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Quarter Wave Resonator based Microstrip Bandpass Filter using Asymmetrical coefficients

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Abstract: ***This paper presents a new concept of bandpass filter design based on quarter-wave resonator which covers ISM band (2.4-2.48 GHz) can be used for applications such as wireless fidelity (Wi-Fi) and Global System for Mobile communication (GSM). A fifth-order Butterworth bandpass filter is designed using standard filter coefficients with fractional bandwidth of 50% for the center frequency of 2.1 GHz. Filter design is achieved using quarter-wave resonator, and the obtained response satisfies the desired filter specifications. The insertion loss of 21 dB is achieved at the cutoff frequency of 2.1 GHz. The passband frequency of 1.877 GHz to 2.772 GHz is achieved in the proposed design. The standard coefficients of the Butterworth filter were modified to propose a new type of asymmetrical filter coefficients. The designed filter has better response than existing method in terms of bandwidth and insertion loss. The designed Bandpass filter has a passband frequency of 1.8 GHz to 2.7 GHz. Therefore, the designed bandpass filter can be used for both Wi-Fi and GSM applications simultaneously.***

Keywords ***: Bandpass Filter (BPF), microstrip, Butterworth, quarter-wave resonator.***

I. INTRODUCTION

Most of the recent wireless technologies have flexible frequency profiles, giving rise to the need for multiband bandpass filters [1]. Band Pass Filter (BPF) is one of the important modules in the radio receiver chain to perform band selection operation as per the application requirements.

The RF receiver block diagram is shown in Fig. 1. In the receiver, the bandpass filter is located just after the antenna and before the low noise amplifier (LNA). It is used to suppress out of band noise and to eliminate the image frequency in super heterodyne receivers. In the transmitter, it is located before and/or after the power amplifier. It is used to reject the spurious signals generated by the Local oscillator (LO) and to minimize the inter modulation products which are generated at the RF up and down converter circuits.

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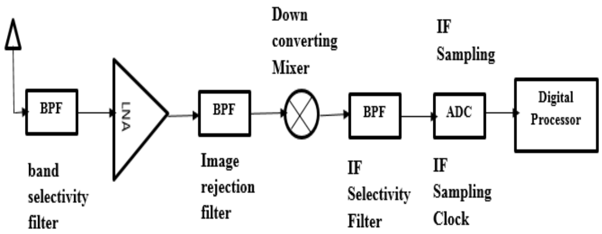

Fig. 1. RF receiver block diagram

The filter design process starts with the selection of a particular type of filter. The most commonly preferred filters for RF applications are Butterworth, Chebyshev and Elliptical Filters [2]. Among these filters, Butterworth exhibits a maximally flat response. In addition, it exhibits a nearly flat passband without any ripple [3].

The usage of Butterworth polynomial based coefficient selection for filter design is one of the universally accepted design methodology [4]. The microstrip bandpass filter designs always demand compact size, sharp roll-off, and wide stopband characteristics [5] – [7]. The width and length of the microstrip filter structure directly depend on the value of the normalized filter coefficients [8]. The normalized coefficients of standard Butterworth approach follow symmetrical distribution, which in turn provides the symmetrical nature of microstrip filter structure.

In this paper, asymmetrical natures of normalized filter coefficients were proposed. These proposed coefficients are used for designing a bandpass filter. The designed filter has the advantages of low power dissipation, less width, and ease of implementation.

In the first section of this paper, the introduction of microstrip bandpass filter was given. In the second section of this paper, the general approach of quarter-wave resonator based bandpass filter design is discussed. In Section III the performance analysis of bandpass filter using the existing and proposed coefficients was done using ADS co-simulation. The proposed work was concluded in section IV.

II. BANDPASS FILTER DESIGN USING QUARTER WAVE RESONATOR

There are several approaches available for the design of a bandpass filter. However, the quarter-wave resonator based BPF design is compact in nature. The specifications for the proposed filter are Butterworth type, order 5, center frequency 2.1 GHz and fractional bandwidth 50%. Table 1 shows the normalized coefficient values of the standard Butterworth filter for the order value (N) up to six.

These coefficients value clearly describes the existence of symmetry between the values. The step by step process of RF filter design is shown as block diagram in Fig. 2.

Table-1: Normalized elemental values of standard Butterworth filter

No	g1	g2	g3	g4	g5	g6	g7
1	2.0	1					
2	1.4142	1.4142	1				
3	1.0	2.0	1.0	1.0			
4	0.7654	1.8478	1.8478	0.7654	1.0		
5	0.6180	1.6180	2.0	1.6180	0.6180	1.0	
6	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176	1.0

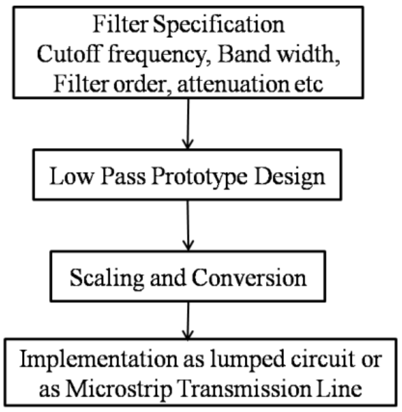

Fig. 2. Design steps of a bandpass filter

The filter design starts from the evaluation of prototype of low pass filter components and converting it to the desired type of filter. Here the low pass to bandpass conversion is followed using equations 1 to 4. The series configured inductor (L) and capacitor (C) is evaluated from (1) and (2). The shunt configured inductor and capacitor are evaluated from equation 3 and 4. The bandpass filter using lumped components is shown in Fig. 3.

$$L_k' = \frac{L_k R_0}{\Delta\omega_0} \quad (1)$$

$$C_k' = \frac{\Delta}{\omega_0 L_k R_0} \quad (2)$$

$$L_k' = \frac{\Delta R_0}{\omega_0 C_k} \quad (3)$$

$$C_k' = \frac{C_k}{\Delta\omega_0 R_0} \quad (4)$$

where L_k and C_k' are inductor and capacitor value placed in bandpass filter. R_0 is the center frequency of the filter and Δ is the fractional bandwidth of the filter.

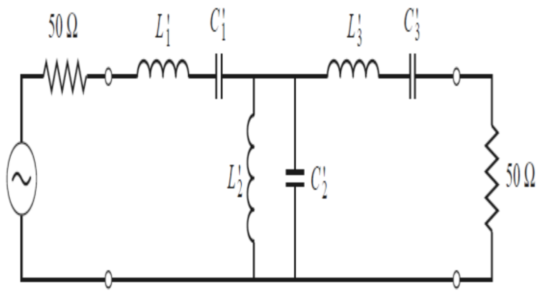

Fig. 3. Lumped Element Bandpass filter

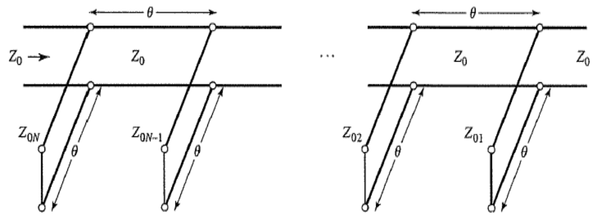

Fig. 4. Structure of bandpass filter using quarter wave resonators

The implementation of the bandpass filter in microstrip form is achieved using quarter wave resonator. Quarter wave based resonators were effectively used to realize the miniaturized version of RF circuits [9]–[10]. The electrical length of microstrip transmission line sections and stubs is λ/4. Fig. 4 shows the final implementation of bandpass filter using quarter wave sections. In the first stage series combination of capacitor and inductor are converted to connecting transmission line with impedance Z_0. In the final stage shunt configured capacitor and inductor are transformed to a short circuited transmission line as shown in Fig. 5. Both connecting transmission line and stubs are λ/4 long at the center frequency (R_0) of pass band.

The bandpass filter design can be accomplished by using equivalent stubs for the parallel resonant circuits and connecting lines, and equating the response to that of a lumped element bandpass filter. The equivalent bandpass filter has two degrees of freedom in terms of L and C, or equivalently ω_0, the slope of the admittance at the resonance. For a stub resonator the corresponding degrees of freedom are the resonant length and characteristic impedance of the transmission line. As shown in Fig. 5, the equivalent structure of short-circuited transmission line stub can be approximated as parallel LC resonator when its length is near 90^0.

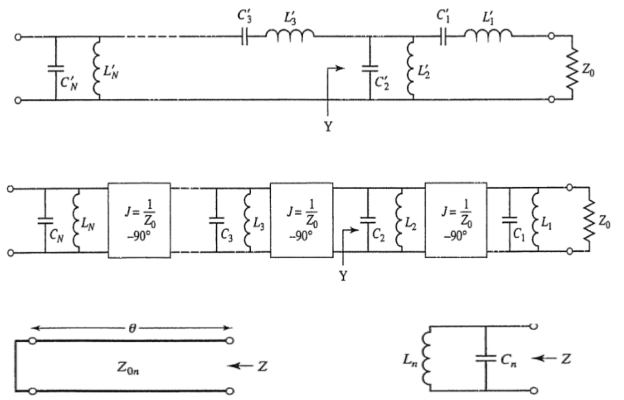

Fig. 5. Simplification of lumped element bandpass filter into transmission line sections.

The input admittance of a short-circuited transmission line with characteristic impedance Z_{0n} is

$$Y = \frac{-j}{Z_{0n}} \cot\theta \quad (5)$$

where $\theta = \frac{\pi}{2}$ $\omega = \omega_0 + \Delta\omega$ for and if $\Delta\omega \langle\langle \omega_0$

then $\theta = \frac{\pi}{2}\left(1+\frac{\Delta\omega}{\omega_0}\right)$ which allows admittance to be approximated as:

$$Y = \frac{-j}{Z_{0n}}\cot\left(\frac{\pi}{2}+\frac{\pi\Delta\omega}{2\omega_0}\right) = \frac{j}{Z_{0n}}\tan\frac{\pi\Delta\omega}{2\omega_0} \cong \frac{j\pi\Delta\omega}{2Z_{0n}\omega_0} \tag{6}$$

For frequencies in the vicinity of the center frequency, the admittance near resonance of the parallel LC network is as follows:

$$\begin{aligned} Y &= j\omega C_n + \frac{1}{j\omega L_n} = j\sqrt{\frac{C_n}{L_n}}\left(\omega\sqrt{C_n L_n} - \frac{1}{\omega\sqrt{C_n L_n}}\right) \\ &= j\sqrt{\frac{C_n}{L_n}}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \cong 2jC_n\Delta\omega \end{aligned} \tag{7}$$

$C_n L_n = \frac{1}{\omega_0^2}$ gives the characteristic impedance of the transmission line stub in terms of the resonator parameters as

$$Z_{0n} = \frac{\pi\omega_0 L_n}{4} = \frac{\pi}{4\omega_0 C_n} \tag{8}$$

Then the quarter-wave sections of line between the stubs as ideal admittance inverters are considered. Then the equivalent circuit can represent the bandpass filter. Thus, with reference to the terminated circuit the admittance Y seen looking toward the L2, C2 resonator is

$$\begin{aligned} Y &= j\omega C_2 + \frac{1}{j\omega L_2} + \frac{1}{Z_0^2}\left[j\omega C_1 + \frac{1}{j\omega L_1} + \frac{1}{Z_0}\right]^{-1} \\ &= j\sqrt{\frac{C_2}{L_2}}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) + \frac{1}{Z_0^2}\left[j\sqrt{\frac{C_1}{L_1}}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) + \frac{1}{Z_0}\right]^{-1} \end{aligned} \tag{9}$$

whereas it is used as $L_1 C_1 = L_2 C_2 = \frac{1}{\omega_0^2}$. The admittance at the corresponding point in the equivalent circuit is given by

$$\begin{aligned} \gamma &= j\omega C_2 + \frac{1}{j\omega L_2}\left[j\omega L_1^{'} + \frac{1}{j\omega C_1^{'}} + Z_0\right]^{-1} \\ &= j\sqrt{\frac{C_2^{'}}{L_2^{'}}}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) + \left[j\sqrt{\frac{L_1^{'}}{C_1^{'}}}\left(\frac{\omega}{\omega_0} - \frac{\omega}{\omega_0}\right) + Z_0\right]^{-1} \end{aligned} \tag{10}$$

These two results are exactly equivalent for all frequencies if the following conditions are satisfied

$$\begin{aligned} \sqrt{\frac{C_2}{L_2}} &= \sqrt{\frac{C_2^{'}}{L_2^{'}}} \\ Z_0^2\sqrt{\frac{C_1}{L_1}} &= \sqrt{\frac{L_1^{'}}{C_1^{'}}} \end{aligned} \tag{11}$$

Using the fact $L_1^{'}C_1^{'} = L_2^{'}C_2^{'} = 1/\omega_0^2$ allows these two equations to be solved for L_1 and L_2 as

$$\begin{aligned} L_1 &= \frac{Z_0^2}{\omega_0^2 L_1^{1}} \\ L_2 &= L_2^{'} \end{aligned} \tag{12}$$

$$\begin{aligned} Z_{01} &= \frac{\pi\omega_0 L_1}{4} = \frac{\pi Z_0^2}{4\omega_0 L_1^{'}} = \frac{\pi Z_0\Delta}{4g_1} \\ Z_{02} &= \frac{\pi\omega_0 L_2}{4} = \frac{\pi\omega_0 L_2^{'}}{4} = \frac{\pi Z_0\Delta}{4g_2} \end{aligned} \tag{13}$$

The required characteristic impedance for the first two stubs is shown in (13). By extension, it can be shown that the general result for the characteristic impedance of the n^{th} stub in a filter of order N is given by

$$Z_{0n} = \frac{\pi Z_0\Delta}{4g_n} \tag{14}$$

These results apply only to filters having input and output impedance of Z_0. Therefore, it is appropriate for maximally flat filters and so cannot be used for equal ripple designs with order 'N' even since in equal ripple design of even order element does not have unit element value for the resistance of 1Ω at the frequency of 1 rad/sec, but maximally flat coefficients have the unit element for all values as shown in Table 1. Therefore these techniques used effectively in maximally flat design for all values of N compared to equal ripple design.

III. RESULTS AND DISCUSSION

The bandpass filter design using the normalized coefficients of standard Butterworth filter will produce the structural overlap between shunt transmission lines. Therefore, the asymmetrical nature of normalized coefficients was proposed for the bandpass filter design. Table 2 shows the proposed normalized element values up to an order of 6.In the design of bandpass filter short-circuited stubs are used. So that the filter cannot be simulated in layout window in ADS. Therefore, the co-simulation is performed in schematic option of ADS. Fig. 6 shows the schematic structure of band pass filter for the proposed coefficients shown in Table 2. Fig. 7 shows the design of bandpass filter using co-simulation in ADS.

Table-2: Normalized elemental values for proposed coefficients

g1	g2	g3	g4	g5	g6	g7
1.4142	1					
1.8478	0.7654	1				
1.9319	1.4142	0.5176	1			
1.9616	1.6629	1.1111	0.3902	1		
1.9754	1.782	1.4142	0.908	0.3129	1	
1.9829	1.8478	1.5867	1.2175	0.7654	0.2611	1

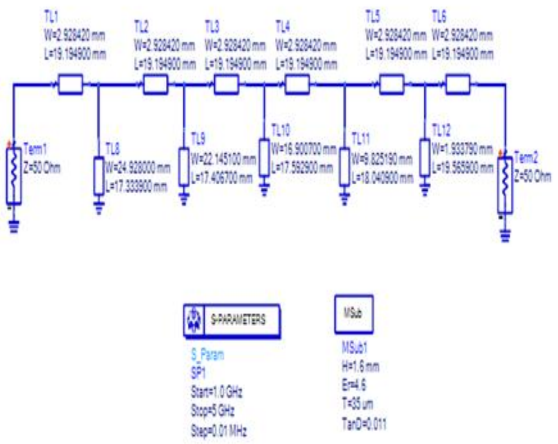

Fig. 6. Schematic Diagram of Bandpass filter

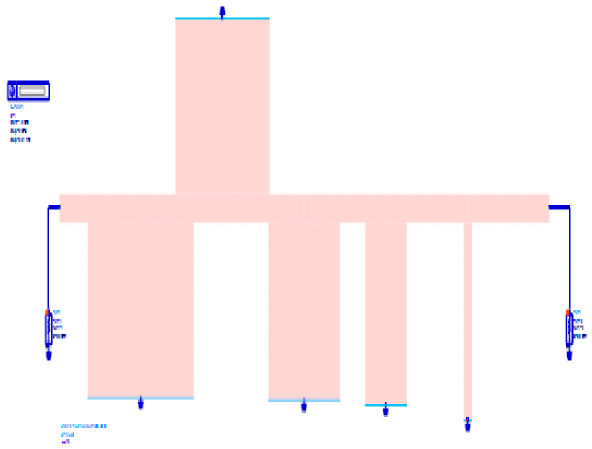

Fig. 7. Design of bandpass filter in co-simulation

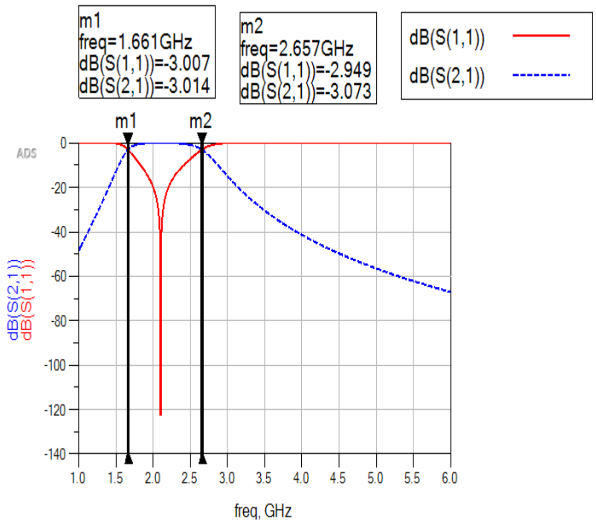

Fig. 8. Response of Bandpass filter using lumped components

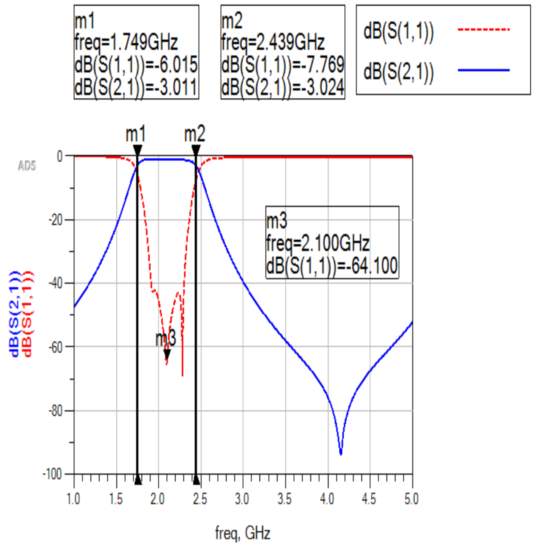

Fig. 9. Response of bandpass filter by using existing coefficients

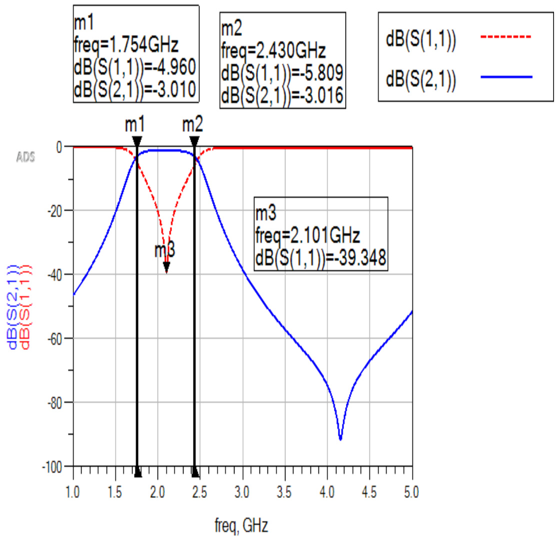

Fig. 10. Response of bandpass filter by using proposed coefficients

The substrate used to design and realize this fifth-order filter is FR4 with height 1.6 mm and permittivity as 4.6. The filter specifications are given as design frequency 2.1 GHz, order 5 and fractional bandwidth of 50%. The response of the bandpass filter using lumped components is shown in Fig. 8.

The lumped filter realization is to verify whether the normalized coefficients were selected appropriately or not. The response of the filter shows that the filter is providing a bandpass response from 1.661GHz to 2.657GHz. This lumped filter realization follows the circuit theory concept. If the lumped structure is transformed into a microstrip structure, then the concept of field theory will be followed for producing simulation response and a small deviation of the response from the desired one is expected. The response of the bandpass filter using standard Butterworth filter and proposed coefficient filters are shown in Fig. 9 and Fig. 10.

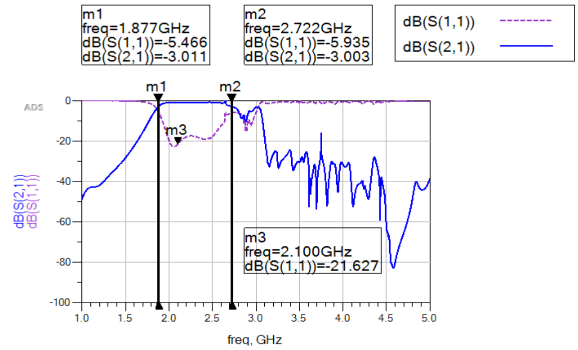

Fig. 11. Response of bandpass filter in co-simulation by using standard butterworth filter coefficients

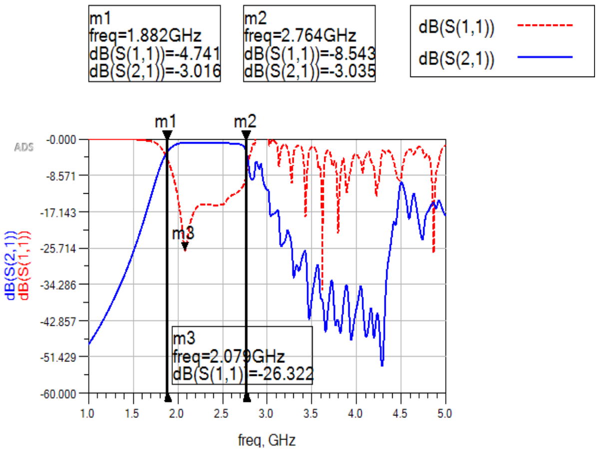

Fig. 12. Response of bandpass filter in co-simulation by using proposed coefficients

Table-3: Comparison of Filter Performance for the order N=5

Filter Parameter	Standard butterworth filter Coefficients	Proposed Coefficients
Transmission line Width (mm) values	5.882	24.92
	19.797	22.14
	25.283	16.90
	19.797	9.82
	5.882	1.93
Passband ripple	Yes	No
Insertion loss at Cutoff frequency	-3.003 dB	-3.001 dB
Bandwidth	845 MHZ	882 MHZ

The response of the bandpass filter in co-simulation using standard Butterworth filter coefficients and proposed coefficients are illustrated in Fig. 11 and Fig. 12 respectively. The passband frequency of the filter using proposed coefficients starts from 1.8 GHz and it ends at 2.7GHz. In the passband frequency, two frequency bands such as 1800 GHz for GSM and 2.45 GHz for Wi-Fi applications are covered with better return loss. Therefore, the proposed bandpass filter has the capability to operate Wi-Fi and GSM simultaneously. In the passband there are no ripples. The bandpass filter response is analyzed between existing and proposed coefficients and some of the filter parameters are tabulated in Table 3.

IV. CONCLUSION

The bandpass filter design using quarter-wave resonator based microstrip structure for standard maximally flat Butterworth filter was verified and then simulated using ADS 2015. The simulation results indicate the shortcomings such as low bandwidth and high transmission line width. In order to overcome these drawbacks an asymmetrical nature of filter coefficients was proposed. The design is implemented in microstrip schematic and layout options and the simulated results are verified using ADS 2015 EM simulation. The response of bandpass filter using proposed coefficients is better than existing method in terms of less passband ripple and better bandwidth of approximately near to 1GHz. The designed Butterworth filters have passband frequency of 1.882GHz to 2.764GHz. Therefore, it can be used for wireless technologies such as Wi-Fi and GSM simultaneously.

REFERENCES

1. Azzedin Naghar, Otman Aghzout,Ana Vazquez Alejos ,Manuel Garcia Sanchez, and Mohammed Essaaidi ,"Design of compact multiband bandpass filter with suppression of second harmonic spurious by coupling gap reduction", Journal of Electromagnetic Waves and Applications, Vol. 29, No.14,2015, pp.1813-1828.
2. Jinping Yang and Wen Wu, "Compact Elliptic-Function Low-Pass Filter Using Defected Ground Structure",IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 18, NO. 9, pp.578-580, 2008.
3. Yun Zhu ; Gang Qiu ; Kai H. Chi ; Bert B. T. Wang ; Chen S. Tsai, "A Compact X-Band Tunable Band pass Filter Module Using a Pair of Micro strip Composite Band pass Filters in Cascade", IEEE Transactions on magnetics, vol.46, No.6, June 2010, pp.1424-1427.
4. David M. Pozar , “Microwave Engineering” , 4th edition.
5. G. Karimi, A. Lalbakhsh, and H. Siahkamari, “Design of sharp roll-off lowpass filter with ultra wide stopband,” IEEE Microw. Wireless Compon. Lett., vol. 23, no. 6, pp. 303–306, Jun. 2013.
6. J. Xu, Y. X. Ji, W. Wu, and C. Miao, “Design of miniaturized microstrip LPF and wideband BPF with ultra-wide stopband,” IEEE Microw. Wireless Compon. Lett., vol. 23, no. 8, pp. 397–399, Aug. 2013.
7. V. K. Velidi and S. Sanyal, “Sharp roll-off lowpass filter with wide stopband using stub-loaded coupled-line hairpin unit,” IEEE Microw. Wireless Compon. Lett., vol. 21, no. 6, pp. 301–303, Jun. 2011.
8. G. L. Matthaei, “Design of parallel-coupled resonator filters,” IEEE Microw. Mag., vol. 8, no. 5, pp. 78–87, Oct. 2007.
9. Tao Yang, Pei-Ling Chi and Tatsuo Itoh, "Compact Quarter-Wave Resonator and Its Applications to Miniaturized Diplexer and Triplexer", IEEE Transactions on Microwave Theory and Techniques, Vol.59, No.2, 2011, pp.260-269.
10. Fang Zhu, Wei Hong, Ji-Xin Chen and Ke Wu, "Quarter-Wavelength Stepped-Impedance Resonator Filter With Mixed Electric and Magnetic Coupling", IEEE Microwave and Wireless components Letter, Vol.24, No.2,2014, pp.90-92.

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