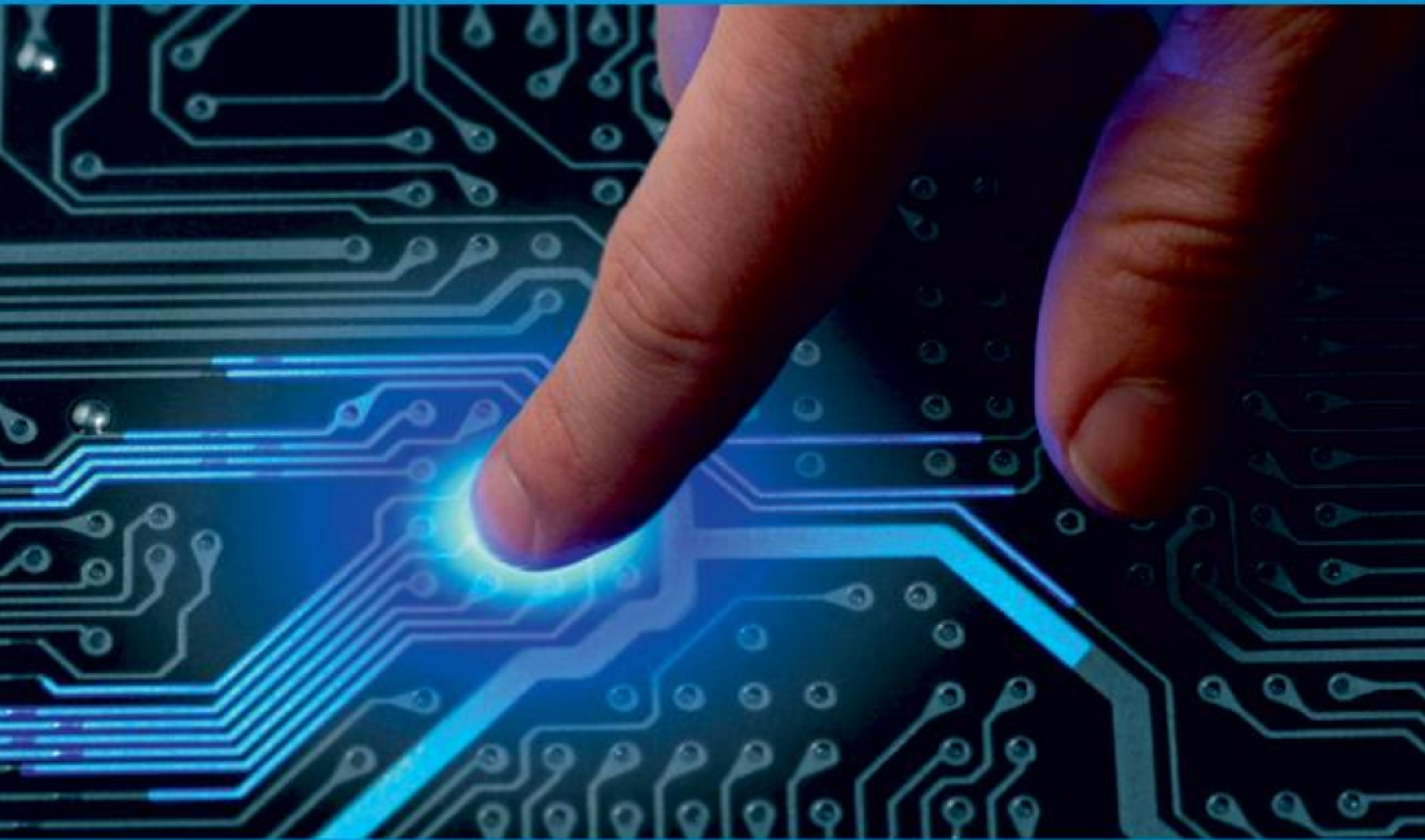
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

Volume 11, Issue 5, May 2023

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.379

International Journal of Innovative Research in Computer and Communication Engineering

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 8.379 |

|| Volume 11, Issue 5, May 2023 ||

| DOI: 10.15680/IJIRCCE.2023.1105085 |

Cost Effective Miniature tri-band Bandpass Filter Featuring SIR, FSLSIR and SSRR with Low Insertion Loss for Bluetooth, WIMAX and WLAN Applications

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ABSTRACT: The purpose of this paper is to present a lowcost compact tri-band microstrip filter which has applications in wireless communication systems such as Bluetooth, WIMAX, and WLAN. Three resonators the Stub-Loaded Resonator (SLR), Stepped Impedance Resonator (SIR), and Square Split Ring Resonator (SSRR) are employed in the proposed filter. The dimensions of the proposed filter are 18 mm2 × 14 mm2 or 0.141λg × 0.109λg. According to these measurements, the proposed structure has reduced the size by about 55% compared to the conventional samples. Fr4 is the substrate chosen for the suggested filter. Therefore, the cost of manufacturing will be quite low. These are the key benefits of the proposed filter. Finally, the proposed filter which operates at 2.35 GHz, 3.6 GHz and 4.8 GHz is simulated in Ansys Electronic Desktop 2022 R2 and Zeland IE3D. The results prove the correctness of the design, analysis, and feasibility in fabrication of the proposed filter.

KEYWORDS: Worldwide Interoperability for Microwave Ac- cess (WIMAX), Wireless Local Area Network (WLAN), Tri-band, Stub-Loaded Resonator (SLR), Stepped Impedance Resonator (SIR), Square Split Ring Resonator (SSRR), Transmission Zero (TZ)

I. INTRODUCTION

In wireless communication systems, filters are contributing a crucial role. They are used to conserve bandwidth in the congested microwave frequency spectrum by achieving sharp frequency selectivity and flat group delay [1,2]. The evolution in wireless communication applications such as Bluetooth, WiMAX, WLAN continue to challenge RF/microwave filters with ever more stringent requirements higher performance, smaller size, lighter weight and lower cost. Depending on the requirements and specifications, RF/microwave filters may be designed as lumped element or distributed element circuits. They may be realized in various transmission line structures such as waveguides, coaxial and microstrip [3]. The general structure of a microstrip filter consists of a dielectric substrate, a conductive strip on the top of the substrate, and a conducting ground plane at the bottom of the substrate [4]. Use of multiband filters (normally designed by using waveguide or microstrip techniques) over single band filters can reduce size as well as cost of the filters [5-7]. Multimode resonators (MMRs) can be utilized to build multiband bandpass filters (MBPFs). Each individual mode serves as the operating mode for one of the passbands in a well-known coupling topology [8]. Some of the popular resonators used for the designing of bandpass filters are Step Impedance Resonator (SIR) [9], Stub Loaded Resonator (SLR) [10], Split Ring Resonator (SRR) [11] etc. Design of a Tri-Band Bandpass Filter Using Multilayer Substrate Technique is introduced in [12]. The main advantage of the filter proposed is the transmission zeros at each passband skirt can be controlled by tuning the proposed resonators. But the cost of fabrication will be quite high in this filter design technique due to the implementation of multilayer substrate. A Tri-Band Bandpass Filter Based on Ring Multi-Mode Resonator (RMMR) is introduced in [13]. The main attribute of that structure is its less complexity. But the dimensions of the strip lines are larger which causes the increment in the size of the filter. Also, the whole three band's characteristics depend on RMMR. Nowadays, the requirement of low cost, compact filters in communication systems is increasing rapidly. Microstrip filters are generally compact in size and the material used as substrate has an important role in determining the overall cost of the filter. Conventional microstrip or strip line filters use common microwave substrates, typically PTFE or ceramic based materials.

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|| Volume 11, Issue 5, May 2023 ||

| DOI: 10.15680/IJIRCCE.2023.1105085 |

These materials introduce losses due to their higher dielectric constant. In mod- ern filter designing, suspended substrate stripline technology uses a printed circuit board suspended between two parallel ground planes, with air as the dielectric instead of a solid material [14]. Design of a Compact Microstrip Bandpass Filter for GSM, GPS and Wi-Fi Applications is presented in [15]. The main advantages of that structure are it is very compact and insertion loss is very low. Also, its pass bands are independently controllable. However, the fabrication cost is quite high because of the use of Rogers material as substrate, and the filter can operate in small range of frequency. Therefore, it cannot be used in WLAN applications. In this paper, a tri- band microstrip bandpass filter with compact size is designed and simulated. The material used as the substrate is FR4. So, the filter fabrication is low cost. The complete simulations are done by using Ansys Electronic Desktop 2022 R2 and Zeland IE3D. The proposed filter is capable of working in wireless technologies such as Bluetooth, WIMAX and WLAN. These ae made possible by using SIR, FSLSIR and SSRR. Multiple transmission zeros can be generated by using this proposed structure which significantly improves selectivity.

II. DESIGN

A. THE PROPOSED TRI-BAND FILTER DESIGN

Figure 1 depicts the suggested filter. Its dimensions are 18×14 mm2 or $0.141\lambda g \times 0.109\lambda g$ where λg is the guided wavelength at 2.35 GHz. In comparison to the sample shown in [14], this dimension has been decreased to 55% by size. In Figure 2, the proposed resonators and other parts are presented. The optimized values of microstrip transmission-lines (TLs) and resonator gaps are shown in Table 1 (all measurements are in millimeters). The process of designing and calculating the above values will be presented.

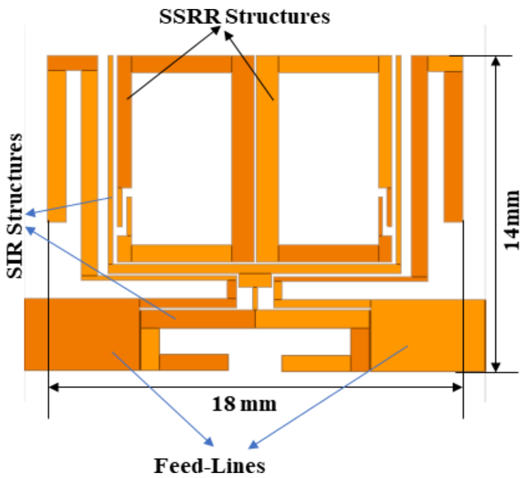

Fig. 1. Configuration of the proposed tri-band filter.

La=4.2	Wa=0.4	Lb=0.8	Wb=0.4	Lc=6	Wc=0.2
Ld=9.8	Wd=0.7	Le=2.2	We=0.7	Lf=7.4	Wf=0.8
L1=9.3	W1=0.2	L2=6.35	W2=0.4	L3=0.6	W3=1.4
L4=1	W4=0.2	L5=9.95	W5=0.8	L6=7.6	W6=0.95
L7=4.35	W7=0.8	Lp=2.1	Wp=0.2	Lq=1.7	Wq=0.2
G0=0.45	G1=0.2	G2=0.1	G3=2.3	G4=0.05	G5=0.4
G6=0.45	W8=0.6	W9=0.7			

TABLEI DIMENSIONS OF THE PROPOSED FILTER

International Journal of Innovative Research in Computer and Communication Engineering

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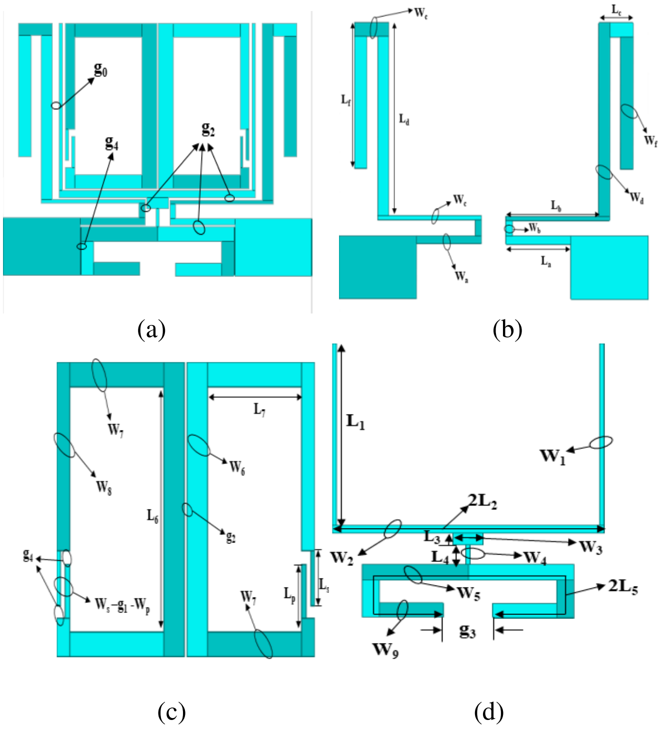

Fig. 2. All parts of the proposed filter. (a) Final configuration, (b) configu- ration of feedlines, (c) SIRs configurations, and (d) SSRR structures

A. Parametric Analysis of the Structure of the filter

The proposed structure consists of three resonators. Res- onator 1 is SIR; resonator 2 is Folded Stub-Loaded Stepped Impedance Resonator (FSLSIR); and resonator 3 is an SSRR. These are shown in figure 3. SIR and FSLSIR are symmetri- cally placed in the final configuration.

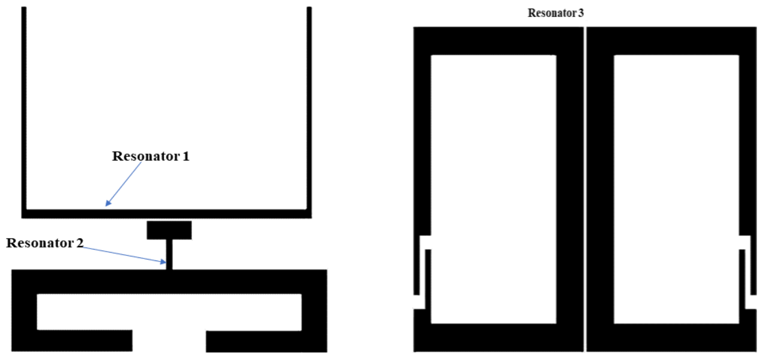

Fig. 3. The configuration of the proposed resonators. (a) Resonators 1 and 2, and (b) resonator 3.

It is necessary to analyze the filter performance while these resonators are placed along with the feedlines to form a single structure. Basically, the length, width, and separation between the adjacent strip lines all have an impact on how well a micro strip filter performs. In parametric analysis, the effects of all the strip line parameters are examined, and changes are made to the strip line parameters according to the improvements in band characteristics. With the aid of parametric analysis, the optimum strip line length, width, and separation between them are discovered. The design process is divided into 5 stages based on the improvements achieved. They are primary, secondary, ternary, quaternary and quinary.

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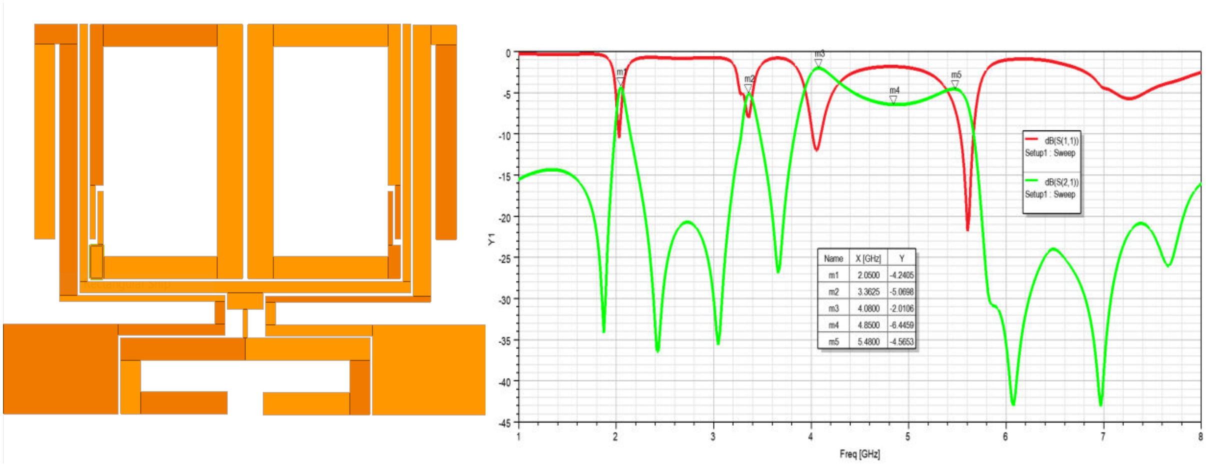
Figure 4(a) depicts the fundamental structure created by simply arranging three resonators and feedlines on which parametric analysis was performed. Figure 4(b) displays the simulated outcome of the relevant filter. The entire simulation process is carried out with Ansys Electronic Desktop 2022 R2.



(a) (b)

Fig. 4. (a) The initial structure of the filter for parametric analysis, and (b) simulated result of the initial structure.

Figure 4(b) makes it evident that the structure is capable of producing two narrow bands centered around 2GHz and 3.3GHz, and a wide band between 4GHz and 5.6GHz. It also features six deep TZs. However, the first and second bands' insertion losses are rather large, and the third band has poor selectivity. Therefore, these must be improved. The structure in Figure 4(a) is subjected to a parametric analysis. In order to achieve the improvement in band characteristics, several dimensional adjustments are made to the strip lines and the separation between them. During the process, the first improvement has been achieved. The changes in the strip line measurements are; g3=1.4, W4=0.2, W6=1, W7=0.8 (initial measurements were; g3=0.6, W4=0.4, W6=0.7, W7=0.5). Sim- ulated result of the first improvements is shown in figure 5.

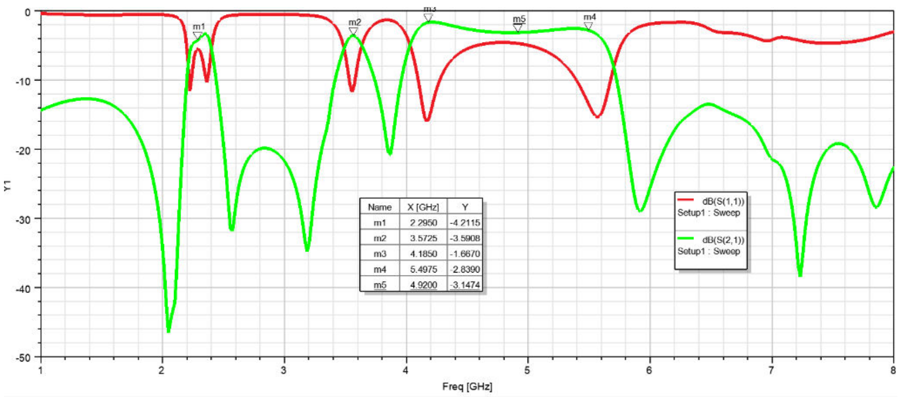


Fig. 5. Simulated result of the primary improvements during parametric analysis

In Figure 5, First and second bands are shifted to 2.3 GHz and 3.5GHz from 2GHz and 3.3GHz respectively. Insertion loss of the second band is significantly improved. It has become 3.5 from 5. The third band characteristics are also improved. There is now less bending involved. The third band becomes more selective and insertion loss also decreases as the gap, g3 increases. In this initial state of parametric analysis, it is understandable that shape of the third band is highly depends on the gap g3. This structure provides 6 TZs which are located at 2GHz, 2.5GHz, 3.2GHz, 3.9GHz, 5.9GHz and 7.2GHz. On the further progression of the parametric analysis, the second band improvement on the performance of the filter has been achieved. The major changes in the strip line parameters are;

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W5=0.5 and g3=3.8 (initial measurements were; W5=0.8 and g3=1.4). The simulated results are displayed in figure 6.

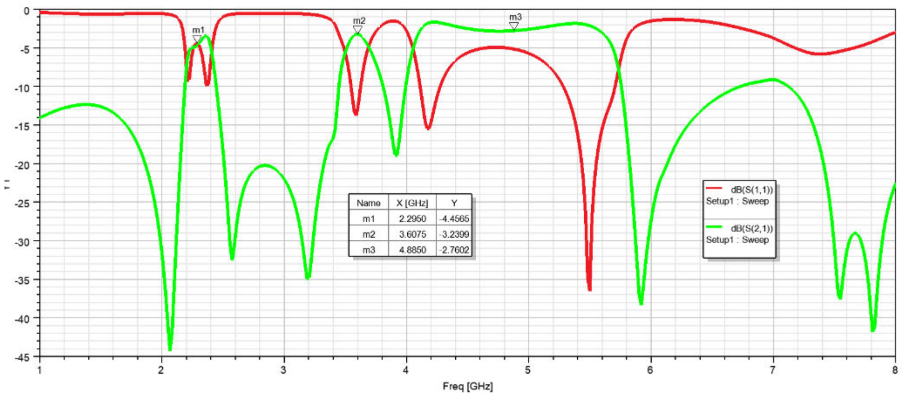

Fig. 6. Simulated result of the secondary improvements during parametric analysis

In Figure 6, It is evident that the second and third bands have an insertion loss of 3.0 and 2.7, respectively. In comparison to the prior improvement data, the data above shows a minor im- provement in the second band's insertion loss and a significant improvement in the third band's insertion loss. The number of TZs has also increased. There are seven TZs in Figure 6 that are situated at frequencies of 2GHz, 2.5GHz, 3.2GHz, 3.9GHz, 5.9GHz, 7.5GHz, and 7.8GHz. Overall return loss has also increased. However, the first band's insertion loss has undesirably increased. It must be avoided. Therefore, further parametric analysis needs to be continued. As a result of further changes in the dimensions of several strip lines, ternary improvements are made. The changes are; W5=0.8, Le= 1.9, g0=0.35 and g3=3.4 (initial measurements were; W5=0.5, Le=1.7, g0=0.35 and g3=3.8). The simulated result is depicted in Figure 7.

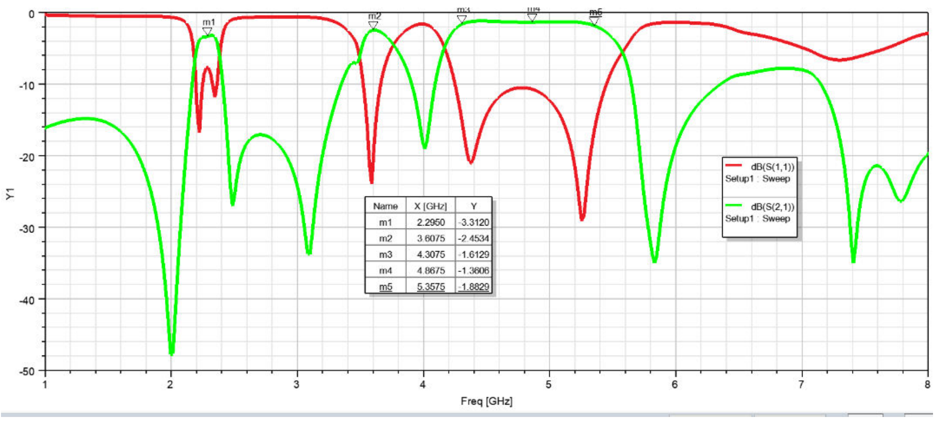

Fig. 7. Simulated result of the ternary improvements during parametric analysis

Figure 7 analysis shows that the first band's insertion loss is 3.0. As a result, it has improved from the earlier data displayed in Figure 6. Other bands' insertion loss remains unchanged. It shows that the measurements of g0 have the direct involvement in first band characteristics. Despite a modest reduction in bandwidth, the third band became more selective and perfectly shaped due to the change in g3.Parametric analysis has continued for more refinement in band characteristics and quaternary improvements have been achieved. Major changes are; the dimension of the filter has become 21mm x 21mm, Ws=Wp=0.15, g3=4.6, g3= 0.3 and g6=0.4 (initial measurements were; dimension of the filter= 19mm x 19mm, Ws=Wp=0.2, g3= 3.4 and g3=g6=0.2). Simulation result is depicted in Figure 8.

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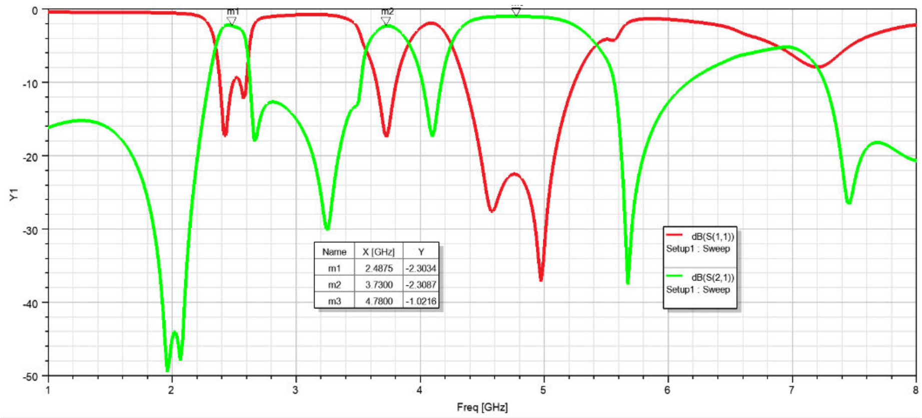

Fig. 8. Simulated result of the quaternary improvements during parametric analysis

In Figure 8, insertion losses of the first, second and third bands are 2.3, 2.3 and 1.0 respectively. It shows a great improvement over the previous data shown in Figure 7. Return loss is also quite good. But stopband attenuation is the problem in this structure. After 5.8GHz, stopband attenuation is poor. It was brought on by the large increase in g3. So, an optimum value for g3 needs to be found. In quinary improvement, some major changes have made in the dimensions of the strip lines. They are; filter size is reduced to 20mm x 20mm, W8=0.6, W9=0.7, Le=2.2, g0= 0.45, g3=2.3 and g4=0.1(initial measurements were; dimension of the filter=21mm x 21mm, W8=0.7, W9=0.8, Le=2, g0= 0.35, g3=4.6 andg4=0.2). Simulated result is displayed in Figure 9.

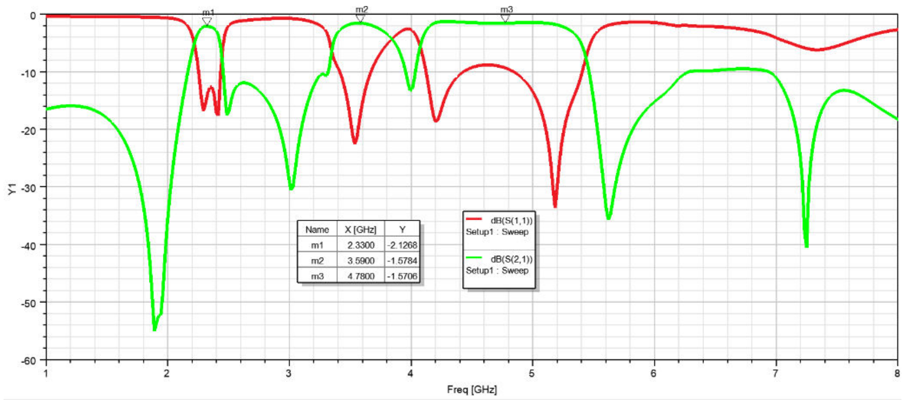

Fig. 9. Simulated result of the quinary improvements during parametric analysis

In figure 9, It is evident that the insertion loss of first, second and third bands are 2.1, 1.5, 1.5 respectively. The structure provides 5 TZs and a decent return loss. The stop-band attenuation has been achieved without disturbing the insertion losses of the bands. So, the corresponding dimensions of microstrip lines are considered as the optimum dimensions. It can be seen that the suggested filter is capable of encompassing the WLAN, WIMAX, and Bluetooth frequency bands.

B. Analysis of the Proposed Filter with Super-position Technique

Analysis of the effects of each resonator is the primary goal of using the super-position technique. In another words, super-position analysis is incredibly helpful for pinpointing the approximate positions of TZs frequencies and frequency resonances. Effects of SIR are investigated first. Figure 10(a) depicts the proposed feedlines and SIR. Figure 10(b) also shows the frequency responses (S11 and S21 parameters) of this structure. Ansys electronic desktop 2022 R2 is used to complete all simulations.

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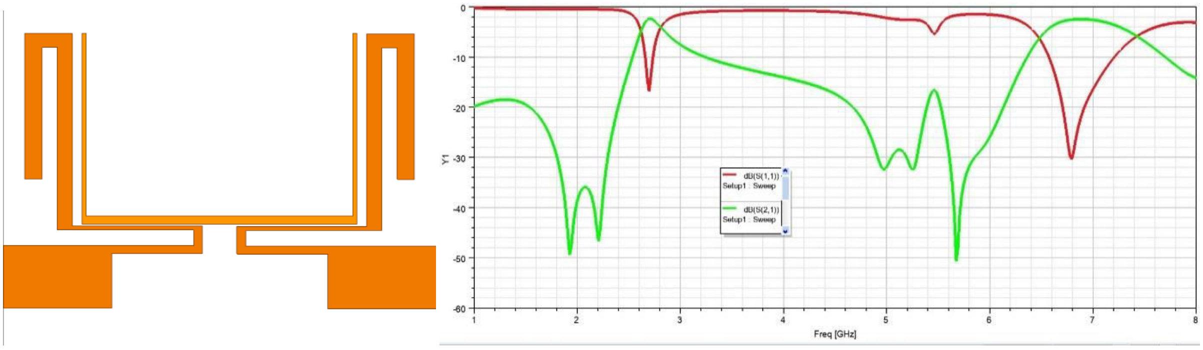
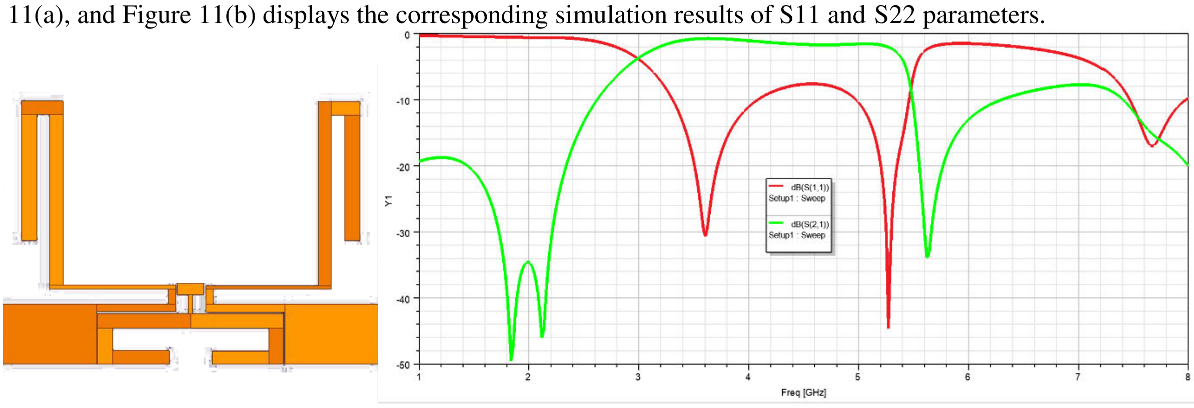


(a) (b)

Fig. 10. (a) Feedlines and SIR structures, and (b) frequency responses of feedlines and SIR.

According to Figure 10(b), it is found that resonance frequency is around 2.8 GHz, and another one is about to create at 5.4 GHz (which can be made possible by employing parametric analysis if it is necessary). In one hand in Figure10(b), we can see that this resonance creates a strong TZ around 2.2 GHz and 5.6 GHz.

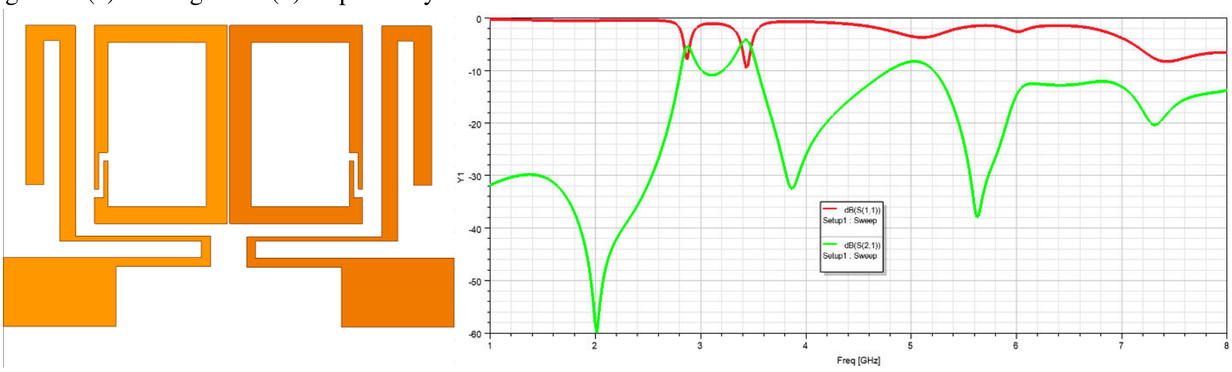
The effects of FSLSIR are investigated as the second step. The suggested feedlines and the FSLSIR are illustrated in Figure 11(a), and Figure 11(b) displays the corresponding simulation results of S11 and S22 parameters.



(a) (b)

Fig. 11. (a) Feedlines and FSLSIR structure, and (b) simulation results with feedlines and FSLSIR.

This structure creates a wide-resonance frequency between 3.4 GHz to 5.2 GHz frequencies. Also, three TZs were discovered which are operating at 1.8 GHz, 2.1 GHz, and 5.6 GHz. As the final step of the super-position analysis, effects of SSRR with feedlines are investigated. SSRR structure with feedlines and simulated results are shown in Figure 12(a) and Figure 12(b) respectively.



(a) (b)

Fig. 12. (a) Feedlines and SSRR structure, and (b) simulation results with feedlines and SSRR.

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According to Figure 12(b), the SSRR structures can generate two resonances in 2.8 GHz and 3.2GHz. Also, a strong TZ is created at 2GHz.

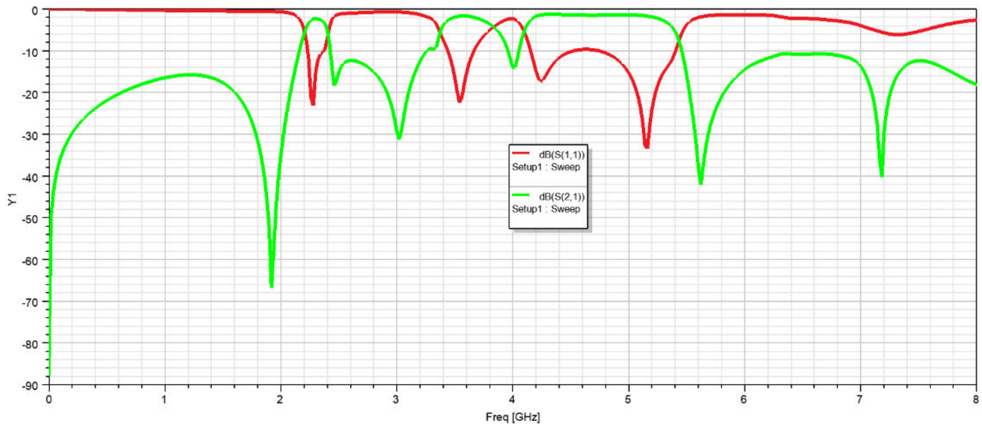

Fig. 13. S-parameters of the final filter configuration simulated in Ansys HFSS Electronic Desktop

While comparing Figure 13 with Figure 10, Figure 11 and Figure 12, the trends of resonators for creating passbands seems to be similar. So, it is clear that the third frequency on FSLSIR, although the third frequency band has a modest dependence on SIR structure.

The finalized structure obtained after parametric analysis and super-position analysis is simulated in Zeland IE3D soft- ware which is also a widely used EM simulation software. The simulated results are shown in Figure 14.

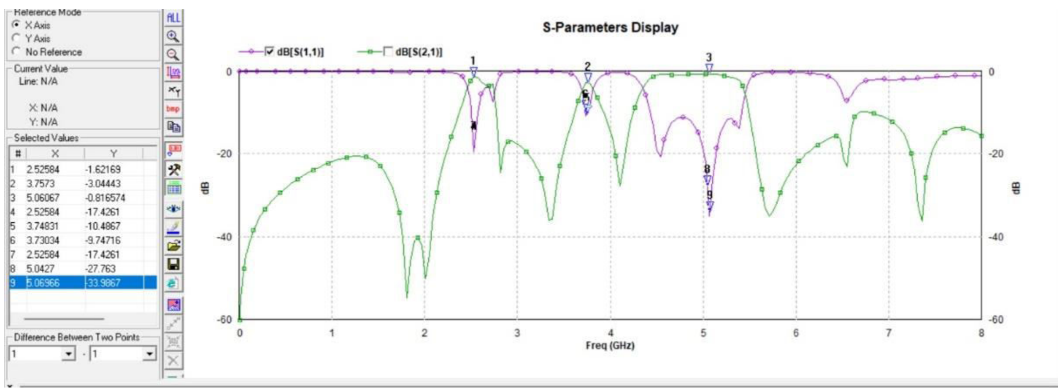

Fig. 14. Simulated results of the finalized structure using Zeland IE3D

Figure 14 shows a clear resemblance with the simulated result obtained from Ansys Electronic Desktop 2022 R2 which is shown in Figure 13. So, the proposed tri-band bandpass filter is practically possible for fabrication.

III. PERFORMANCE COMPARISON

Comparisons between this work and other filters are shown in Table 1. This table can well illustrate the advantages of the proposed filter.

Ref	*Pass band(GHz)*	*Insertion Loss(dB)*	*Return Loss(dB)*	*3-dBFBW(%)*	*TZ*	*Size (mm2)/(λg×λg)*	*Substra-te*
[12]	2.4/3.5/5.2	0.5/1.2/1.4	30/28/34	36.6/ 27/18	4	0.37 λg ×0.34 λg	RT Duroid5880

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[13]	1.21/2.16/3.1	0.8/0.9/1.2	>15	NA	4	22.4× 31.5mm	Taconic [2]RF-35
[16]	0.98/3.6/5.8	<3	>11	11/4.4/4.3	5	0.055λg ×0.143λg	RT/ Duroid5880
[17]	1.8/2.45/3.5 /5.5	<2.3	>15	6.7/4.2/3.7 /14.8	6	0.19λg × 0.15λg	RT/ Duroid5880
Propose dfilter	2.35/3.6/4.8	2.1/1.5/1.5	19,10.48, 33.98	6/10/25	6	0.141λg ×0.109λg	FR4

From Table 1, the proposed filter has the advantages in low cost and compact in size. All other filters are made up of costly substrates such as Rogers substrates. Rogers substrates are less lossy when compared to FR4 substrate. But, the proposed filter shows slight increment in insertion loss when comparing with other reference filters. The pass band frequencies of the suggested filter are 2.35GHz, 3.6GHZ and 4.8GHz. Therefore, the proposed filter can work in wireless communication techniques such as Bluetooth, WIMAX and WLAN. So, these facts can well illustrate the advantages of the proposed filter.

IV. CONCLUSION

This work designs and analyses a compact, low-cost tri- band bandpass filter. The Bluetooth, WIMAX, and WLAN frequency bands are all covered by the proposed filter. There are three different types of resonator structures that are em- ployed to achieve tri-band performance. The filter has the advantage of lower manufacturing cost because of the use of FR4 as substrate. The suggested filter is suitable for standard frequency bands and is compact in size (20mm x 20mm). The structure of the filter is simulated in both Ansys HFSS and Zeland IE3D. Both software programs produced simulated results that are quite close. Therefore, the suggested design is technically feasible. The conclusion of the paper is that the suggested filter can operate smoothly in tri-bands for wireless communication system.

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