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# Miniaturized Dual-Band Bandpass Filter Using Multilayered Dual-Mode Resonator

Raaed T. Hammed [1], Dhuha G. Hammood [2]
[1,] Lecturer, [2] M. Sc. Student, *Department of Electrical Engineering, University of Technology*
30209@uotechnology.edu.iq [1], eng.dhuha@yahoo.com [2],

**Abstract**

This paper presents a miniaturized dual-band bandpass filter using two coupled dual-mode resonators (DMRs). The dual-mode resonator is a short-circuited stub loaded square loop resonator. The concept of miniaturization achieved using multilayered technology. Therefore, the filter circuits are achieved in three layers. On the first layer, two coupled dual-mode resonators are designed and shorted to a ground layer to specify the required passbands. Next, a second layer employs two shorted quarter wavelength stubs coupled through one via hole are capacitively coupled to the first layer circuit to achieve the filtering response. For our demonstration, a multi-band bandpass filter is designed to serve a multifunctional wireless system has centre frequencies of 1.9 GHz GSM and 3.5 GHz WiMax systems. The filter is implemented and simulated using the momentum simulator of the *Advanced Design System* (ADS) software package. The filter response has two second-order passbands with four transmission zeros leads to a high skirt selectivity. The filter circuit area is very small, less than 37 mm$^2$ terminating the feeding ports.

**Keywords:** Dual-mode resonator (DMR), multilayered technology, dual-band filter, bandpass filter (BPF), Worldwide Interoperability for Microwave Access (WiMax**),** Global System for Mobile communication (GSM).

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## Introduction

Through the fast evolution of contemporary wireless technologies miniaturized dual-band bandpass filters for integrated multi-service systems of communication have become a most common inclination. Such filters are required to have compact size, low insertion loss, good isolation between bands, and high selectivity. To this end, academic and industrial researchers have proposed numerous dual-band filters using several methodologies and constructing.

Using two coupled asymmetric stepped-impedance resonators (SIRs), a dual-band BPF with high isolation between bands is reported in [1]. This filter has a suitable attenuation between bands but high insertion loss and large size. By mixing the shunt stub BPF and shunt serial resonator BSF, [2] designed a dual-band BPF with widely bandwidth passbands. In [3], controllable bandwidths of a dual bandpass filter is achieved through two coupling paths of two coupled stub-loaded resonators. However, this filter suffers from high insertion loss and poor out-of-band. Based on $\lambda/4$ stepped impedance resonators (SIRs), [4] introduced a good synthesis method for a class of dual band BPFs. Unfortunately, the proposed filters have large circuit size. Using stub-loaded resonator and coupled source-load lines, [5] presents a dual- band bandpass filter with different bandwidths. In this filter, the rejection level between bands was improved by etching a super-line in coupled feeding lines. Moreover, [6] proposed a design method to develop a dual-band BPF with compact size. In this method, two modified open or short-circuited sub-loaded quarter wavelength resonator are designed and coupled to produce dual band bandpass filter having second-order behavior. In order to develop a miniaturize dual-band BPF, [7] and [8] followed multilayered technology in which the former used stub-loaded stepped-impedance and uniform impedance resonators while the latter used substrate-integrated waveguide (SIW) with loaded posts.

In this work, a design method to miniaturize dual-band BPF is developed using multilayered dual-mode resonator. In this method, two microstrip dual-mode resonators are realized and patterned on a first substrate to perform the desired passbands center frequencies. Next, the second substrate circuit including two shorted quarter wavelength stubs coupled by one via hole are capacitively coupled to the first substrate circuit and hence the frequency response is enhanced. The proposed filter is designed to operate at center frequencies of $f_1 = 1.9$ GHz and $f_2 = 3.5$ GHz to serve multifunctional communication system of GSM and WiMAX applications respectively. The developed filter is very compact (smaller than 37 mm$^2$), has low insertion and good return losses of (0.03/21.55 dB and 0.07/17.62 dB) at the first and second band respectively, and good selectivity resulting from four transmission zeros around the two bands.

**Design and Analysis of Dual-Mode Resonator**

Recently, a kind of dual-mode resonator (the E-shape microstrip structure) is proposed as two coupled resonators to design a miniaturized ultra wideband (UWB) bandpass filter, [9]. Due to its features in miniaturization circuits, this structure is reconfigured as a square-loop resonator loaded by middle short-circuited stub. Therefore, the design steps proposed in [9] still valid in this work. Figure 1 shows the schematic of the proposed dual-mode resonator and its equivalent circuit. In Fact the square-loop resonator, Figure 1(a), is a halve wave open-circuited stub resonator having physical dimensions $2l_1$and $d_1$. This resonator is considered as a two $\lambda/4$ open-circuit stub resonators and the grounded stub, ($l_2$, $d_2$), modulates the coupling between resonators. Following the design steps and the equivalent circuit in [9], the proposed DMR generates two original resonant frequencies $f_1$ and $f_2$ in which the chief resonant frequency ($f_2$) belongs to the square-loop resonator set by length $2l_1 = \lambda/2$.

In the equivalent circuit, Figure 1 (b), the values of $L$ and $C$ are determined at the resonant frequency ($f_2$) of the square-loop resonator meeting the condition $2l_1 = \lambda/2$, as given in [10]:

$$C = \frac{\pi}{2\omega_0 z_0} \quad (1)$$

$$L = \frac{1}{\omega_0^2 C} \quad (2)$$

Where $C$, $L$,$z_0$ and $\omega_0$ refer to the capacitance, inductance, characteristic impedance and angular resonance frequency for the equivalent circuit.

At low frequency ($f_1$), the dual-mode resonator considered as three stubs having wave lengths less than $\lambda/8$ (i.e: $l_1$ and $l_2$< $\lambda/8$ at sufficient low frequencies). Therefore, the value of the element $L_m$ (the mutual inductance) in the equivalent circuit, Figure 1 (b), is given by the low frequency approximation and its magnitude is calculated from [11]:

$$L_m = \frac{z_0 l}{V_p} \quad (3)$$

where $V_p$, $z_0$, and $l$ represents the wave velocity, characteristic impedance, and physical length of the transmission line involved in the structure respectively. From the above information and the given equations, the proposed dual-mode resonator DMR is working as two coupled resonators and its resonant frequencies are [9]:

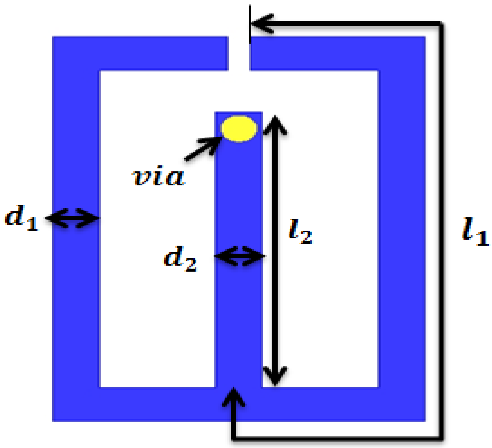
$$f_1 = \frac{1}{2\pi\sqrt{(Lm+L+Lm)\,C}} \leftrightarrow \frac{1}{2\pi\sqrt{C(L+2Lm)}} \quad (4)$$

(4)

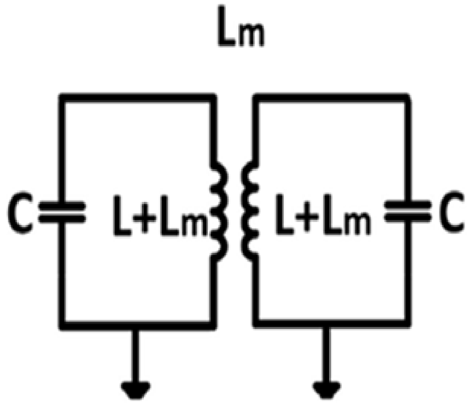
$$f_2 = \frac{1}{2\pi\sqrt{(Lm+L-Lm)C}} \leftrightarrow \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

Where $f_1$ and $f_2$ indicate for the lower and upper resonance frequencies respectively.

Based on the above information, a dual-mode resonator (DMR) is realized with two frequencies, $f_1$=1.9 GHz and $f_2$=3.5 GHz. The lumped element values and the physical dimensions of the proposed DMR, Fig. 1, are summed up in Table I. This DMR was patterned on a 0.5 mm thick substrate with $\varepsilon_{r1} = 10.2$ (Rogers RO3010). Next, the dual-mode resonator and its equivalent circuit are simulated using the momentum simulator of ADS program [12], and their responses are plotted in Figure 2. This figure shows the imaginary part of the input impedance ($Z_{in}$) of the DMR and its equivalent circuit with respect to frequency. It is clear that the dual-mode resonator response has two resonant frequencies at $f_1$=1.9 GHz and $f_2$=3.5 GHz which almost agrees with its equivalent circuit behavior.



(a)



(b)

**Figure 1:** Configured dual-mode resonator (DMR), (a) conductor layout, and

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(b) its equivalent circuit

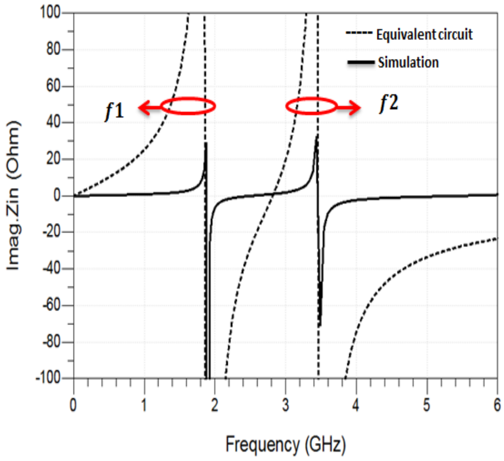


**Figure 2:** Impedance characteristic response of the dual-mode resonator and its equivalent circuit

**Multilayered Dual-Mode Dual –Band BPF**

The analysis and simulation evidences outlined in the previous section indicate that the dual-mode resonator can generate two coupled frequencies $f_1$ and $f_2$. In fact these frequencies are the center frequencies of the developed dual-band bandpass filter. Consequently, a dual-band bandpass filter is realized to operate at two center frequencies $f_1 = 1.9$ GHz and $f_2 = 3.5$ GHz and hence a multi communication system of GPS and WiMax systems. Figure 3 shows the three dimension geometry of the proposed dual-band bandpass filter. The developed filter is composes of two microstrip circuits capacitively coupled using multilayer technology. The first microstrip circuit is a two grounded dual-mode resonators etched on the first layer and coupled using a separate gap ($g_c$) to specify the desired dual-band passbands as shown in Figure 3. In the same Figure, the second microstrip circuit is a two grounded quarter wavelength stubs etched on a second layer and coupled through one via hole to achieve the filtering response. Both circuits are shorted to the ground layer. The two filter circuits are capacitively coupled using overlapping microstrip lines. The strength of the coupling coefficient between the essential coupled lines can be controlled and adjusted through the thickness of the second dielectric layer $h_2$ shown in Figure 3.

For evidence the prior idea, two dual-mode resonators having the same physical dimensions and electrical properties stated in Table 1 are realized to specify the desired passbands frequencies $f_1 = 1.9$ GHz and $f_2 = 3.5$ GHz. Due to the change in electromagnetic field distribution caused by the existence of the second substrate, the dimensions of the designed DMR shown in Figure 1 (a) are need to be retuned and hence $l_1 = 6.9\ mm$ and $l_2 = 3.1\ mm$ to maintain the desired passbands frequencies. Next, two of the desired DMR are separate and coupled through a space gap of $g_c$=0.3 $mm$. The top layer circuit (the two $\lambda/4$ short-circuited stubs) patterned on the second substrate has a width of $d_1 = 0.4\ mm$ and length of $l_1 = 8.85\ mm$ fabricated on a Rogers RO3010 has a dielectric constant of $\varepsilon_{r2} = 10.2$ and a thickness of $h_2$=0.25mm. The 50 ohm feeding ports width of $d_P = 0.6\ mm$ are directly connected to the upper end of the second layer circuit. As shown in Figure 3, the middle circuit and the top circuit are overlapped and coupled through essential coupled length of $l_e = 4.6\ mm$. From the above information, it is clear that the filter response can be enhanced by adjusting the two basic coupling degrees the separate gap ($g_c$) and the thickness of the second substrate ($h_2$). With the aid of the momentum in ADS software, the two coupling degrees are studied and their responses are plotted in Figures 4-6. The reported Figures 4-6 are present the filter responses with a constant $g_c$ and variable $h_2$. Obviously, the study in all cases show that the decrease in $g_c$ and $h_2$ lead to a better filter response. Finally, the response of the proposed dual-band bandpass filter is improved at $g_c$=0.3 mm and $h_2$=0.25mm, Fig. 7. The simulated response, Figure 7 (b) and (c), indicates that the resulted passbands have a second-order response with a 3dB bandwidths of about $66.5/98$ MHz at $f1/f2$. The filter offer good insertion/return losses about $0.03/21.55$ dB and $0.07/17.62$ dB at the $first/second$ bands respectively and high skirt selectivity resulted from four transmission zeros allocated at 1.754 GHz/-45.181 dB, 2.455 GHz/-54.855 dB, 3.123 GHz /-54.286 dB, and 3.877 GHz /-47.102 dB around the two passbands. Moreover, the filter response shown in Figure 7 (a) show that the filter has good isolation between the two bands run to $-33$ dB for the frequency range (2.312 GHz – 3.184 GHz). Based on the above analysis, flexible design steps of the proposed filter can be abbreviated by the flow chart cleared in Figure 8.

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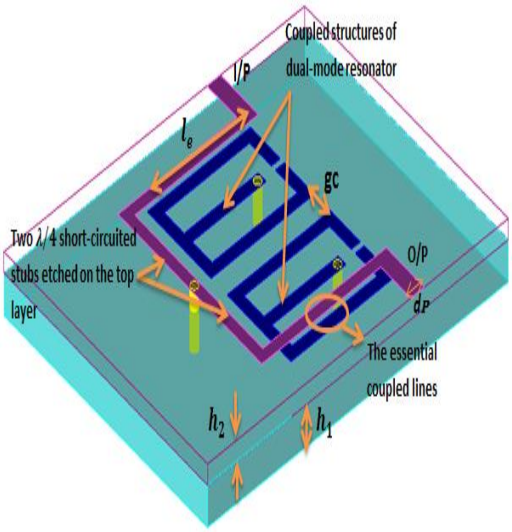
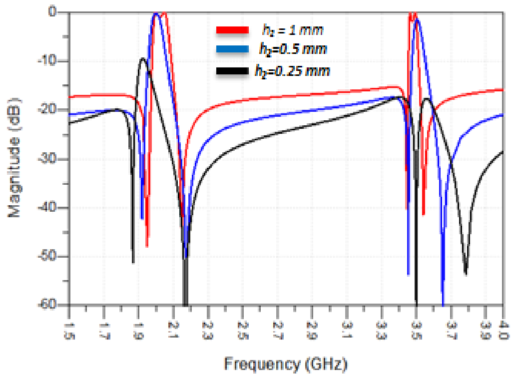


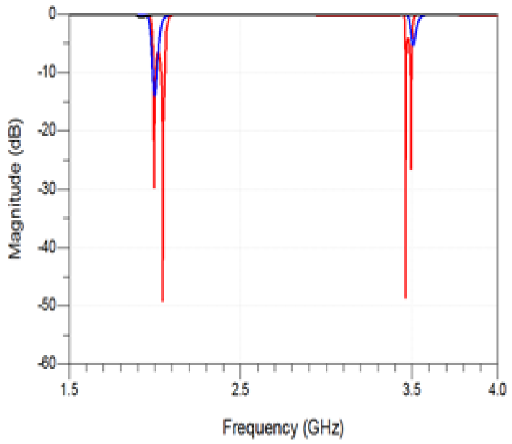

**Figure 3:** Three dimension layout of the multilayered dual-band BPF

Table 1 Basic Dual-Mode Resonator (DMR) Physical Dimensions and its Lumped Elements Equivalent Circuit Values.

| | |
|---|---|
| Physical dimensions | $l_1 = 8.6\,mm,\ l_2 = 4.75\,mm,\ d_1 = 0.4\,mm,$ and $d_2 = 0.4\,mm$ |
| Lumped element values | $L = 1.38\,nH,\ Lm = 1.66\,nH,$ and $C = 1.48\,pF$ |

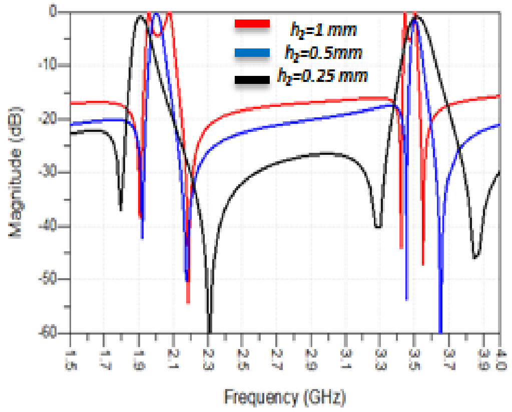



(a)

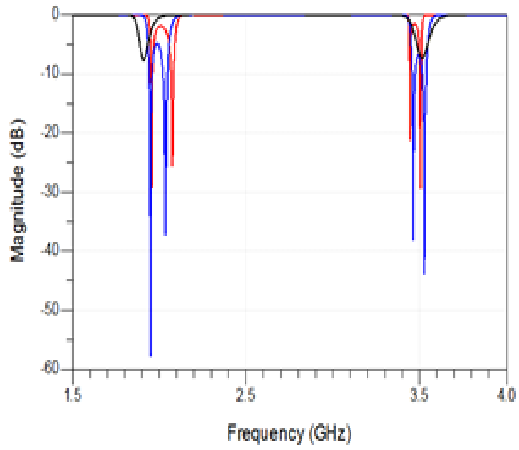



(b)

**Figure 4:** S-parameter response of dual-band BPF filter, Fig. 3, with $g_c$=1 mm: (a) insertion loss (b) return loss

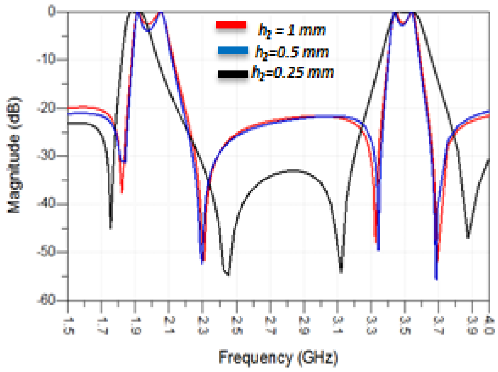



(a)

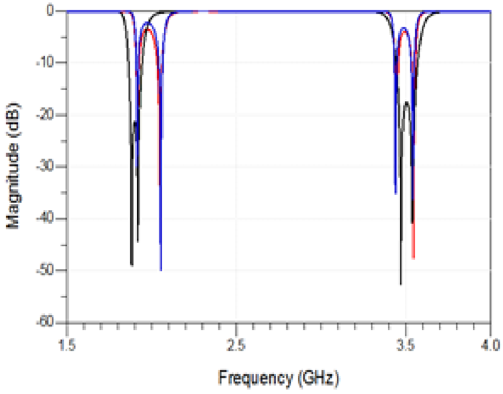



(b)

**Figure 5:** S-parameter response of dual-band BPF filter, Fig. 3, with $g_c$=0.5 mm: (a) insertion loss (b) return loss

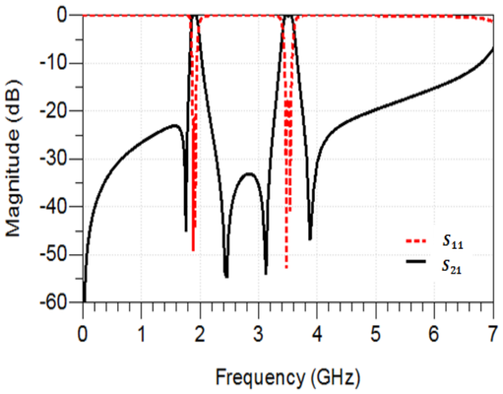



(a)

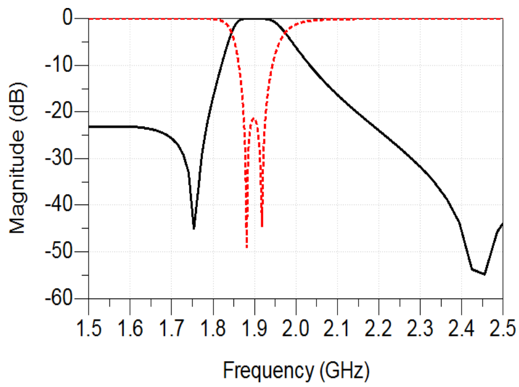



(b)

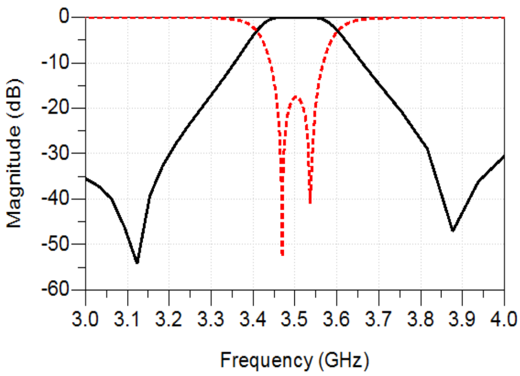
**Figure 6:** S-parameter response of dual-band BPF filter, Fig. 3, with $g_c$=0.3 mm: (a) insertion loss (b) return loss




(a)




(b)




(c)

**Figure 7:** Simulated S-parameter of the proposed dual-band BPF, Fig. 3: (a) enhanced response with $g_c$=0.3 mm and $h_2$=0.25 mm, (b) expanded response of the first band, and (c) expanded response of the second band

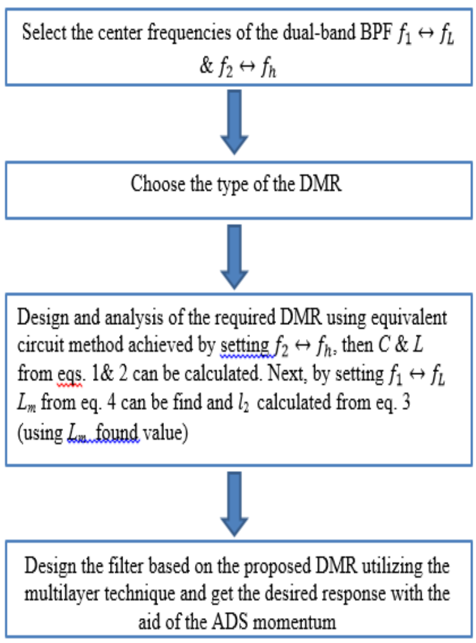



**Figure 8:** The flow chart of the filter design

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**Conclusion**

A compact design of multilayered dual-mode dual-band BPF was presented in this paper. The overall designed structure patterned on three layers so as the concept of miniaturization achieved properly. The dual-mode resonator that utilized was a short circuited stub loaded square loop resonator. Two of DMRs were designed and coupled gathering on a middle layer. Then, two of $\lambda/4$ short-circuited stubs were coupled by one bunker-down via hole on a second layer. The two Filter circuits in the first and second layer were capacitively coupled. The compactness size of this filter reached less than $37\,mm^2$ terminating the feeding ports. For this multi-band filter, the available center frequencies came to serve a multifunctional communication system as 1.9 GHz GPS and 3.5 GHz WiMax system. The resulting response from this filter has a good selectivity from the four transmission zeroes generated around the two second-order passbands.

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