# Design Techniques used in Microstrip Quad-Band Bandpass Filter

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**Abstract** —Recently, multiband bandpass filters have become the key component in front-end radio frequency applications in multiservice communication systems. Quad-band filters with low loss, compact circuit size, and high passband selectivity have become increasingly crucial. Microstrip band pass filters satisfy all these requirements such as light weight, low volume, low power handling, easy fabrication and low loss. For next generation of wireless communication system, multi band filters have become essential requirement. Due to the applications of multi band filters in wireless networks such as wireless local areas networks (WLAN), long distance radio telecommunication, global system for mobile communication (GSM) and WiMAX, nowadays they have attracted more attention. Quad-band Bandpass Filter (BPF) is one of the critical frontend components in multiband wireless communication systems. In this paper we discussed some design techniques used in the Quad-band Bandpass Filter and also compared the Quad-band Bandpass Filter on the basis of design techniques.

**Keywords**—*Bandpass filter (BPF), applications, microstrip, high selectivity, quad-mode resonator, SLRs and triangular loop resonators, Quad band filter,design techniques*

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## I. INTRODUCTION

In the previous years, wireless communication systems has developed tremendously, there was a prompt development in ultra-wideband systems, wireless internet like WiFi and WiMAX, broadband personal communication systems and 3G (third generation), 4G (fourth generation) technologies. Due to this rapid development there was a need for more rigid microwave components. And now a days satellite systems changed their path from static telecommunications systems to mobile, remote sensing and navigation applications [1]. Microwave components plays an important role in the satellite systems. Microwave components include microwave resonant components such as microwave filters, dielectric resonant antenna arrays (DRA), duplexers. Because of the rapid growth in the wireless communication area, it created more challenging requirements that enforce challenges on various novel designs, optimization and understanding of components.

In microwave filters the challenges are to be faced in miniaturization, bandwidth, phase linearity, and selectivity of the filters [14].A filter is used to regulate the

frequency response at a fixed point in the EM spectrum by providing low loss transmission at the preferred frequency band and high attenuation at remaining frequencies. Filters are extensively used in many applications like communications, remote sensing, radars etc. A filter is generally a two-port network. Filters play an irreplaceable role in virtually any type of radio frequency (RF)/ microwave system today. With the recent rapid development and wide spread use of various wireless communication systems, ever-more stringent requirements are posed on RF/ microwave filters smaller size, higher performance, considered necessary to solve the challenges of insufficient capacity of the various wireless systems [14].

Development of a number of wireless communication standards and devices imposed a requirement for components to simultaneously operate at two or more frequencies that correspond to the standards such as IEEE 806.16, IEEE 806.11, GSM, CDMA, etc. Dual-band bandpass components were the first multi-band circuits to answer this requirement [13]. The first dual-band filter was proposed almost twodecades ago, and since then there has been a growing interest in dual band filters. In comparison to dual-band filters, design of bandpass configurations with three or more bands represents a greater challenge when it comes to filter performance and compactness, because good characteristics have to be achieved in three or more closely positioned passbands. In addition to possible signal crosstalk in closely positioned passbands, design of these filters is a demanding task since it requires a steep slope of transfer function. What is more, almost all bands that are commercially used are closely positioned for instance GSM, WLAN, WiFi, WiMAX and UWB systems that operate at 0.9/ 1.8 GHz, 2.4/ 2.45 GHz, 3.5 GHz, and 5.2/ 5.25 GHz.

## II. DESIGN TECHNIQUES

### A. Quad-band BPF using quad-mode resonator

A compact quad-band bandpass filter utilising the quad-mode resonator is presented. This resonator, which has four tunable symmetrical resonant poles, can be treated as a two-side open-circuit stepped-impedance resonator with short-circuit stubs in its low-impedance sections [2]. Transmission zeros among each passband are generated to improve passband selectivity and achieve high isolation, because of the multi-paths propagation mode configuration of the two resonators.

In fig 1a shows the quadmode resonator under the weakly capacitive coupling configuration. In fig 1b four resonant poles can be observed at $f_1$ = 1.95 GHz, $f_2$ = 3.02 GHz, $f_3$ = 4.19 GHz and $f_4$ = 5.26 GHz, respectively. Interestingly, it can be verified that $(f_4 + f_1)$ is equal to $(f_3 + f_2)$. If $f_0 = (f_4 + f_1)/2 = (f_3 + f_2)/2$ is defined, it can be observed that $f_4$ and $f_1$ are symmetric along $f_0$, which is the same for $f_3$ and $f_2$. This characteristic may be due to the symmetrical geometry of the proposed resonator.

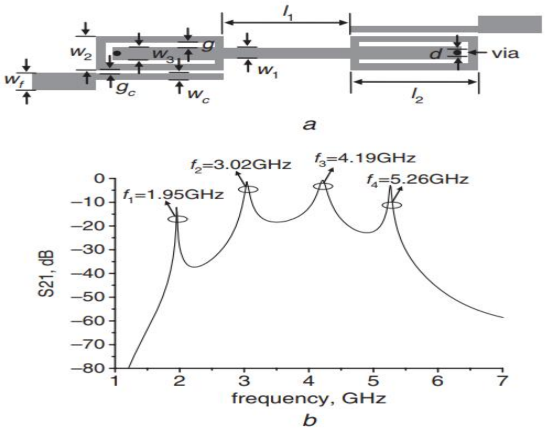


Figure 1: (a) Topology (b) Weakly coupling frequency response of the Quad-mode resonator

The layout of the new quad-band bandpass filter based on the quad-mode resonator is shown in fig 2. In the filter realisation, for the purpose of generating transmission zeros among each passband to improve passband selectivity and isolation, two resonators are folded to form the multi-path propagation mode configuration introduced. The new filter is designed on the substrate ARlon DiClad 880 ($\varepsilon_{re}$ = 2.2, h = 0.508 mm) and simulated using the fullwave EM-simulation HFSS.

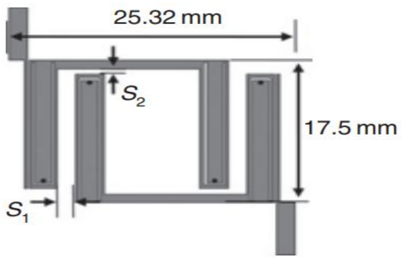


Fig: 2 Layout of Quad-band BPF

This Quadband Bandpass Filter has four passbands centering at 1.9/2.8/4.3/5.2GHz, the 3 dB fractional bandwidths of which are 5.3 /3.4 /3.5 /3 % as shown in fig 3. The measured minimum insertion losses are 2.3/3.6/3.5/3.4 dB, respectively, while the return losses of each passband are better than 12 dB. The depth of all of the transmission zeros among each passband are below 240dB, which can improve passband selectivity and result in a high isolation. The total size of the new filter is 25.32 × 17.5 mm.

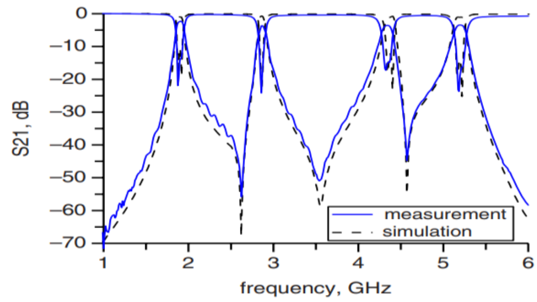


Fig 3: Simulated and measured results of Quad-band bandpass filter

B. Quad-Band Bandpass Filter Using Multilayer Substrate Technique

The filter is designed to have quad-band at 1.8, 2.4, 3.5 and 4.2 GHz. The four passbands are simultaneously generated by controlling the impedance and length ratios of the stub-loaded stepped impedance resonators (SIRs). The filter with closed passbands can be easily achieved, by using the stub-loaded SIRs. The frequency response of wide stopband is generated by using the defected ground structure (DGS) and having around -25 dB stopband from 4.2 to 12 GHz. The filter can provide the multi-path propagation to enhance the frequency response and achieving the compact circuit size [3].

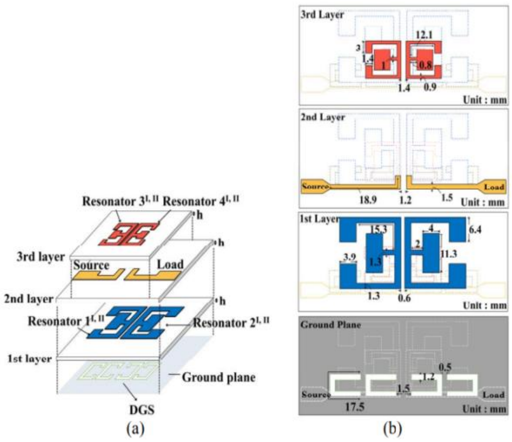


Fig 4: (a) 3D view, (b) top view of the Quadband filter.

Fig 4 shows 3D view and top view of the proposed filter. In fig 4(a), resonator 1, 2, 3 and 4 indicate the order of stub-loaded SIRs and having two coupling paths for achieving quad-bands (resonator $1^{I}$ and $2^{I}$ for 1.8 GHz, resonator $1^{II}$ and $2^{II}$ for 2.4 GHz, resonator $3^{I}$ and $4^{I}$ for 3.5 GHz and resonator $3^{II}$ and $4^{II}$ for 4.2 GHz). The filter consists of the coupled stub-loaded SIRs on 1st and 3rd layer, source and load on 2nd layer and defected ground structure (DGS) on ground layer, as shown in fig 4(b). The features of the quad-band filter are the use of multilayer technique to further reduce the circuit size and providing very close quadband with high in-band isolation and good passband selectivity.

In this technique, the even- and odd-mode of the stub-loaded SIR can be controlled individually, resulting in the quad-band filter with very close passbands. The multilayered filter could not only save the circuit size but also generate the cross-coupling effects, which the extra transmissions zeros near the passband edges can be easily achieved. The stub-loaded SIR is composed of a conventional half-wavelength SIR (2[($Z_1$, $\Theta_1$), ($Z_2$, $\Theta_2$)] for path 1 at 1.8 and 3.5GHz) and a stub-loaded SIR ([($Z_1$, $\Theta_1$), ($Z_2$, $\Theta_2$), ($Z_3$, $\Theta_3$) ($Z_4$, $\Theta_4$)] for path 2 at 2.4 and 4.2 GHz). By tuning the dimension of the stub-loaded SIR, such as impedance ratio ($K = Z_2/Z_1$) and length ratio ($\alpha_1 = \Theta_2/(\Theta_1+\Theta_2)$), the arrangements of every resonant modes become more flexible. The stub-loaded SIR can be analyzed to even- and odd-mode along the symmetric plane. The resonant modes of the resonator can be derived by setting $Y_{ine} = Y_{ino} = 0$ and expressed as

$$Y_{ine} = -j\,\frac{Z_2(\cot\Theta_1 - K_1\tan\Theta_2) + (Z_s\cot\Theta_s)(K_1 + \cot\Theta_1\tan\Theta_2)}{Z_2 Z_s\cot\Theta_s(\cot\Theta_1 - K_1\tan\Theta_2)} = 0 \quad (1)$$

$$Y_{ino} = -\frac{1}{jZ_2}\,\frac{(K_1 - \tan\Theta_1\tan\Theta_2)}{(\tan\Theta_1 + K_1\tan\Theta_2)} = 0 \quad (2)$$

where,

$$Z_s = -jZ_3\,\frac{Z_4\cot\Theta_4 - Z_3\tan\Theta_3}{Z_3 + Z_4\cot\Theta_4\tan\Theta_3} \quad (3)$$

And $\Theta_S = \Theta_3 + \Theta_4$

Therefore, the design of quad-band filters with very close passbands can be easily achieved and having a high isolation between the passbands.

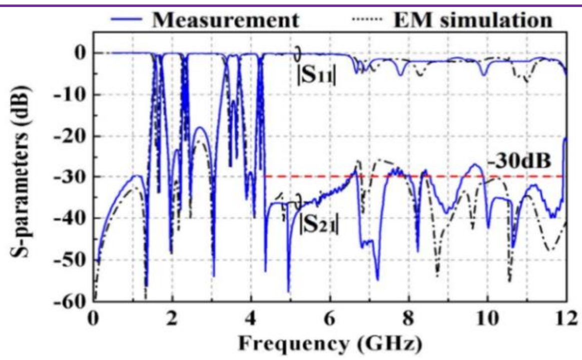


Fig 5: Simulated and measured frequency response of Quad-band BPF

The proposed filter was then fabricated and measured by an HP8510C Network Analyzer. Fig 5 shows the simulated and measured frequency response of the Quad-band BPF.This quad band bandpass filter occupies a small size; around 28.45 mm × 19.15 mm. The measured passbands have insertion losses of 0.2 dB, 1.2 dB, 0.3 dB and 0.8 dB, return losses are 33 dB, 22 dB, 28 dB and 28 dB corresponding to 1.8 GHz, 2.4 GHz, 3.5 GHz and 4.2 GHz, respectively. The 3-dB fractional bandwidths (FBW) are 10%, 3%, 9% and 4%. The wide stopband under 30 dB over around 4.2 to 12 GHz is well achieved.

C. Quad-band BPF using SLRs and triangular loop resonators

The schematic layout of designed quadband filter is shown in fig 6. The quad-band response is achieved by combining two different types of the dual-band BPFs, each pair of resonators possesses two passbands [4]. Triangular loop resonators and ring-resonators with stubs are developed by using degenerate modes which are excited by perturbations. Figure 6 shows a triangular loop resonator with a stub which provides high return loss and design freedom. Its right triangular shape contributes to the compact structure of designed quadband BPF. Two patches are, respectively, located at right and left angles of the loop as two perturbations, which can evidently generate dual-band feature.

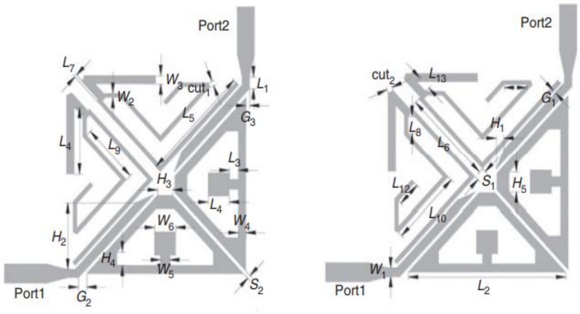


Fig 6: Configuration of the Quad-band BPF

The stub-loaded resonator is a good candidate for multi-band filter designs. The characteristic admittance and the lengths of a half of microstrip line ($L_8 + L_9 + L_{10} + L_{11} + L_{12}$) and the open stub ($L_{13} + L_{14}$) are denoted by $Y_o$, $L_o$, $Y_s$, and $L_s$, respectively. Due to the symmetrical construction, SLR can be analyzed by even–odd mode theory. Assuming that $2Y_o = Y_s$ the even and odd mode resonant frequencies $f_1$ and $f_2$ can be calculated by

$$f_1 = \frac{c}{4(L_o+L_s)\sqrt{\varepsilon_{eff}}} \quad (4)$$

$$f_2 = \frac{c}{4L_o\sqrt{\varepsilon_{eff}}} \quad (5)$$

where c is the light velocity in free space and $\varepsilon_{eff}$ denotes the effective permittivity of the substrate. It can be seen that $L_s$ only effects $f_1$ while $f_2$ only counts on $L_o$. Thus both these two passbands can be adjusted independently.

The configuration of the designed filter is shown in fig 6, the SLRs generate the dual passband at 2.4 and 3.5 GHz and the modified triangular loop resonator produces the dual passband at 5.2 and 5.8 GHz. Both the tunabilities of external quality factors Qe and coupling coefficients are realized. By adjusting $G_1$ and $L_5$, $Q_{e1}$ at 2.4 GHz and $Q_{e2}$ at 3.5 GHz can be easily changed simultaneously, and the control of $Q_{e3}$ at 5.2 GHz as well as $Q_{e4}$ at 5.8 GHz can be achieved by tuning $G_2$, $G_3$ and $L_2$. In addition, by properly changing $S_1$ and $S_2$, the coupling coefficients $M_{12}$ between adjacent two SLRs and $M_{34}$ between triangular loop resonators are, respectively, tunable.

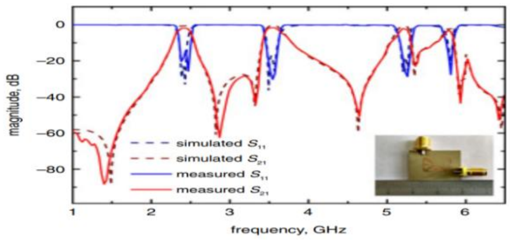


Fig 7: Frequency responses of the Quadband Bandpass Filter

In fig 7, the simulated and measured results, along with the photograph of the fabricated filter, are indicated. The centre frequencies are 2.4/3.5/5.2/5.8 GHz, and the 3 dB fractional bandwidths are 6.87/6.1/3.1/1.4%. The fabricated filter has the minimum insertion losses of 1.8/1.5/2.1/2.9 dB and the return losses of 18/30/28.7/27.6 dB. Seven TZs are produced. The designed filter has high return loss, low insertion loss, multiple TZs, compact area, and serviceable centre frequencies.

D. Quad-band BPF using Six-Mode Resonator and a Hairpin Resonator

The structure of the Proposed Quadband BPF as shown in fig8. It utilizes the stub-loaded six-mode resonator and a hairpin resonator. A hook-shape feed line is used not only to feed the resonator, but also to create the transmission zeros. A half wavelength microstrip transmission line open circuited at both ends and bent into a U shape is called a Hair-Pin Resonator , which is placed below the six mode resonator. To design the Quadband BPF, the pass-band frequency and bandwidth should be considered. According to the analysis of the even- and odd-mode circuit, the four passband frequencies can be controlled individually.

To verify the analysis, some simulations are carried out under the condition of weak port coupling. It can be observed that Band 1 and Band 3 change with different $L_4$ and $L_6$, whereas Band 2 is fixed, and when $L_3$ is changed; only Band 3 is shifted while Band 1 and Band 2 are nearly unchanged; Band 4 changed with different $L_{10}$ , whereas other three Bands are fixed. Therefore, the frequencies of the four passbands $f_1$, $f_2$, $f_3$ and $f_4$ can be controlled individually. As for the separation of every two modes $G_4$, $L_7$, $G_3$ and $L_6$ should be taken into consideration. Since $G_4$and$L_7$ affect the coupling region, all six modes will therefore be affected by them.

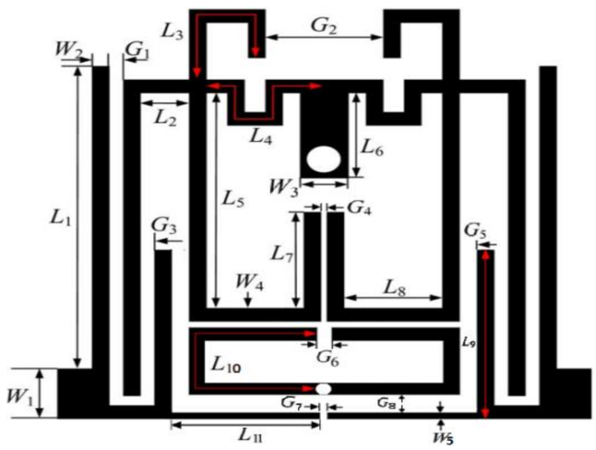


Fig 8: Structure of the Proposed Quadband BPF.

Thus, the design procedures can be summarized as follows.

Step 1. According to the required $f_2$ to determine the length $L_5 + L_7 + L_8$ which is nearly a quarter-wavelength at $f_2$.

Step 2. Determining the length $L_4$ and $L_6$ according to $f_1$. In particular, $L_4$ is predominant in controlling $f_1$, while $L_6$ is used for fine tuning.

Step 3. Achieving $f_3$ without affecting $f_1$, $f_2$ and $f_4$ by tuning $L_3$.

Step 4. The bandwidth should then be considered. The separation of $f_{odd2}$ and $f_{even2}$ can be achieved by controlling the coupling region of $G_4$and $L_7$.

Step 5. By tuning $L_6$ and $L_4$, the desired $f_{odd1}$ and $f_{even1}$ can be achieved.

Step 6. $G_2$ is used to obtain $f_{odd3}$ and $f_{even3}$.

Step 7. Achieving $f_4$ without affecting $f_1$, $f_2$ and $f_3$ by tuning $L_{10}$ of the Hairpin resonator. Thus, the four center frequencies can be obtained.

Step 8. Source load coupling is used for the adjustment of the TZs in between the third and fourth passband

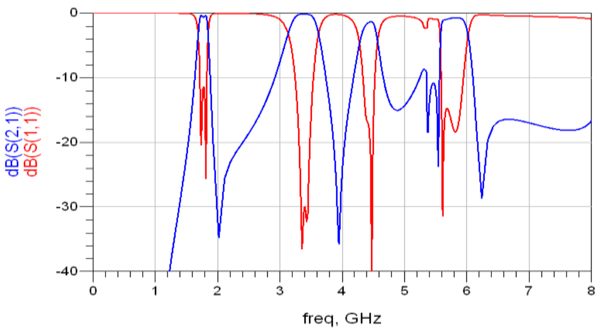


Fig 9: Simulated results of the Proposed Quadband Bandpass Filter

Finally, fine tuning is used to achieve overall good performance. It should be mentioned that the center frequencies will be slightly shifted when tuning the bandwidths. The simulated frequency responses of the Quadband Bandpass filter as shown in fig 9. The overall size of the filter is 13.9 mm x 15.9 mm. The four bands are centred at 1.8/3.3/4.4/5.8 GHz with the 3dB bandwidth of 11.7/14.7/5.2/8.7% that means Band1 is located at 1.8GHz with a 3-dB bandwidth of 11.7% the measure minimum insertion loss is 0.3 dB and return loss is 26dB. Two transmission zeros are generated at 1.1 and 2.01 GHz. Band2 is centred at 3.3GHz with 3-dB bandwidth of 14.7%. The minimum insertion loss is 0.1 dB and return loss is 36dB. The two transmission zeros are generated at 2.01 and 3.9GHz. Band3 has a centre frequency of 4.4GHz with a 3-dB bandwidth of 5.2%. The minimum insertion loss is 1.3 dB and return loss is 40dB. The two transmission zeros are centred at 3.9 and 4.8.Band4 has a centre frequency of 5.8GHz with a 3-dB bandwidth of 8.7%. The minimum insertion loss is 0.7 dB and return loss is 32 dB. The two transmission zeros are centred at 5.5 and 6.2.

TABLEI

Comparison of the Quadband Bandpass Filter using different design techniques

| | Frequency (GHz) | Insertion Loss (dB) | Return Loss (dB) | TZs | Filter Size ($mm^2$) |
|---|---|---|---|---|---|
| **Quad-band BPF using quad-mode resonator** | 1.9/2.8/4.3/5.2 | 2.3/3.6/3.5/3.4 | 20/24/15/22 | 5 | 25.32 x 17.5 |
| **Quad-Band Bandpass Filter Using Multilayer Substrate Technique** | 1.8/2.4/3.5/4.2 | 0.2/1.2/0.3/0.8 | 33/22/28/28 | 7 | 28.45 x 19.15 |
| **Quad-band BPF using SLRs and triangular loop resonators** | 2.4/3.5/5.2/5.8 | 1.8/1.5/2.1/2.9 | 18/30/28.7/27.6 | 7 | 11 x 11 |
| **Quad-band BPF using Six-Mode Resonator and a Hairpin Resonator** | **1.8/3.3/4.4/5.8** | **0.3/0.1/1.3/0.7** | **26/36/40/32** | **7** | **13.9 x 15.9** |

From this comparison table we can see that Design of Quadband Bandpass Filter using different design techniques. Here the centre frequency, insertion loss is much better in Quad-band Filter using Six mode Resonators and Hairpin Resonator as compared with the other design techniques. This filter have controllable frequencies and bandwidths using Six mode Resonators and Hairpin Resonator. Meanwhile, the total size is greatly reduced due to this two resonators is utilized. This filter used in GSM, WIMAX, WLAN, and ISM applications.

## IV. CONCLUSION

In modern wireless communication systems, compact microwave devices capable of operating at more than one frequency band have been developed extensively. Quadband bandpass filter (BPF) is one of the critical frontend components in multiband wireless communication systems. To minimise the overall size further, a novel compact Quadband Microstrip Bandpass Filter is designed by using different design techniques has been observed. The characteristics of the Quadband Filter indicate that the filter is applicable in microwave integrated circuits ensuring high performance in the radio frequency front-end systems, while the wide range of attenuation bandwidth makes it possible to use the filter in microwave satellite and mobile communication systems.

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