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Compact UWB Bandpass Filter with Two Notched Bands Using SISLR and DMS Structure

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Abstract—This paper presents a design and fabrication of an ultra-wideband bandpass filter with two notched (rejection) bands. Ultra-wideband (UWB) systems are systems with the electromagnetic spectrum from 3.1 GHz to 10.6 GHz. The designed filter removes WLAN and satellite signals which are 5.8 GHz and 8 GHz. For designing filter, we use a stepped-impedance stub-loaded resonator (SISLR). To provide two notched bands, a radial stub loaded resonator with a defected microstrip structure (DMS) is used. The presented filter has more analytic relations and simpler structure than prior works. This filter is fabricated on an RO4003 substrate with dielectric constant of 3.55. The dimensions of the filter are $10 \times 25\,\text{mm}^2$ which are more compact than prior structures. The measurements have a good agreement with predicted results which verifies the feasibility of the UWB filter.

1. INTRODUCTION

In February 2002, the Federal Communications Commission (FCC) declared the frequency band of 3.1 GHz to 10.6 GHz as unlicensed spectrum for ultra-wideband systems (UWB). This commission set up initial rules in commercial and industrial applications. In this report, bandwidth of 3.1 GHz to 10.6 GHz was considered as a UWB bandwidth [1–3]. However, unwanted radio signals of narrow band such as local area network (WLAN) and some satellite communication systems signals can interfere with UWB. Therefore, UWB bandpass filters with one or several notched bands are required to reject these interfering signals. Two important bands of unwanted signals are WLAN and satellite communication band which are in 5.8 GHz and 8 GHz [4–6].

Different methods have been used to design UWB filter (BPF) like: multi-mode resonators (MMR), electronic band-gap (EBG), coupled line structure, and defected ground structure (DGS) [7–13]. However, one of the challenging steps in designing filter is to provide two notched bands in WLAN and satellite frequencies. Designers use several ways in order to create one or more notched bands. Some of the important ways are multiple-mode resonator (MMR), defected ground structure (DGS), and other innovative structures [14–16].

MMR structure is one of the most important ways to implement UWB filters. This structure is mostly a Step Impedance Resonator structure (SIR). MMR, when being placed near different structures such as SISLR, provides a UWB filter with smooth response [17–20]. MMR structure can also provide a UWB bandpass filter near the coupled lines [21–23].

Multiple-mode resonators have different structures such as hexagon [23] and ring [21]. Circular (ring) filter [21] can provide two notched bands, but six edged filter [23] has only one notched band.

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Unlike these two structures, other structures which have regular shapes and analytical relations are based on SIR. These structures can be fabricated on substrates with high dielectric constant [24, 25] which is about 8 or 10. Using high dielectric constant leads to decreased dimensions of the circuit and increased cost of the structure. Other combined SIR structures are proposed in [26–28]. Using a low-pass filter leads to increasing bandwidth and flatness of the filter [28]. In [28], unlike [25] two parts of the designed filter are put near each other consecutively. Hung et al. have used a curved Step Impedance Resonator (SIR) structure [27]. In [27] two parts of the top impedance are curved and used as a single line couple. This innovation has led to a compact circuit and decreases dimensions.

In this paper, we use a stepped-impedance stub-loaded resonator. A redial stub loaded resonator (RSLR) with DMS is used to provide two notched bands. The numerical results show that the designed circuit is more compact and simpler than prior structures. The structure is fabricated, and experimental results are compared with simulation.

2. ANALYZING STRUCTURE OF THE PRESENT SISLR

We derive an SISLR initial structure from [18] which is longer than the structure in [19]. Therefore, we attempt to compress the structure with analytical relations. Fig. 1 shows the used structure.

$$k_4 \tan(\theta_4) \tan(\theta_3) = 1 \tag{1a}$$

$$K_1 = \frac{Y_1}{Y_2}; \quad K_2 = \frac{Y_3}{Y_2}; \quad K_3 = \frac{Y_3}{Y_4}; \tag{1b}$$

$$\frac{K_2 - K_1 K_2 \tan(\theta_1)\tan(\theta_2)}{2(\tan(\theta_3)\tan(\theta_4) - K_3)} = \frac{K_1 \tan(\theta_1) + \tan(\theta_2)}{\tan(\theta_4) + K_3 \tan(\theta_3)} \tag{1c}$$

In these equations, K_i is the coefficient of the admittance ratio [18, 19]. By solving Equation (1c), we can obtain unknown values. These coefficients can be calculated by using initial values for K_i like 1.2, 2, and 3, respectively [27]. To simplify the calculations, Equation (1c) is rewritten as Eq. (1d), and according to symmetric shape, we can solve Equation (1d) numerically. The numerical results are shown in Fig. 2. These values are calculated for $K_1 = 1/3$ and with initial assumption of $\theta_1 = \theta_3$ and $\theta_2 = \theta_4$.

$$\frac{K_2 - K_1 K_2 \tan(\theta_1)\tan(\theta_2)}{K_1 \tan(\theta_1) + \tan(\theta_2)} = \frac{2(\tan(\theta_3)\tan(\theta_4) - K_3)}{\tan(\theta_4) + K_3 \tan(\theta_3)} \tag{1d}$$

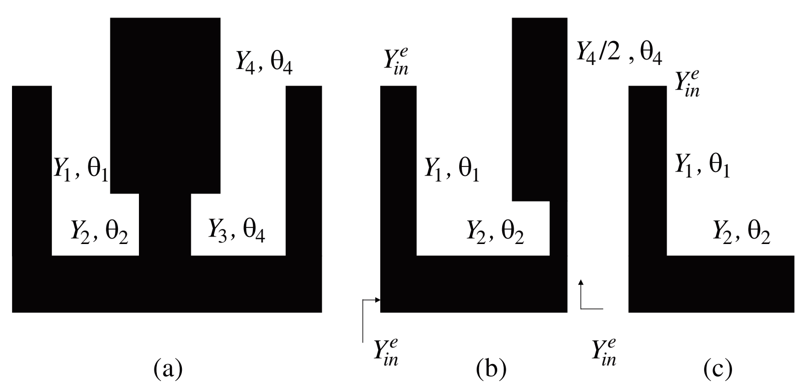

Figure 1. (a) Configuration of MMR; (b) Even-mode; (c) Odd-mode.

According to the relation in Eq. (1d), we can plot Fig. 2, where their intersection gives us the values of electric lengths. Calculated impedances for the lines are equal to $Z_1 = 145$, $Z_2 = 47.85$, $Z_3 = 55$, and $Z_4 = 16.5$.

In designing the filter, an interdigital coupler is used. This type of coupler is taken from [22]. According to [22] in parallel single-line couplers, current density passes less than interdigital one. Due

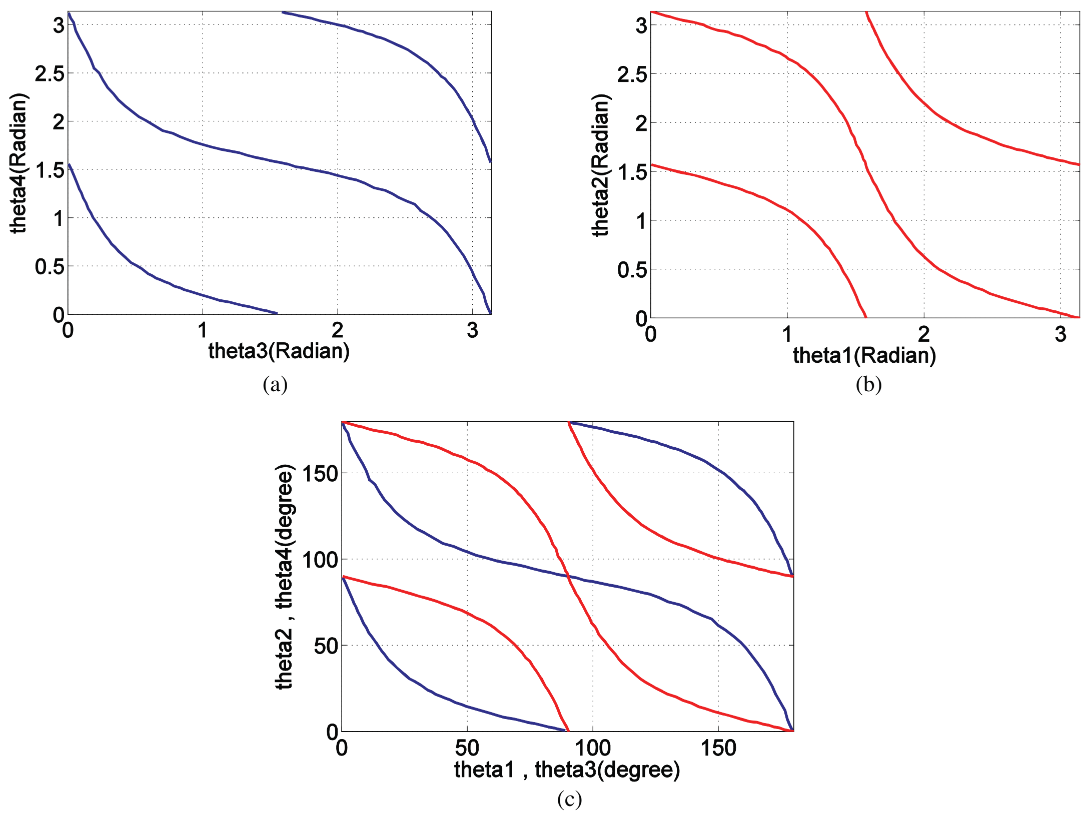

Figure 2. (a) Right side of Equation (1d). (b) Left side of Equation (1d). (c) Both side of Equation (1d).

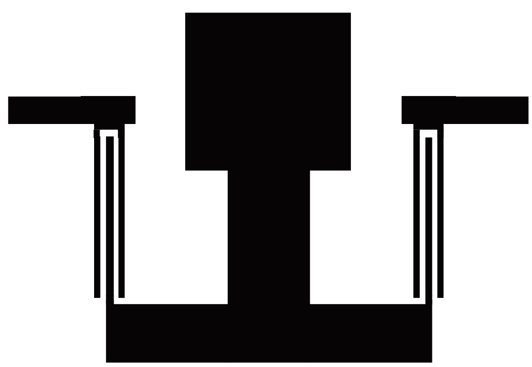

Figure 3. Basic proposed UWB (BPF).

to Fig. 2(c), all electric lengths are about 88–100 degrees, and optimal value is obtained by small variations. The structure is shown in Fig. 3.

Figure 4 shows the response of the filter in HFSS. The response has a slight difference in losses and bandpass due to the meshing and solving methods.

3. DESIGNING TWO NOTCHED BANDS

To create two band gaps, the structures of [29] (Fig. 5) with the structure of RSRL [30] have been used. In [29], a UWB bandpass filter was designed with two notched bands by using Genetic algorithm. Equations (1e) and (1f), which are extracted from [29], can be used to calculate the notch band

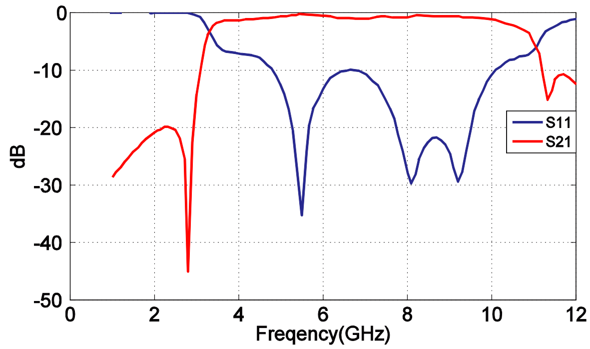

Figure 4. Proposed filter response.

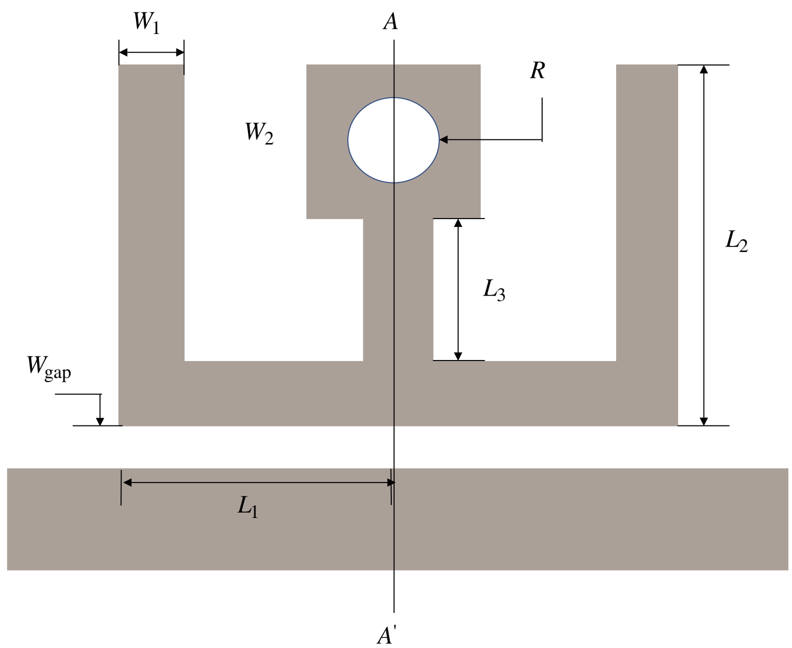

Figure 5. A filter two notched band.

frequencies. With regard to Figs. 3 and 5, the choice of L_1 will be limited.

$$\lambda_{notch-even} = \frac{c}{4(L_1 + L_2 + L_3)\sqrt{\varepsilon_{eff}}} \tag{1e}$$

$$\lambda_{notch-odded} = \frac{c}{4(L_1 + L_2)\sqrt{\varepsilon_{eff}}} \tag{1f}$$

The stubs of structure [29] with radial stubs of [30] are combined to form the structure in Fig. 6 as a filter with two notched bands. Short circuit stubs are used to increase the attenuation in the notch bands.

Due to more circuit compression and easy fabrication, all distances between the microstrip lines are at least 0.15 mm. This compression causes change in the circuit size and frequency shifting.

4. UWB FILTER WITH TWO NOTCHED BAND

Figure 6 shows the combination of an E-shape stub [29] and a radial stub [30]. Fig. 7 shows the arrangement of these stubs. In this figure, $S1$ and $S2$ are added to increase the width of notch band. The length of the filter is 30 mm.

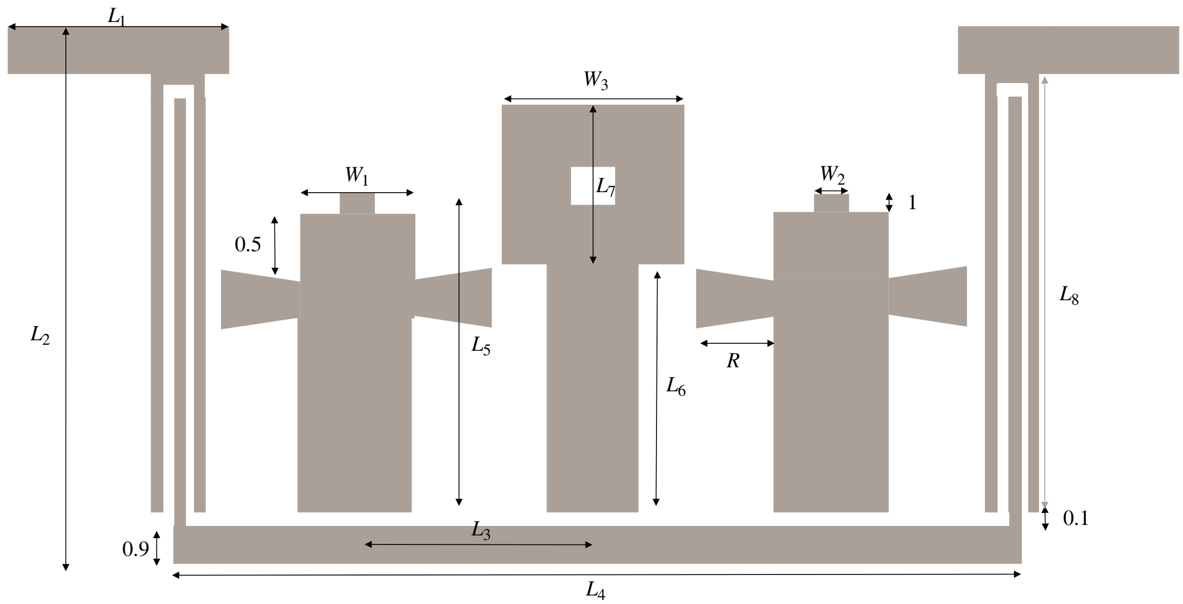

Figure 6. Proposed UWB filter with two notched bands.

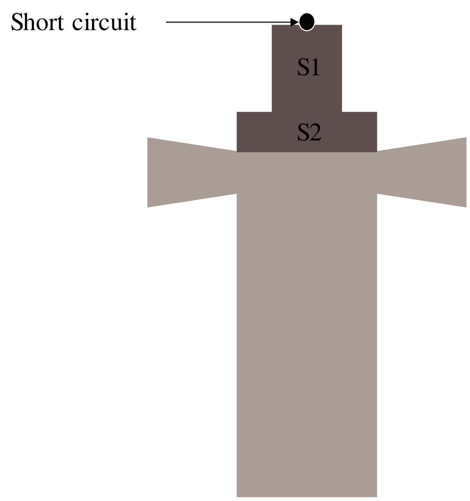

Figure 7. A sample of proposed stub filter.

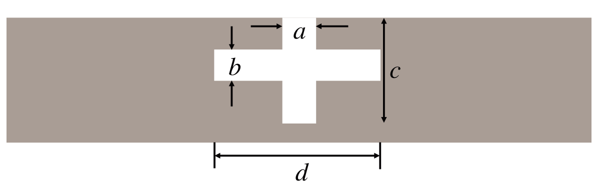

Figure 8. DMS structure.

The parameters of Fig. 6 are $L1 = 4$, $L2 = 11$, $L3 = 5.1$, $L4 = 18$, $L5 = 5.5$, $L6 = 3.8$, $L7 = 5.8$, $L8 = 8.8$, $R = 1.7$, $W1 = 1.3$, $W2 = 0.6$, $W3 = 5$. All dimensions are in millimeters.

To solve the challenge of increasing the dimension and frequency shift, a DMS structure is used. The structure of the DMS used in [31] is extracted and shown in Fig. 8. By putting together three of these structures with each other and applying them to the final structure, the filter can be obtained.

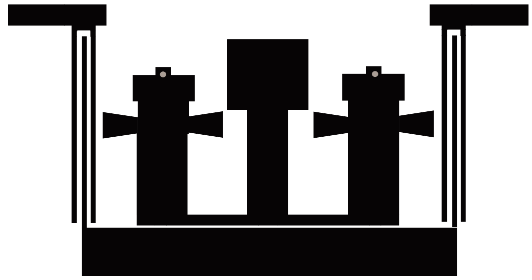

Figure 9. Final Proposed UWB filter with two notched band and DMS.

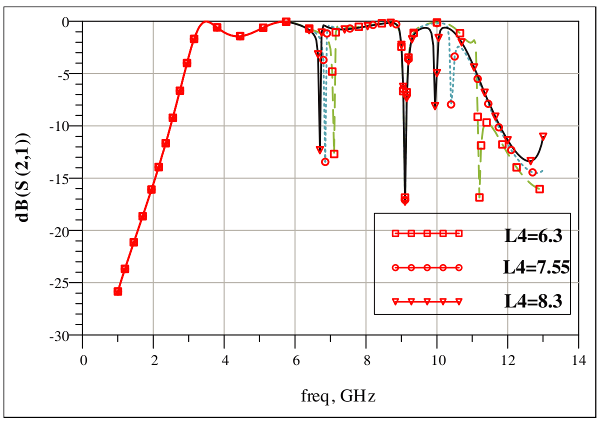

Figure 10. Sensitives analyzing for SLR.

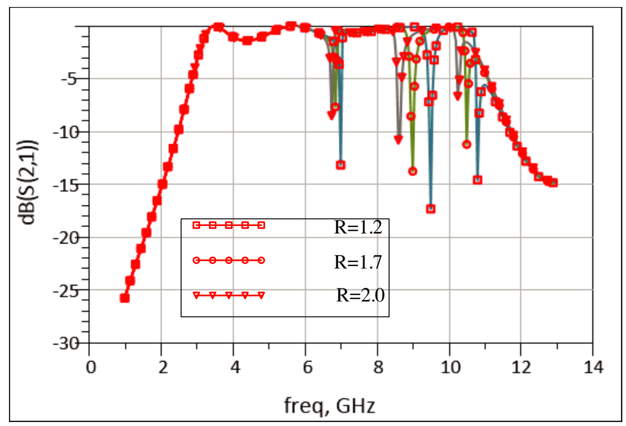

Figure 11. Sensitives analyzing for radius (mm).

Fig. 9 is the proposed final filter.

The parameters of Fig. 8 are $d = 0.1$, $c = 0.8$ and $a = 0.2$ mm which are optimized with CST.

The proposed filter is sensitive to the sector radius and stub length. The effects of these sensitivities are measured in three different quantities and are presented in Figs. 10 and 11 (All dimensions are in millimeters.). With regard to Fig. 10, it is clear that with an increase in length, the 5.8 GHz stopband can be changed. In the other stub, decreasing the radius causes decrease in the frequency of the second notch band (Fig. 11).

5. EXPERIMENTAL RESULT AND DISCUSSION

The designed filter has been fabricated and tested. Fig. 12 shows the proposed filter dimensions. The result of experiment on the dispersion parameters is shown in Fig. 13. This filter is made on a Rogers 4003 substrate with dielectric constant of 3.55. The thickness is one millimeter, and its dimensions are 25 mm and 10 mm. The results of the simulation of this filter indicate that the selected filter has the same bandwidth of notched band as previous structures. Its dimensions are also more compact than other filters and have more analytical relations.

In Table 1, a comparison has been made between this work and a few recent works. Table 1 shows that the filter proposed in [32] has the smallest length. According to the shape of this filter, it is clear that small dimensions have led to a huge complexity of the filter. The proposed filter in [33], like [32], has a complex structure and in comparison with the proposed structure, has fewer analytical relationships. Analytical relations, reduce the need of researchers for optimization algorithms and save the time. One of the common points in both [32, 33] is many parameters, which leads to the complexity of these two structures. Therefore, finding the correct relationship between the components is not easy.

The proposed structure has larger dimensions but simpler structure than the structures in [32, 33].

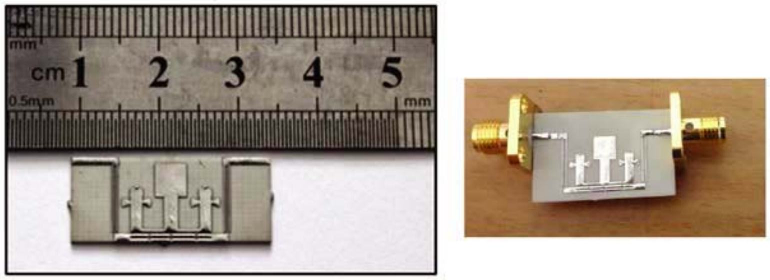

Figure 12. Fabricated final filter.

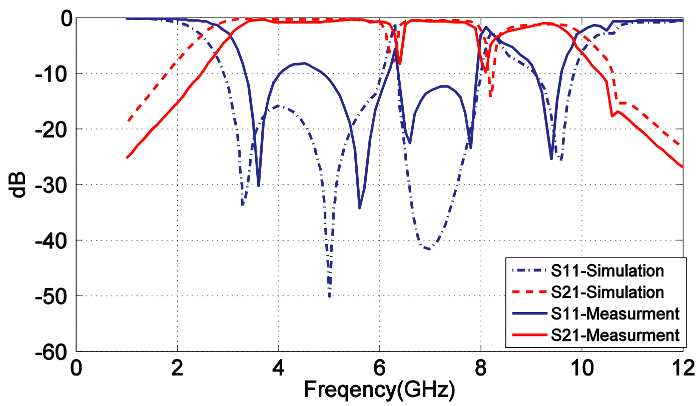

Figure 13. Simulation and measurement result.

Table 1. Comparison our work with other UWB with notched band.

Dim (mm^2)	Notch bands (GHz)	Basic structure	Technics	Ref	Year
24*12	5.8–8	RSLR	GA	[29]	2013
19*16	5.14–8	Metamaterial	DGS	[34]	2013
11*4.8	5.18–8	SLR	DGS	[32]	2014
34*20	6–8	SCRL	-	[33]	2011
39*6	5.1–5.7	MMR	-	[21]	2011
25*10	5.8–8	SISLR+RSLR	DMS	proposed	2018

Most of the design process in this paper is analytical which can be used to design filters in other frequency bands. However, the optimization performed with the DMS technique, failed to compensate frequency shift in the WLAN bands. The first notch band occurs at 6.2 GHz, which is also visible in Fig. 13.

6. CONCLUSION

The designed filter in this paper is an ultra-wideband filter with two notched bands. The basic structures of the filter are RSLR and SISLR, which have different analytical relations. In this paper, we use DMS technique for compaction and compensating the shift frequency. Frequencies of notched bands are 6.2 GHz and 8 GHz. The filter is fabricated on a Rogers 4003 substrate with 25*10 (mm^2) dimensions which is simpler and more compact than previous works.

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