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Tunable Band pass filter for RF coexistence

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***Abstract*— In this paper, a miniature compact tunable bandpass filter that addresses the RF coexistence problem effectively has been presented. This filter uses folded stub method for reducing the physical size at microwave and radio frequencies commonly used in communication systems. Final fabricated filter size is 0.096λ mm X 0.112λ mm. The tunable filtering functionality is achieved with varactor diode switching circuit. The proposed filter design offers insertion loss values approximately near to 1dB. An addition of via at specific location achieves better band rejection and tuning. The filter structure was designed, investigated, and simulated using ANSYS HFSS software. The prototype was fabricated using FR4 substrate having 1.59 mm thickness and dielectric constant of 4.4. The testing is done on Vector network analyzer.**

Keywords— RF coexistence, folded stub, tunable filter, varactor diode

I. INTRODUCTION

All new wireless devices coming to market and their requirements include addition of multiple wireless technologies into one device. These technologies include short-range and long-range applications. There is also rise in newer communication protocols and standards in last few years [1-3]. Semiconductor devices and chips also have been fabricated to support the multi-standard and multi-band operations. Such a high integration of multiple technologies into single device has created a problem, mostly referred as 'RF coexistence' problem [4-5]. RF coexistence problem refers to functioning of multiple devices and multiple wireless standards in the same or closely spaced frequency bands [6]. Frequency band of 2.4 GHz is the best example of this scenario. This band contains Bluetooth classic, Bluetooth Low Energy (BLE), ZigBee, WLAN and unlicensed Industrial-Scientific-Medical (ISM) bands also. This has been explained in Fig.1, band 40 ranging from 2300 MHz to 2400 MHz and band 41 used for TDD-LTE services in China and Wi-Fi operate from 2400 to 2482 MHz. Both bands have common boundary at 2400 MHz with no guard band present. When a wireless device that supports both standards is to be designed, we need filter that can support steep transition from one band to other by rejecting adjacent frequencies. Traditional filters having longer roll-off can cause considerable interference [7-8]. In this work, the tunable filter is design using the folded stub method is proposed.

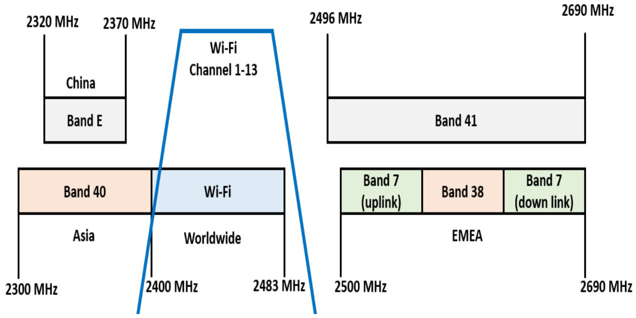


Fig.1. 2.4 GHz spectrum with all the existing standards. Observe that there is hardly any guard band present between frequencies. This makes RF coexistence problem more important.

With the addition of new applications and standards, this band has become very crowded. A similar situation is occurring with other parts of the radio spectrum. This has resulted in a significant reduction in signal bandwidth and sometimes elimination of guard bands which are allocated between two adjacent technologies to avoid interference. Due to such modifications in the spectrum allocation for newer technologies, filter specifications have changed, and closely spaced frequencies need steeper transitions between passband and stop bands. Filters that are commonly known as coexistence filters [9-10].

With advancement of technology and increased power integrity of semiconductor and PCB materials, the size of the electronic devices is reducing significantly. This puts another restriction on filter designs that the new designs should be as small as possible [11]. Filter integration is a technical challenge for the designers and manufacturers as they fit filters that operate on multiple channels into a device that is the size of a human thumb. It can be easily understood that newer filters should be miniature, multi-band and should effectively tackle RF coexistence problem, accordingly, to address those factors the design is proposed in this paper.

II. FILTER CHARACTERISTICS AND CONFIGURATION

The proposed filter design is a folded resonator structure, which makes the filter more compact. In the proposed work, band pass filter is designed such that the resonator is centered at a frequency of 2.4 GHz and designed based on the insertion loss method [15] shown in Fig 2.

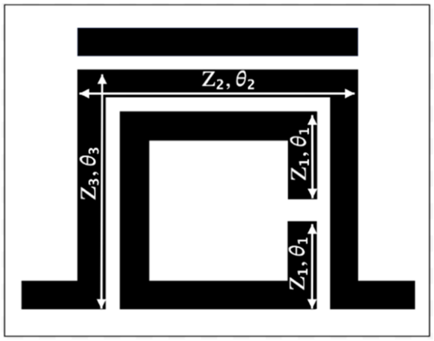


Fig. 2. Designed filter for resonance frequency of 2.4 GHz.

The design is simply derived from complementary split ring resonator (CSRR) whose width was adjusted for filter tuning and targeted frequency cut-offs. As CSRR itself behaves as frequency selective structure, that principle used to derive the proposed structure. To evolve such a structure, outer ring from CSRR was opened and hence, converted into open-circuited stub. An open-circuited stub length can be varied and easily used to change the frequency selective performance as proposed in [18]. Inner ring of CSRR was kept the same, however, simulation experiment was carried out to change the length of inner ring to achieve desired filter response. The gap between outer resonator and the open-ended stub has been managed such that the open-ended stub does not affect the filter performance in any way. This has been ensured by simulation.

Calculation of resonator stub can be described using following equations:

$$\theta_1 \cong \frac{\pi}{2} \tag{1}$$

The open-ended stubs Z1 connect to stubs Z2 , to tune even and odd mode. If we assume, $R = \beta Z_3/\alpha Z_2$ and we assume R>1, then the electrical length of other two stubs can be obtained from [18]:

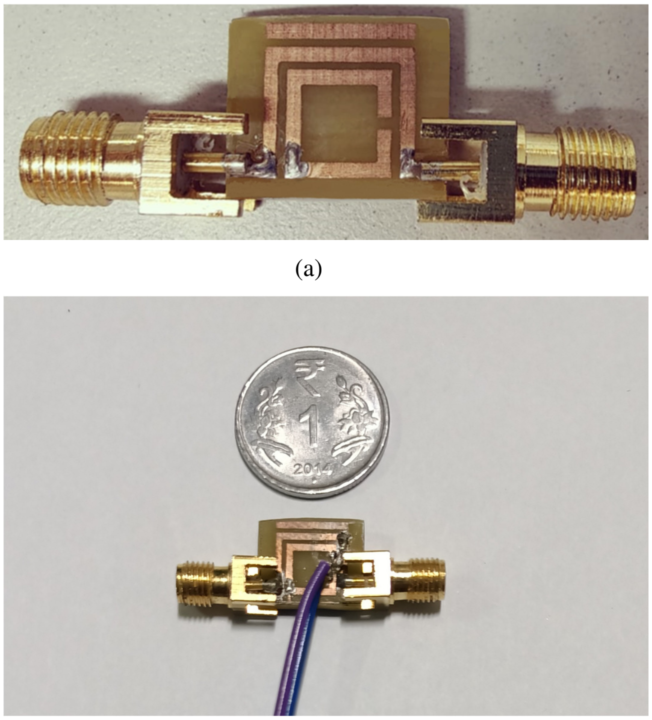
$$\theta_2 \cong \cos^{-1}\left(\sqrt{\frac{R(R-1)}{R^2-1}}\right) \tag{2}$$

$$\theta_3 \cong (\pi + \alpha \tan(-R\tan(\theta_2))) - \left(\frac{c}{4F\sqrt{\varepsilon_{eff}}}\right) \tag{3}$$

III. FABRICATION AND TESTING

For achieving switching functionality used varactor diode part SMV1232 [19]. This diode switching circuit is readily available in [20-21] and utilized the same circuit. Location of biasing the varactor diode in the filter structure was decided from assuming multiple points on filter.

Table 1 shows the typical capacitance values provided by Skyworks SMV1232 varactor diode [19]. The association between the bias DC voltage, ranging from 0 to 4 V, and the capacitance range of 1.22 to 4.15 pF is clearly observable. This correlation produces the suitable tuning response of the filter.



(a)

(b)

Fig. 3. (a) Fabricated filter structure on FR4 substrate (b) Photograph of filter with coin

Reverse Voltage (V)	Capacitance (pF)
0	4.15
1	2.67
2	1.97
3	1.51
4	1.22

Table 1. Table for reverse bias voltage vs capacitance of SMV1232 varactor diode

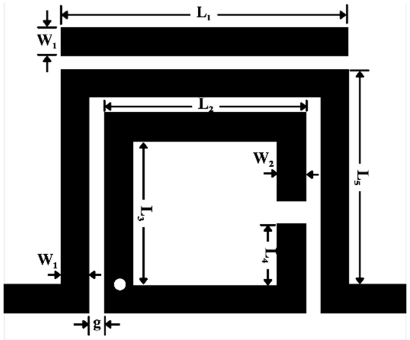
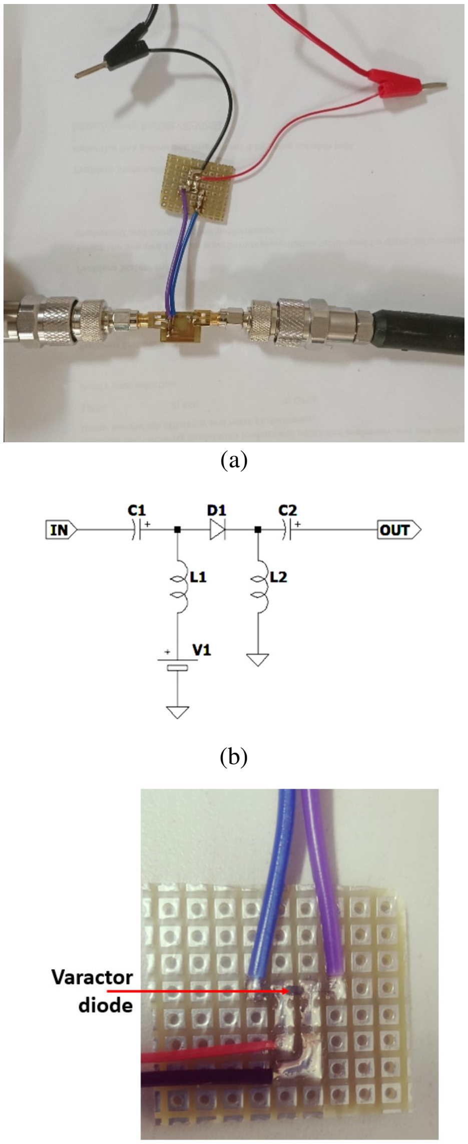


Fig. 4. Proposed filter structure dimensions

All the simulations presented so far were carried out in ANSYS HFSS. Fabrication was done with copper thickness of 35 microns on FR4 substrate of thickness of 1.59 mm and dielectric constant of 4.4 as shown in Fig. 3 (a).

W_1	$0.008\lambda0$
W_2	$0.0085\lambda0$
L_1	$0.08\lambda0$
L_2	$0.056\lambda0$
L_3	$0.056\lambda0$
L_4	$0.025\lambda0$
L_5	$0.052\lambda0$

Table 2. Filter structure dimensions ($\lambda0$ is free space wavelength at 2.4 GHz)



(a)

(b)

(c)

Fig. 5 (a) Testing filter structure with varactor diode, varactor diode (b) switching circuit (c) photograph.

In Fig. 5 (c), varactor diode switching circuit is shown, where red and black wires go to the power supply for biasing the diode, while blue and purple wires are connected across the filter structure as shown in Fig. 5 (a). The proposed technique and the work can be later used for addition of other communication frequency bands for further expansion of the idea.

IV. SIMULATION AND MEASUREMENT RESULTS

For measured results, Vector network analyzer (VNA) is used. The tunable range from 2.2GHz to 2.6GHz is achieved from the proposed system as shown in Fig. 6.

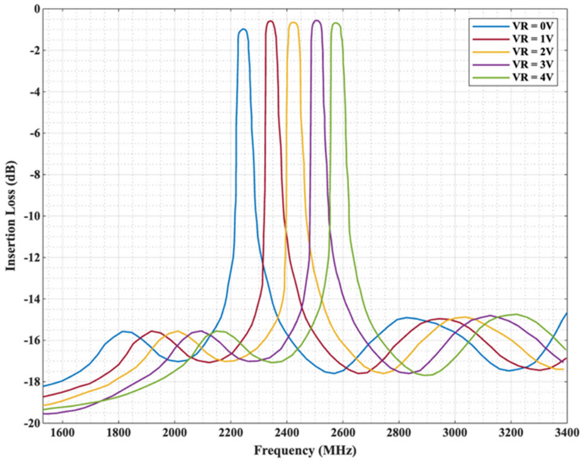


Fig. 6. Measured insertion losses with different DC reverse bias voltages for the presented filter

V. CONCLUSION

A compact tunable bandpass filter that addresses the RF coexistence problem in highly integrated communications systems has been presented. This filter uses folded stub method and designed based on omega-shaped microstrip filter structure. The tunning band achieved approximately from 2.250 GHz to 2.580 GHz. By optimizing the propsed filter, it can be used in various application like mobile services, satellite services and ISM band. The filter structure was designed, investigated, and simulated using ANSYS HFSS software. The prototype was fabricated using FR4 substrate having 1.59 mm thickness and dielectric constant of 4.4. The proposed filter size is 0.096λ mm X 0.112λ mm. The proposed filter is compact in size.

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