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Design and Simulation of Six-Band Triplexer Filter for WLAN Systems

Abstract- *This paper presents microstrip triplexer with 6 bands frequency responses. The design of triplexer uses 6 cross coupled resonators based on step impedance resonator. Each one of these resonators has short or open-ended section that initiates dual-band response with a large rejection band. The presented device has 3 two-pole dual band filter channels that are joint with regular T-shaped feeders. This triplexer has miniature area in term of* λ_g *is about* $0.4\lambda_g \times 0.3\lambda_g$ *and interesting insertion loss, isolation band responses at (1.8 and 2.3 GHz), (3.45 and 4.1 GHz), and (5.2 and 5.75 GHz) band frequencies. From the simulated result, it is found that the isolation value is around 45 dB. All results are simulated using Advanced Design System (ADS) and IE3D simulators.*

Keywords*- Triplexer, coupled resonators, step impedance resonator.*

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1. Introduction

In modern microwave circuits, microstrip filters and diplexers have been used due to its reasonable cost, uncomplicated fabrication, low dispersion and radiation losses. Therefore, much attention has been devoted for compact diplexers with reasonable frequency responses, since miniaturization is one of important demands [1, 2, 3]. A diplexer is a simplest type of a multiplexer. It multiplexes two signal ports into one port. On the other hand, triplexer represents extended version of diplexer that multiplexes three-port into one-port. A good considered diplexer must comprise of small circuit size, high performance and reasonable cost. Microstrip diplexers create a center of attention because of their properties of low cost, circuit design simplicity, and they can be straightforwardly etched on the dielectric substrate. Diplexers allow two transmitters (on different frequencies) to use a common antenna at the same time. In addition, they may be used as shapes of duplexers, which allow to receiver and transmitter operating on different frequencies to share one common antenna with a lower interaction between the received and transmitted signals. Therefore, due to the use of a single antenna, it is possible to reduce the mass and volume [3,4].

Diplexer configuration has been presented in [5] based on microstrip electromagnetic band gap (EBG) structure and quarter wave resonator. The proposed design has very miniature size with satisfactory frequency responses. Yang et al. [6], had presented a compact microstrip diplexer with high isolation, by using compact hybrid resonators. The diplexer has been designed with center frequencies at 1.8 and 2.45 GHz, and output isolation is better than 55 dB.

Zeng et al. [7], had presented a microstrip quadruplexer with high isolation using distributed coupling feeding line, uniform resonator pairs and output feeding lines. The proposed design has flexible passband frequencies because each pair of resonators controls a specific channel frequency independently and very small loading effect among channels. Wu et al. [8], presented a microstrip triplexer with big isolation level. It has improved the isolation without escalating any circuit size. The diplexer is converted to triplexer by adding third channel using distributed coupling technique. Deng and Tsai [9], presented a new lowpass-bandpass diplexer with a simple matching design. For lowpass channel, the simulated cutoff frequency is at 1.5 GHz. In bandpass channel, the simulated center frequency is at 2.4 GHz. The isolation between bands is 35 dB. Wu et al. [10], presented a quad channel diplexer with compact design operating at (1.5/2 GHz, 2.4/3.5 GHz) using coupled pair of (stepped impedance resonators). The quad channel diplexer had shown an uncomplicated design method and compact size. Zhang et al. [11], presented triplexer with six band responses using six cross coupled resonators based on step impedance resonator (SIR) as short and open ended sections. This triplexer has been designed at (1.9/2.4, 3.5/4.2 and 5.2/5.8 GHz) and realized a compact size, high isolation and low insertion loss. Lin et al. [12], presented miniature quad-channel diplexer using quad-mode stub-loaded

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resonators (QMSLRs). The projected device has dual-band BPFs using QMSLRs and source-load coupling lines. This quad-channel diplexer has been designed for 0.9/1.2 GHz at first load and 1.5/1.8 GHz at second load.

In this paper, microstrip triplexer has been developed with a compact dimensions. Six cross-coupled resonators realize six bands with a wide stop band that are connected by a T-shaped step impedance resonator feeders to accomplish triplexer design. The frequency responses of this triplexer are in good quality with excellent isolation bands around 45 dB. This triplexer offers 6 band frequency responses with bigger isolation levels and lower insertion losses as compared to [3, 8, 10, 11], by employing stub-loaded step impedance resonator (SLSIRs).

2. Design of Stub-Loaded Stepped Impedance Resonators (SLSIR)

This design consists of six cross-coupled SLSIRs that are joint via joint T-shaped feeders. To realize a six-band triplexer, three independent channels are presented as channel 1, 2 and 3. Every one of channel has a 2nd order odd-mode passband and an even-mode passband. Furthermore, non-effective cross-coupling is existing among the non-adjoining odd-mode and even mode resonators, realizing further dual transmission zeros. Channel 1 has dual lowest passbands operates at 1.8 and 2.3 GHz, channel 2 resonates at 3.45 and 4.1 GHz and channel 3 has highest passbands operates at 5.2 and 5.75 GHz.

Figure 1 shows dual types of SLSIRs which have short and open ended stub sections. The added stub at the midpoint of the SIR gives an effectual even mode near to the first odd mode, realizing a dual-band response with adjacent passbands and a high rejection band levels. Given that the resonators are structurally regular, the even-odd-mode scheme is adopted to resolve the EM method of operation by inserting a magnetic wall or an electric wall in the regular plane of the resonators [13].

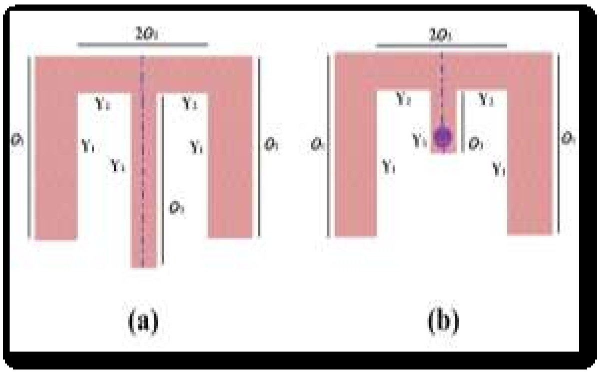


Figure 1: Illustration of SLSIRs: (a) Open-ended section. (b) Short-ended section.

When the effective dielectric constant (ε_{re}) of a microstrip is calculated, the guided wavelength can be determined directly in millimeters by [14]:

$$\lambda_g = \frac{300}{f(GH_z)\sqrt{\varepsilon_{re}}} \text{ mm} \tag{1}$$

where f represents the operating frequency. On the other hand, the effective substrate coefficient is evaluated by [12]:

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \tag{2}$$

The phase velocity v_p and associated propagation constant β are computed by [14]:

$$\beta = \frac{2\pi}{\lambda_g} \tag{3}$$

$$v_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{\varepsilon_{re}}} \tag{4}$$

The light speed (c) in free space is 3×10^8 $meter/second$. Accordingly, the electrical lengths and characteristic admittances for Figure 1 are Y_1, θ_1, Y_2, θ_2, Y_3 and θ_3.

For simplicity, assume:

$$Y_2 = Y_3/2 \tag{5}$$

and

$$K = Y_2/Y_1 \tag{6}$$

$$\theta_t = \theta_1 + \theta_2 \tag{7}$$

$$\alpha = \theta_1/\theta_t \tag{8}$$

$$\beta = \theta_3/\theta_t \tag{9}$$

Based on above equations, the calculated guided wavelength, electrical dimensions and propagation constant are illustrated in Table 1.

Table 1: The values for each resonator channel.

Channels	λ_g (mm)	β	θ_1	θ_2	θ_t	θ_3
1	117.56	3.06	30.60°	29.07°	59.67°	12.85°
2	58.87	6.11	26.27°	30.55°	56.82°	14.66°
3	40.89	8.80	44.00°	25.52°	69.52°	86.24°

Table 2: The results of two kinds of SLSIR resonator mode.

Parameters	Resonator in Channel 1	Resonator in Channel 2	Resonator in Channel ٣
α	0.513	0.462	0.633
β	0.215	0.258	1.240
Odd mode	K = 0.329	K = 0.291	K = 0.461
Even mode (short ended)	K = 0.530	K=0.500	K = -2.420 (Neglected)
Even mode (open	K = -0.660 (Neglecte	K = -0.490 (Neglecte	K = 0.385

ended) d) d)

SIR technique is not adequate to realize a multiple band triplexer since it is also dependent on resonant modes. The odd-mode resonant conditions is expressed by [11]:

$$K.\cot(\alpha\theta_t) = \tan[(1-\alpha)\theta_t] \quad (10)$$

On the other hand, operation mathematical expressions of the even-mode for the short-ended and the open-ended SLSIR are explained by [13]:

$$K.\cot(\alpha\theta_t) = \tan[(1-\alpha+\beta)\theta_t] \quad (11)$$

$$K.\cot(\alpha\theta_t) = -\cot[(1-\alpha+\beta)\theta_t] \quad (12)$$

These values of K are calculated by using equations from (10) to (12).

The result of even mode resonator with positive value of k is accepted, but the negative value of k is neglected which represents no mode available in this channel. So, that the resonator in channel 1 and channel 2 is considered as short-ended SLSIR while the resonator in channel 3 is considered as open-ended SLSIR. Table 2 shows these results.

Regardless of the type of coupling, the coupling factor (M_{ij}) and quality factor (q_{ei}) are derived and given in the equations below [14]:

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}}, \quad for\ i = 1, \dots\dots\dots, N-1 \quad (13)$$

$$q_{e1} = \frac{g_0 g_1}{FBW}, \quad q_{eN} = \frac{g_N g_{N+1}}{FBW} \quad (14)$$

Where FBW can be defined as [11, 12]:

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \quad (15)$$

The g-values are very important in the design equations since they correspond to the circuit elements of the lowpass prototype filter, such as the resistance, conductance, inductance, and capacitance.

Table 3: Specifications and coupling coefficients.

Band	Frequency f_o (GHz)	FBW	$\mathbf{M_i}$	$\mathbf{q_{ei}}$
1	1.80	0.111	0.091	12.90
2	2.30	0.087	0.050	16.56
3	3.45	0.050	0.041	28.82
4	4.10	0.049	0.030	29.40
5	5.20	0.038	0.031	37.90
6	5.75	0.034	0.011	42.30

These values are useful to compute the external quality and coupling coefficients factors of coupled resonator bandpass filters [14].

$$\text{When} \quad \Omega_a = \frac{1}{g_m}\sqrt{J_m^2 - \frac{J_m}{J_{m-1}}} \quad (16)$$

The coupling coefficients, bandwidth and quality factor are calculated by using equations (13) to (15). $\Omega_a = 1.35$, is determined by equation (16) as stated in [14]. Table 3 illustrates the specification and coupling coefficient for this design.

3. Simulation, Modeling and Results

Six SLSIRs structures have been utilized to build microstrip triplexer with 6 band frequency responses. A straightforward folded SIR feeder for the output ports has been employed to be compatible with the external quality factor for each band, whereas for the regular input port, a folded T-shaped SIR feeder has been used to satisfy the input impedance for every band. A dielectric material is Polystyrene adopted with a height of 0.9 mm and a relative permittivity of 2.45. Figure 2 and Figure 3 show the simulated layout of the six-band triplexer in ADS simulator. Table 4 explains the dimensions of each microstrip resonator in each channel.

The EM simulation results are shown in Figure 4. The operating resonances for the developed triplexer are 1.8/2.3 GHz (GSM/ WiMAX application), 3.45/4.1 GHz (WiMAX/ WiFi application) and 5.2/5.75 GHz (WLAN application) with the lowest insertion losses of 0.6/0.9, 2.9/1.9 and 1.9/2 dB for the entire bands. The simulated values of return loss are less than 5 dB, while the majority of channel isolations are nearly 45 dB. So that this triplex has small size, low insertion losses, good frequency selectivity and good isolation.

Figure 5 to Figure 7 show the current distribution of the six-band triplexer at three channels. The highest and lowest couplings are represented by red and blue colors respectively.

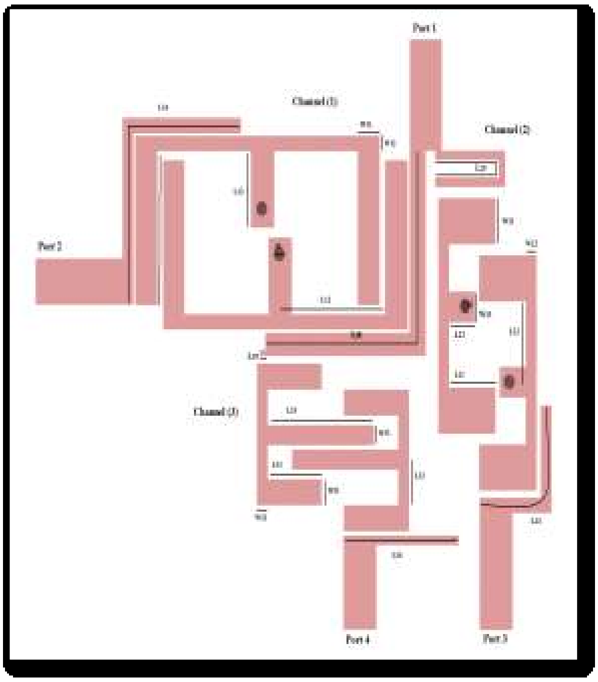


Figure 2: Implementation of conceptual six band triplexer

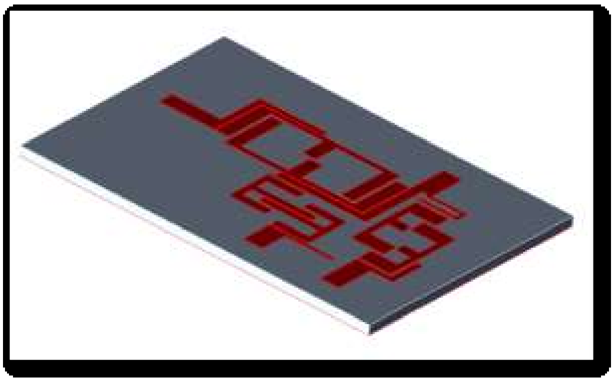
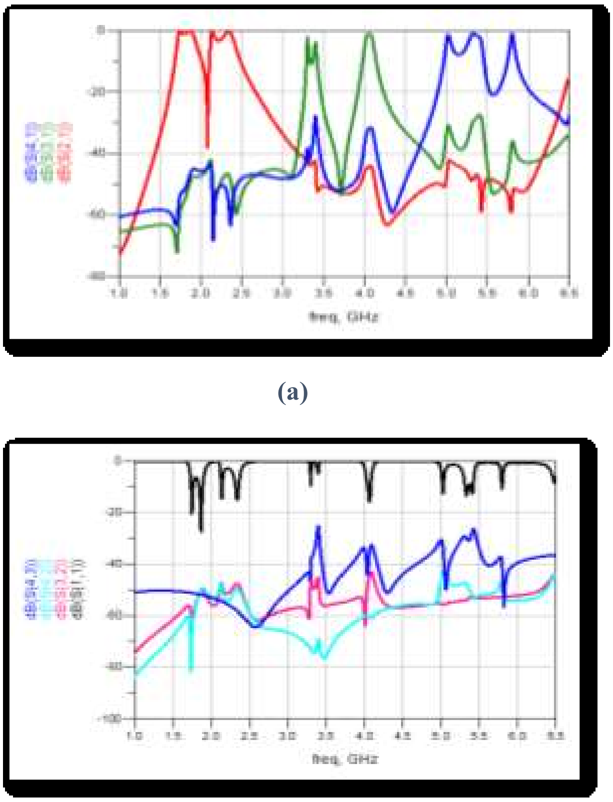


Figure 3: A layout of six-band triplexer

Table 4: The dimensions of each channel

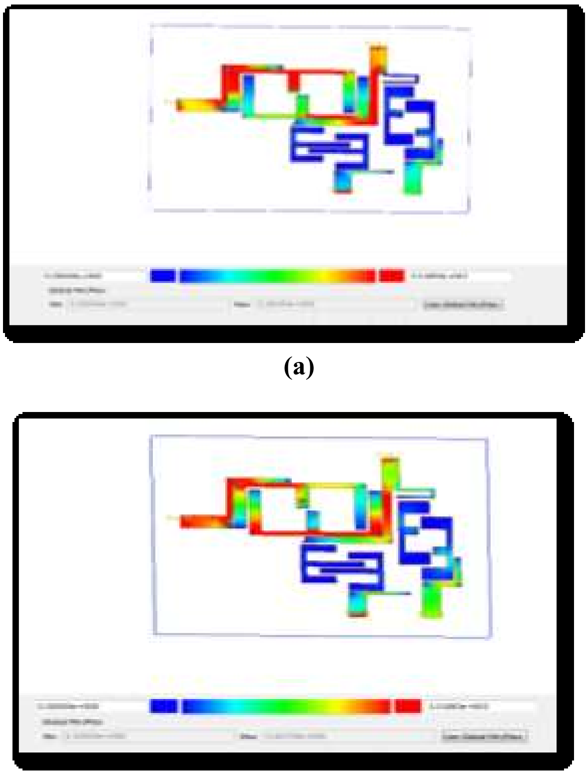
Dimension (mm)	Channel 1	Channel 2	Channel 3
Length	$L_{11} = 10.0$ $L_{12} = 9.5$ $L_{13} = 4.2$ $L_{14} = 22.0$ $L_{15} = 25.6$	$L_{21} = 4.3$ $L_{22} = 5.0$ $L_{23} = 2.4$ $L_{24} = 12.6$ $L_{25} = 13.5$	$L_{31} = 5.0$ $L_{32} = 2.9$ $L_{33} = 9.8$ $L_{34} = 10.6$ $L_{35} = 0.5$
Width	$W_{11} = 2.0$ $W_{12} = 1.0$ $W_{13} = 2.2$	$W_{21} = 3.0$ $W_{22} = 1.0$ $W_{23} = 1.2$	$W_{31} = 1.7$ $W_{32} = 1.0$ $W_{33} = 2.0$
Diameter	$d_1 = 1.0$	$d_2 = 1.0$	-------



(a)

(b)

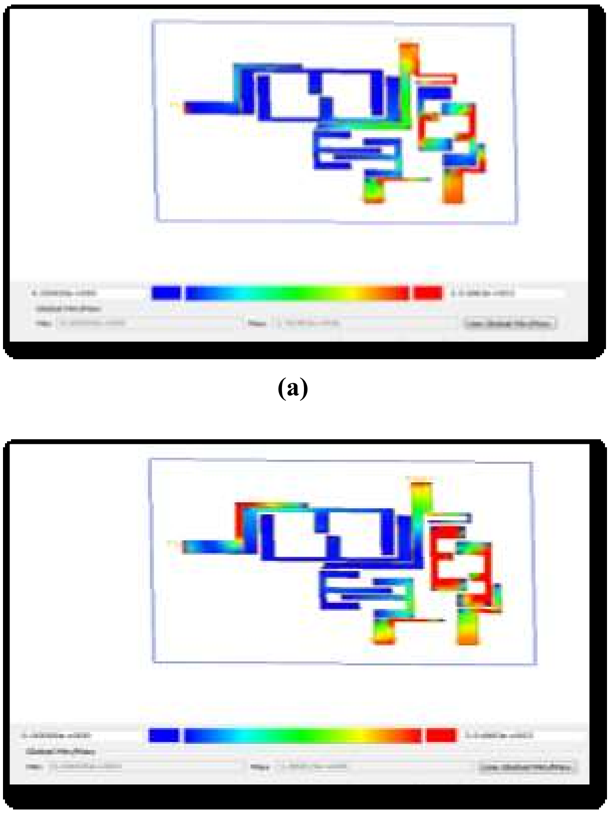
Figure 4: (a) and (b) simulated S-parameters results of the six-band triplexer using ADS simulator.



(a)

(b)

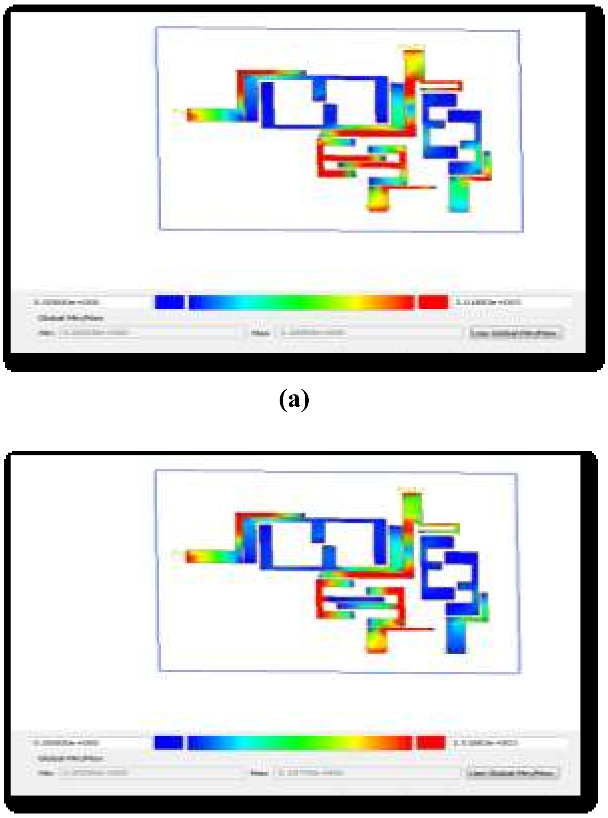
Figure 5: Current distribution of the six-band triplexer at channel 1 (1.8/2.3 GHz).



(a)

(b)

Figure 6: Current distribution of the six-band triplexer at channel 2 (3.45/4.1 GHz)



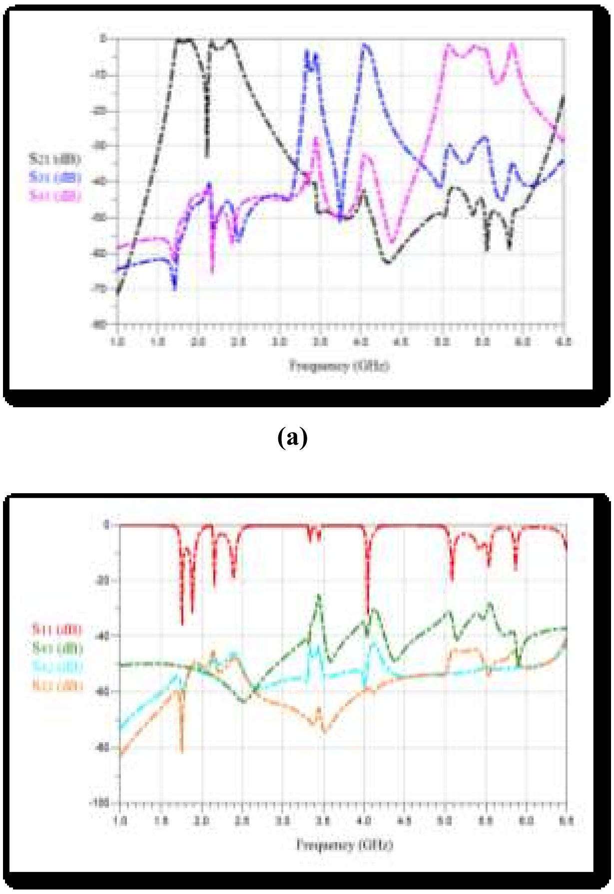
(a)

(b)

Figure 7: Current distribution of the six-band triplexer at channel 3 (5.2/5.75 GHz)

The EM simulation results in IE3D simulator are shown in Figure 8. The operating resonances for the developed triplexer with the lowest insertion losses of 0.7/1, 3/1.6 and 1.9/1.6 dB for the entire bands. The simulated values of return loss are less than 5 dB, while the majority of channel isolations are nearly 45 dB. The output frequency responses by ADS simulator are in good agreement with resultant frequency responses using IE3D simulator.

The developed six-band triplexer design has a compact size, small insertion loss value and fine-quality passband selectivity for every channel. The isolation is better than 45 dB. Table 5 illustrates the comparison results between this design and reported designs in [3, 8, 10, 11]. Accordingly, the developed design has higher isolation and lower insertion losses than the reported other designs in Table 5. So, it has better signal passband selectivity and isolation at each channel.



(a)

(b)

Figure 8: (a) and (b) simulated S-parameters results of the six-band triplexer using IE3D simulator.

4. Conclusion

Six-band channel triplexer has been presented in this study. Accordingly, three pairs of SLSIRs have been used and joined via a T-shaped SIR feeder using a substrate with a thickness of 0.9 mm and a dielectric constant of 2.45. The developed six-band triplexer design has interesting band responses for all channels in addition to its compactness. The isolation is better than 45dB. The developed design has higher isolation and lower insertion losses than the reported other [3, 8, 10, 11]. So, it has better signal passband selectivity and isolation at each channel. The simulation results using ADS and IE3D software packages are in good agreement.

5. Acknowledgement

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Table 5: Comparison between this work and previous published works.

Reference	Passband (GHz)	Insertion losses (dB)	Isolation (dB)	Type of substrate and ε_r	Thickness of substrate (mm)	Size
[3]	1.75/2.35/3.68	1.3 / 1.4 /1.7	25	Roger 5880 (ε_r= 2.20)	0.508	$0.13\,\lambda_g \times 0.2\lambda_g$
[8]	3.2/3.7/4.4	2.7/ 2.5/1.8	35	Roger RO4003C (ε_r= 3.55)	0.508	$0.12\,\lambda_g \times 0.4\lambda_g$
[10]	1.5/2/2.4/3.5	0.8/1.5/2.5/ 4	30	Roger 5880 (ε_r= 2.20)	0.787	$0.19\,\lambda_g \times 0.4\lambda_g$
[11]	1.9/2.4/3.5/ 4.2/5.2/5.8	0.95 /1.05/ 2.1/ 1.9/ 2.1/ 2	40	Polystryene (ε_r= 2.45)	1.000	$0.44\lambda_g \times 0.38\lambda_g$
This work with ADS simulator	1.8/2.3/3.45/ 4.1/5.2/5.75	0.6/ 0.9/ 2.9/ 1.9/ 1.9/2	45	Polystryene (ε_r= 2.45)	0.900	$0.4\lambda_g \times 0.3\lambda_g$
This work with IE3D simulator	1.75/2.45/3.45/ 4.1/5.3/5.8	0.7/1/ 3/ 1.6 /1.9/1.6	45	Polystryene (ε_r= 2.45)	0.900	$0.4\lambda_g \times 0.3\lambda_g$

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