of -23dB for S_{12} with a higher magnetic and electrical couplings are observed at the parametric value of s=0.45mm. For the parametric value of H=6.25mm the transmission co-efficient S_{12} is given as -32dB at an operating frequency of 6.6 GHz.

5. CONCLUSION

A design of narrow band stop filter using modified edge-coupled SRR has been presented in this paper. Here the modified edge couple in the form of tapered width SRR provides proper electrical and magnetic couplings. Using this method the electrical area of SRR is reduced by 40% compared to the conventional SRR. Moreover the proposed structure gives the stronger resonance of 90% with wider bandwidth in the stop band. This wide bandwidth and high resonance are used in wideband filter design applications.

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