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Microwave Filter Based on Split Ring Resonators

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ABSTRACT

The design and simulations of a compact 3-pole Chebyshev filter using dielectric split ring resonators (DSRR), is explained. The DSRR filter is designed based on the method of coupled resonator filter. This filter is high unloaded quality factor (Qu is about 19000), small size, and high performance suitable for mobile communication. The filer has a bandwidth of 50 MHz, centred at 2.26 and return loss about -20 dB.

Keywords: Microwave Filters, Passive Filters, Chebyshev, Dielectric Filter, Split Ring Resonators.

INTRODUCTION

Filters represent an important part in microwave systems; they are used to select or confine the microwave signals within assigned spectral limits [1]. The split ring resonator filter is a microwave filter implemented by resonators called split rings, which is small structure, medium to high quality factor (i.e. metal 2000-5000, dielectric (TiO_2) 15000-20000), and can produce large range separation between the resonant frequencies of fundamental and higher orders modes with metal split ring resonators [2]. These features give an advantage when developing compact filters for mobile communications. The configuration and dimensions (thickness H, gap G, inner and outer radius (Rin, Rout)) of the split ring resonator are shown in Figure 1. The split ring resonator has a hollow cylindrical ring with a longitudinal gap. The loop of the split ring resonator represents the inductor, and the gap is the capacitor. The structure of a 3 split ring resonators filter is shown in Figure 2, shielded by a conductive enclosure.

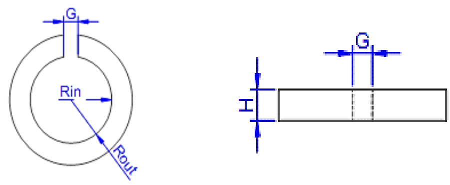

Figure. 1. Dimensions (thickness H, gap G, inner and outer radius (R_{in}, R_{out})) of the split ring resonator.

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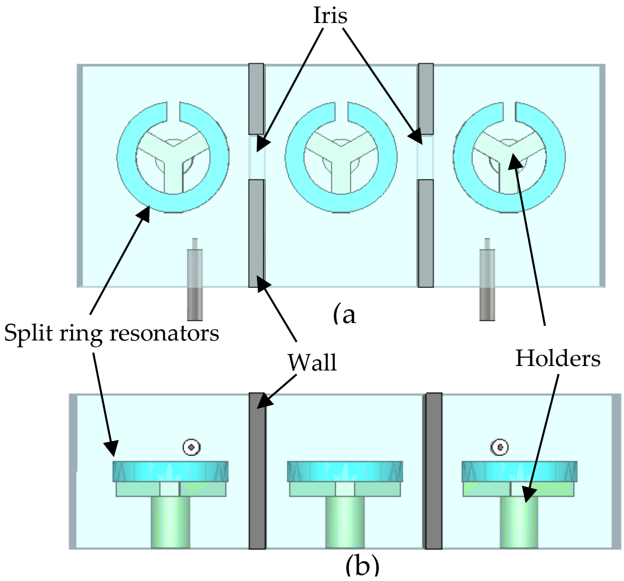


Figur. 2. (a) Top view 2 ports 3 split ring resonators SRR filter, (b) side view.

The design of microwave filter using dielectric split ring resonators (DSRR) develops an approach for designing reconfigurable microwave filters, with different order and bandwidth. Reconfiguration or adaptation property of DSRR filter depends on varying the coupling coefficients between adjacent resonators to achieve new bandwidths. This varying in coupling coefficients will be obtained by rotating the adjacent resonators. Figure 3 shows two different configurations when the angle is 0° and 180°, and figure 4 shows the relationship between rotation angle and coupling coefficients Kc. This research also aims to present low insertion loss and remain selectivity unchanged during bandwidth varies.

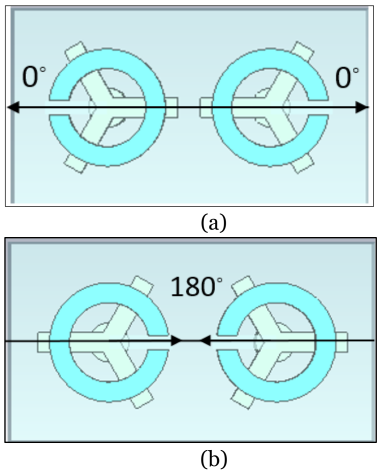


Figure. 3. (a) configuration of angle 0°, and (b) configuration of angle 180°

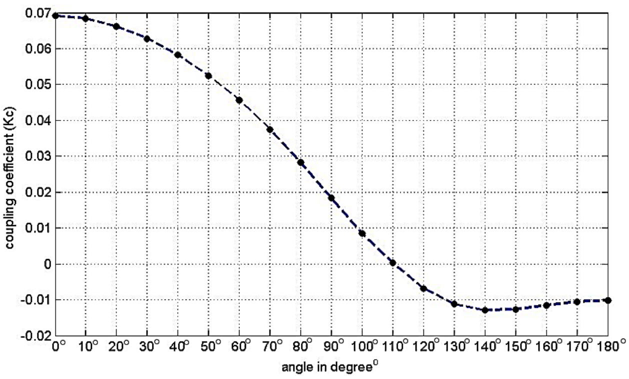


Figure. 4. coupling coefficient Kc against rotation angle in degree.

LITERATURE REVIEW

The split ring resonator, also known as slotted ring-cylindrical resonator [3], or loop-gap resonator [7], has been used in the past in pulsed electron paramagnetic resonance measurements, magnetron design and heavy-ion particle accelerators [4]. There is very limited literature about split ring resonator used in microwave filters. However, the limited literature reveals the design of split ring resonator filters needs accurate knowledge of coupling coefficient, quality factor, and resonant frequency. The split ring resonator can be coupled to external ports by capacitive or inductive coupling as in [7]. The inductive coupling can be achieved by a coupling loop, also called horseshoe in [2]. Capacitive coupling can be used by utilizing the monopole probe of a coaxial cable and resonator gap [7].
The coupling between two split ring resonators can be achieved electrically as shown in Figure 5 [6]. The position of resonators is side by side with their slots facing each other with an aperture between the resonators. The width of the aperture has more influence to coupling coefficients than the length of the aperture. There is a gradual decrease in the coupling coefficients when aperture thickness and separation (s) between resonators increases [6]. Magnetic coupling can also be used as demonstrated in [2], between two split ring resonators as shown in Figure 6.

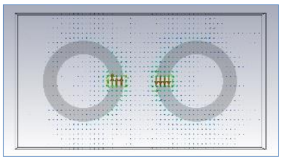


Figure. 5. Most electric field inside gaps.

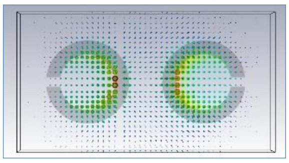


Figure. 6. Most magnetic fields around loop opposite to the gap.

Design of DSRR Filter

This section introduces a new bandpass filter design that uses a dielectric split ring resonator (DSRR). The DSRR filter is developed using the coupled resonator filter method. Its design process involves two primary stages: first, creating an ideal lossless filter, and second, realizing the filter's physical structure with 3D electromagnetic software. The specifications for this filter are detailed in Table 1.

TABLE 1: Filter Specifications

Centre frequency f_o	2.26 GHz
Bandwidth BW	50 MHz
Fractional bandwidth FBW	0.022
Return loss S_{11}	-20 dB
Filter order	3

A. Ideal Filter Design
In this step of design and according to filter specifications shown in table 1 the filter parameters, topology and frequency response are found. These results will then be utilized for the realisation of DSRR filter structure. The following three-points describe the design of ideal RF/microwave filter.

1. Chebyshev Lowpass Prototype
A two port Chebyshev lowpass prototype network is shown below in figure 7 [1].

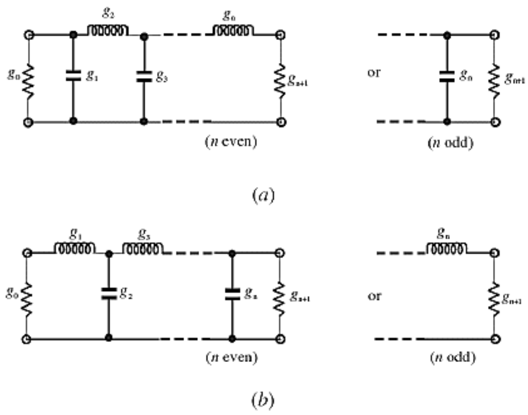


Figure. 7. Two types of lowpass prototype ladder circuits for all-pole filters. Circuit (a) begins with a shunt element, while circuit (b) starts with a series element. Both circuits produce the same response [1].

All lumped elements or g values in the figure 7 (with passband ripple L_{Ar} and the cut-off frequency of one) can be calculated from formulas in [1].

The two circuits in figure 7 are duel to each other they generate same response [10]. The g values for third order Chebyshev lowpass filter correspond to filter specifications are listed in table 2.

TABLE 2: g values of third Chebyshev prototype

g_o	1.0
g_1	0.8516
g_2	1.1032
g_3	0.8516
g_4	1.0

2. Coupled Resonator Filters

Coupled Resonator Filters are designed using the coupled resonator circuit method, which is based on the coupling values between resonators [1]. Figure 8 illustrates the topology for a two-port, n[th]-order coupled resonator filter. In this topology, the resonators are represented by circles, and the lines connecting them represent the coupling coefficients . The topology also shows the external coupling, represented by $M_{i,i+1}$ and (Q_{e1} & Q_{en})

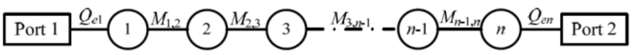


Figure. 8. displays the coupling topology diagram for an n-coupled resonator filter, as sourced from reference [9].

($M_{i,i+1}$) and (Q_{e1} and Q_{en}) represent the main parameters to design n^{th} coupled resonator microwave filters. With given g values of lowpass prototype filter, ($M_{i,i+1}$) and (Q_{e1} and Q_{en}) are formulated directly [1] as

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \qquad for\ i = 1\ to\ n-1$$

$$Q_{e1} = \frac{g_1 g_0}{FBW} \quad \text{and} \quad Q_{en} = \frac{g_n g_{n+1}}{FBW} \qquad (1)$$

Where the FBW is the fractional bandwidth. For two ports third order Chebyshev filter the coupling coefficients between adjacent resonators are $M_{12} = M_{23} = 0.022$ and the external quality factor $Q_{e1} = Q_{e2} = 48$. These parameters calculated from equations (1) with given g values in table 2 and filter specification in table 1.

3. General $n \times n$ Coupling Matrix of n-Coupled Resonator Circuit with 2-Port

The ideal filter response corresponds to filter specifications calculated using coupling matrix $[A]$ and scaled external quality factor q [1]. The coupling matrix $[A]$ as given in [1]

$$[A] = [q] + p[U] - j[m] \quad (2)$$

$$p = j\frac{1}{FBW}\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right)$$

In the equation, [U] represents the n×n identity matrix. The complex lowpass frequency variable is denoted by the n×n matrix p. The filter's center frequency is ωo, and its fractional bandwidth is FBW. The scaled external quality factor is an n×n matrix, [q]. The normalized coupling coefficients are given by the n×n matrix, [m]. The normalized coupling coefficient ($m_{i,i+1}$) and the scaled external quality factors (q_{e1} and q_{en}) can be directly calculated.

$$m_{i,i+1} = \frac{M_{i,i+1}}{FBW} = \frac{1}{\sqrt{g_i g_{i+1}}} \quad \text{for } i = 1,2,\dots,N-1 \quad (3)$$

$$q_{e1} = FBW.Q_{e1} = g_0 g_1 \quad \text{and}$$

$$q_{en} = FBW \cdot Q_{en} = g_n g_{n+1}$$

The S-parameters of ideal filter response can now be calculated and plotted corresponding to filter specifications using coupling matrix $[A]$ and scaled external quality factor results, in the two equations given below [1]

$$S_{11} = \pm\left(1 - \frac{2}{q_{e1}}[A]^{-1}_{1,1}\right) \quad (4)$$

$$S_{21} = 2\frac{1}{\sqrt{q_{e1} \cdot q_{en}}}[A]^{-1}_{n,1}$$

B. Realisation of DSRR Filter

This step of design presents simulations using 3D electromagnetic software. The key purpose behind the following CST simulations is to obtain the physical dimensions of DSRR filter that keep the performance and parameters close as possible to desired filter specifications in table 1 and the ideal filter in the previous step (section *A*). Depend on dimensions of filter structure that will be obtained from CST simulations can manufacture the DSRR filter.

1. Dielectric Split Ring Resonator DSRR Simulation

This section present CST simulation using Eigenmode solver for one Dielectric split ring resonator. Four dimensions of DSRR (thickness *H*, gap *G*, inner and outer radius (R_{in}, R_{out})), and dimensions of housing (length a, width b, and height h) as shown in figure 9 are varied to obtain the optimum size which can achieve a resonant frequency close to filter specifications. Titania (TiO_2) with 97.65 dielectric constant material (ε_r), and 7.2×10^{-5} loss tangent at 2 GHz has been chosen to implement the Dielectric split ring resonator (DSRR). Table 3 states the optimum dimensions of DSRR and housing. The unloaded quality factor Q_u for optimum dimensions is 18000, the value of Q_u is calculated with CST software.

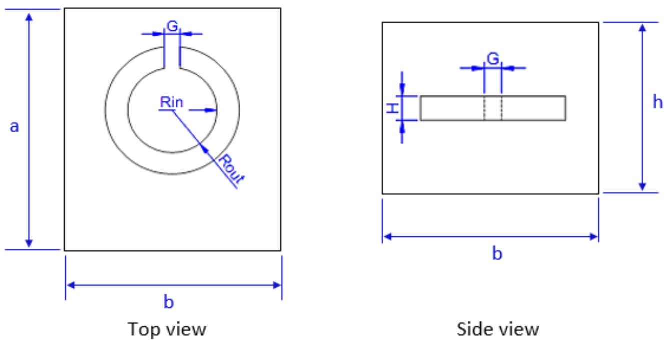
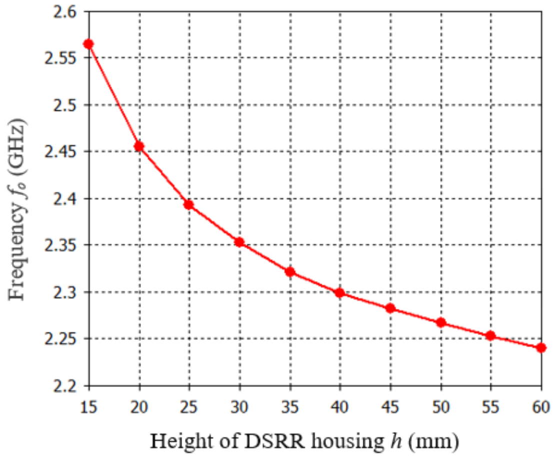


Figure. 9. Dimensions of dielectric Split Ring Resonator DSRR.

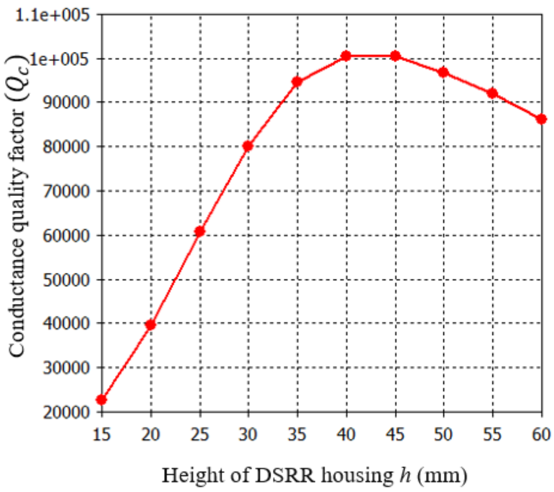
TABLE 3
Dimensions of Dielectric Split Ring Resonator DSRR in (mm).

R_{out}	15
R_{in}	10
H	5
G	3.5
a	60
b	50
h	40

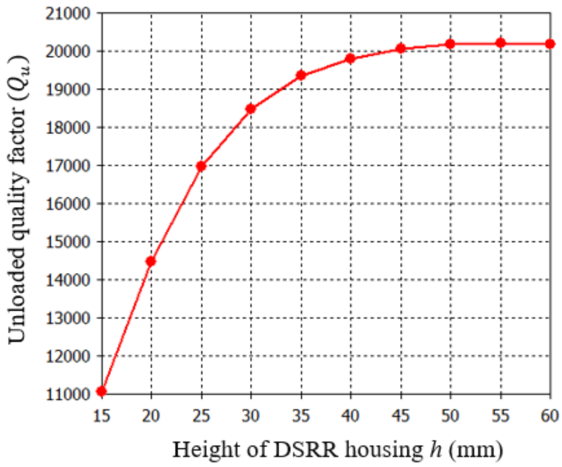
Simulation results presented in Figure 10 (a, b, and c) demonstrate that the conductance quality factor (Qc), unloaded quality factor (Qu), and frequency (f) are all significantly affected by the height of the DSRR housing. This information is used to help select the appropriate unloaded quality factor and housing size.



(a)



(b)



(c)

Figure. 10. The variation of (a) frequency, (b) conductance quality factor and (c) unloaded quality factor with the housing height of the dielectric split ring resonator (DSRR).

2. Extraction of External Quality Factor

A method for extracting the external quality factor (Q_e) from a physical structure using CST software is discussed [1]. This process also determines the ideal probe feeding position and dimensions [1]. The external quality factor (Q_e) can be directly obtained from the magnitude of S_{21}, as illustrated in Figure 11. This S_{21} response is based on simulations of the structure shown in Figure 12. The external quality factor can be calculated using the formula provided [1],

$$Q_e = \frac{f_o}{\Delta f_{3dB}} \qquad (5)$$

f_o refers to the resonant frequency, and Δf refers to the 3dB bandwidth.

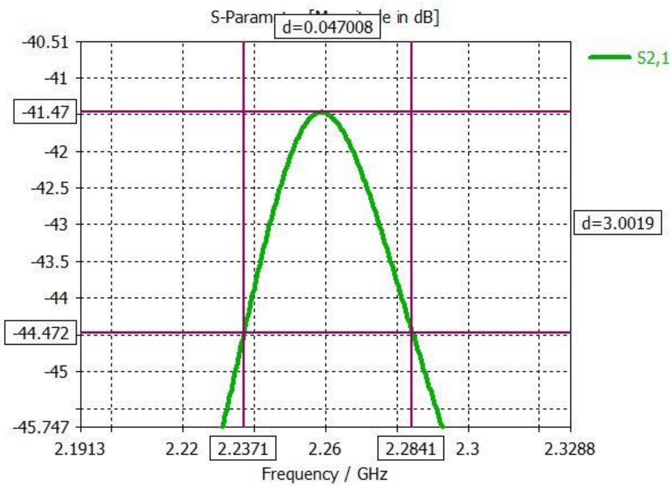


Figure. 11. The S_{21} simulated results of the model shown in figure 12.

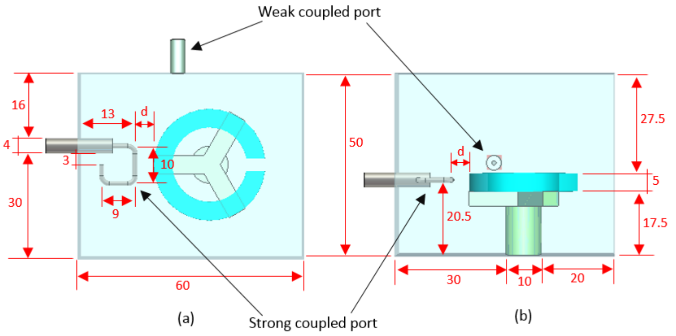


Figure. 12. Model with Two ports and one resonator, (a) is top-view and (b) is side-view.

Figure 13 displays the external quality factor Q_e against various values of d. The DSRR filter's design will make use of this Q_e graph.

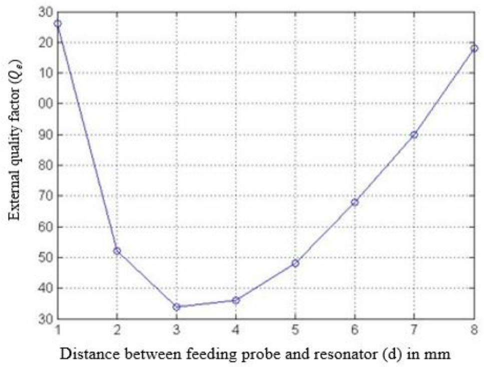


Figure. 13. The Q_e values obtained from the simulated S_{21} response for different values of d.

3. Extraction of Coupling Coefficient

Here we discuss method used to find coupling coefficients between two adjacent resonators described in [1]. The physical structure in this process need two ports loosely coupled to two adjacent resonators [11], as shown in figure 14. The physical structure simulated using CST software to calculate coupling coefficient from two split resonant frequencies in S_{21} magnitude as shown in figure 15. The relation between the coupling coefficient K_c and the resonant frequencies f_1 and f_2 is as follows [1]:

$$K_c = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \qquad (6)$$

Varying the size of iris and distance between resonators to find the desired coupling coefficient K_c that correspond to coupling coefficients $M_{12} = M_{23} = 0.022$ of ideal filter calculated in section A.

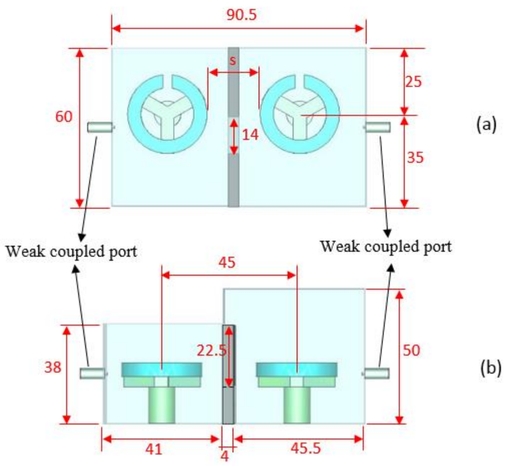


Figure. 14. Structure of Two loosely coupled ports

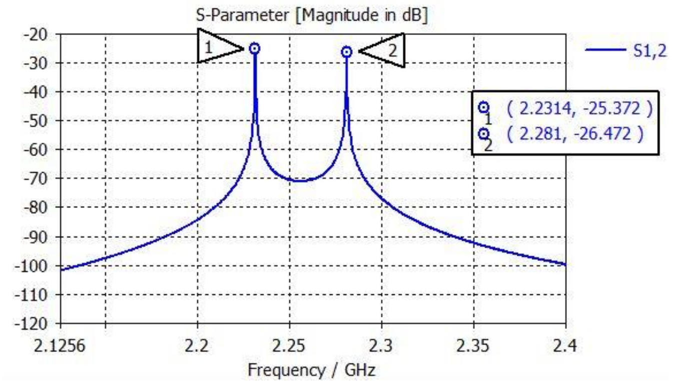


Figure.15. S_{21} simulated results for the model of two DSRRS.

Figure 16 shows the coupling coefficients K_c against various values of s. The DSRR filter's design will make use of this K_c graph.

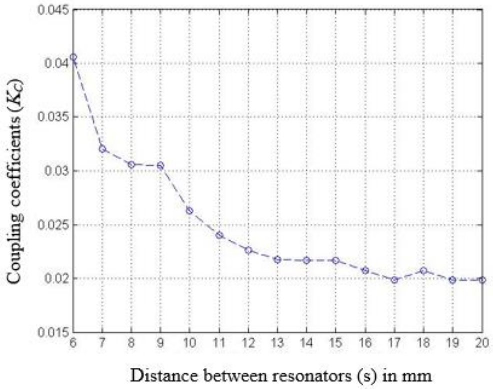


Figure. 16. Kc values obtained from the simulated S_{21} response for different values of s.

RESULTS AND DISCUSSION

DSRR Filter Simulation

The dimensions of DSRR filter structure are collected from previous simulations of sections 1, 2, and 3. These dimensions represent the initial values (before optimisation) are supposed to achieve as possible the parameters of ideal filter in section *A*. Figure 17 shows simulation response of DSRR filter structure with the initial dimensions. The response after optimisation by using CST software is shown in figure 18.

The optimised physical structure dimensions are shown in figure 20. The optimised passband response has insertion loss varying between -0.1 to -0.06 dB and return loss vary between -18 to -21 dB. As well there is one transmissions zero is increased the attenuation in one side of the pass band, and on the anther side of the pass band a new modes is found near to passband as is shown in figure 19. The simulated response shifted by 10 MHz from the filter specification in table 1, and bandwidth decreased by 10 MHz.

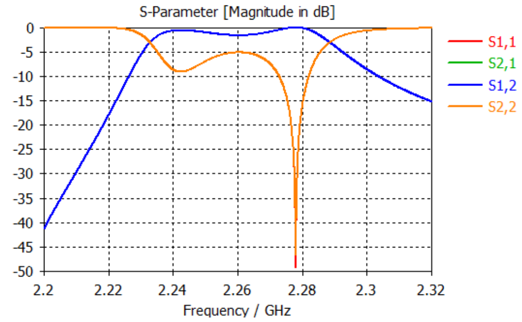


Figure. 17. Simulated results of DRSS filter with initial dimensions

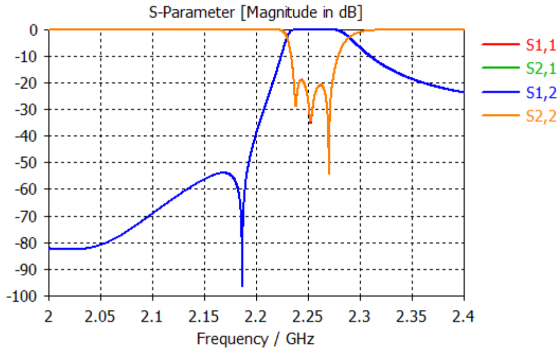


Figure. 18. Simulated response of DRSS filter with optimised dimensions

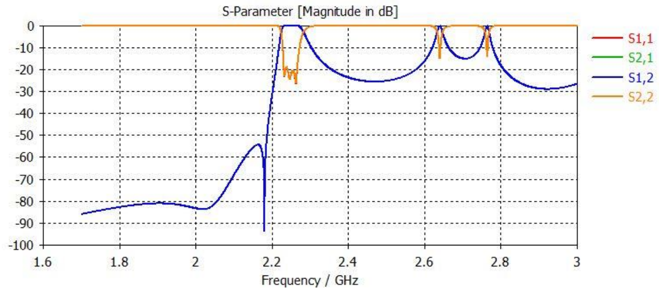


Figure. 19. Simulated response of DRSS filter with optimised dimensions

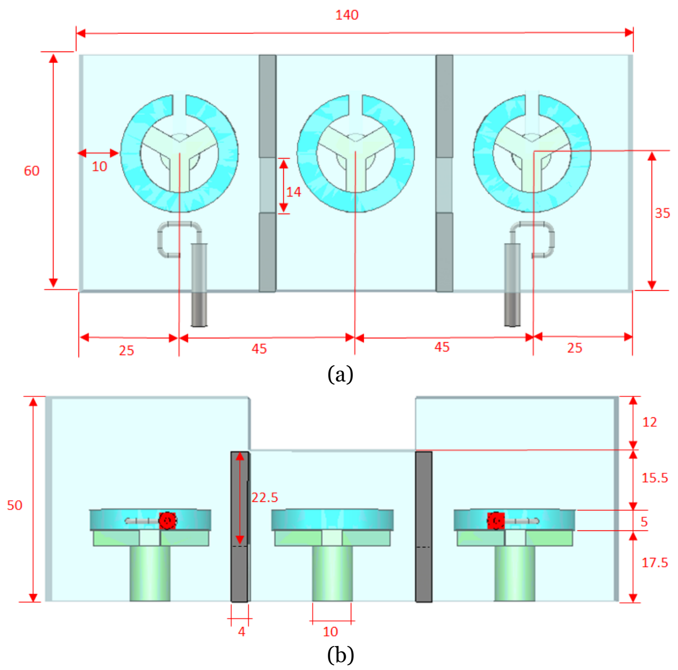


Figure. 20. DRSS filter dimensions after optimisation in (mm), (a) is the top view and (b) is the side view.

CONCLUSION

The design and simulations of DSRR filter based on coupled resonator circuit method was reported. The filter designed and simulated in the two main steps. The design of ideal filter as first step then realization by CST studio software as second step. This filter which is about 140 mm long, 60 mm width and 50 mm height. The filter response is about -0.1 insertion loss and -20 return loss. For future work, a bandwidth tunable filter can be designed using same SRRs in this paper. The filter resonators can be rotated to achieve this bandwidth tuning without the need for additional tuning components.

REFERENCES

[1] J-S Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications," John Wiley & Sons, Inc.,NY, 2001.

[2] Mostafavi, R.F., Mirshekar-Syahkal, D., and LIM, Y.C. "Small filters based on slotted cylindrical ring resonators," IEEE MTT-S, Int. Microw. Symp. Dig., Phoenix, USA, May, 2001, pp. 1795-1798

[3] D. Mirshekar-Syahkal, Y. C. M. Lim, and R. F. Mostafavi, "Resonant frequency of slotted ring resonator," in Proc. 30th Eur. Microwave Conf., vol. 2, Paris, France, Oct. 2000, pp. 197–200.

[4] Y.C.M., R. F. Mostafavi and D. Mirshekar-Syahkal'' unloaded Q factor of sloted cylindrical ring resonator'' university of essex.

[5] R. F. Mostafavi, and D. Mirshekar-Myakal'' small filter based on slotted cylindrical ring resonator'' Microwave Symposium Digest, 2001 IEEE MTT-S International Volume: 3 Year: 2001 , Page(s): 1795 - 1798 vol.3

[6] J. M. chuma and D. Mirshekar-Syakhal ''analysis of electric coupling between slotted cylindrical ring resonators'' electronics letters ,2001, vol 37 No 19

[7] M. Mehdizadeh, T. K. Ishi, J. S. Hyde, andW. Froncisz, "Loop-gap resonator: A lumped mode microwave resonant structure," IEEE Trans. Microwave Theory Tech., vol. MTT- 31, pp. 1059–1063, Dec. 1983.

[8] Chi and kawthar A. zaki ,Dielectric combline resonator and filter, 1998 IEEE

[9] E. Nugoolcharoenlap "New Design Approach of Antennas with Integrated Coupled Resonator Filters" ," Ph.D. dissertation, EESE School., Birmingham Univ., Birimigham, MA, 2015.

[10] W. Xia "Diplexers and Multiplexers Design by using Coupling Matrix Optimisation" ," Ph.D. dissertation, EESE School., Birmingham Univ., Birimigham, MA, 2015.

[11] X. Shang "SU-8 Micromachined Terahertz Waveguide Circuits and Coupling Matrix Design of Multiple Passband Filters" ," Ph.D. dissertation, EESE School., Birmingham Univ., Birimigham, MA, 2011.