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PROPOSAL OF MULTI-BAND BAND PASS FILTER THROUGH DEFECTED GROUND STRUCTURE TECHNIQUE

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Abstract

In the present global scenario, owing to the continuous development of wireless communications, the need for different allocated frequency bands for each service increases. The main challenge in the development of wireless technology is to meet this advancement with low cost, small size and high performance. The design of multi-band band pass filters thus finds great interest in wireless receivers. The specifications of the band pass filter such as center frequency and location of transmission zeros can be adjusted depending on the applications. In this paper, the filter is designed using open circuited stubs. The concept of open circuited stubs also adds to one pass band. Also, the concept of defected ground structure is used. The main characteristics of DGS are slow wave effect and improved band stop characteristics. The designed band pass filter has the pass bands at 2 GHz and 4 GHz covering the frequency range of 1.5 GHz-2.5 GHz and 3.5 to 5.6 GHz.

Keywords: Wireless Communication, Center frequency, Transmission zero, DGS, BPF

1. Introduction

Band Pass Filters (BPF) are used primarily in wireless transmitters and receivers. The main function of such a filter in the receiver is to reduce image response. This removes any signals at the image frequency, which would otherwise interfere with the desired signal. It also prevents strong out-of-band signals from saturating the input stages. It also optimizes the signal-to-noise ratio (Sensitivity) of the receiver.

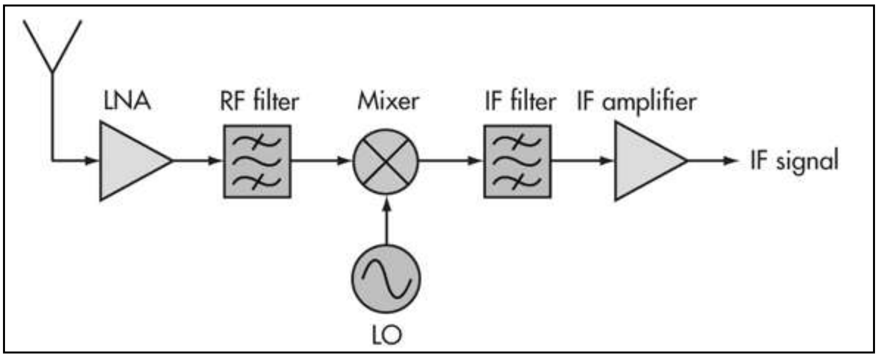

Figure 1 Receiver Front End

The filter performance can be analyzed using return loss and insertion loss. When the load is mismatched, not all of the available power from the generator is delivered to the load. This loss is called Return Loss (RL), and is defined as the ratio of reflected power to input power and is expressed in decibel (dB).

Return loss $\mathrm{RL} = -20 \log|\Gamma|\ \mathrm{dB}$

Where, Γ is the reflection coefficient.

Insertion Loss (IL) is the loss of signal power resulting from the insertion of a device in a transmission line or optical fiber and is expressed in decibel (dB). It is defined as the ratio of transmitted power to incident power.

Insertion loss, $\mathrm{IL} = -20 \log|\Gamma|\ \mathrm{dB}$

Where, Γ is the transmission coefficient.

Band pass filters can be realized using the open or short circuited stubs attached to J – inverter (transmission line inverter) [1]. Dual band filters can be designed easily using stepped-impedance resonators (SIRs) and the spurious responses of the filters can be controlled by adjusting the impedance ratios and electrical lengths [3]. The concepts of Defected Ground Structure (DGS) and Defected Microstrip Structure (DMS) also exist. These techniques are widely used to improve the stop band characteristics and the out-of-band performance. The work in this paper, focuses on designing a band pass filter with center frequency of 2 GHz and fractional bandwidth as 50%, as it covers most of the frequency bands of wireless standards such as Global Standard for Mobile Communication (GSM – 1.8 GHz) , Universal Mobile Telecommunication system (UMTS – 2.1 GHz) and certain Long Term Evolution (LTE) channels (1,3, 40, 41 with frequencies 2.1, 1.8, 2.3 and 2.5 GHz respectively). The concept of DGS is implemented to get better stop band performance. The simulation of the designed filter is being done using advanced design system 2016.01 and the fabricated filter has been tested using vector network analyzer.

2. Related Work

Band pass filters with multiple transmission zeros can be realized using open/short circuited stubs. The number of Transmission Zeros (TZ) can be increased by replacing shorted stubs with open stubs. The drawback of the shorted stubs is via holes which may degrade the signal [1]. To improve the selectivity and sharpness of the filter, the concept of Defected Ground Structure (DGS) has been proposed [2]. In this paper, a new configuration of dumbbell shaped DGS loaded with metal strips were used. Due to this effective capacitance is increased and the inductance is decreased. While focusing on the dual band filter design, it is observed that the use of slots acts as series capacitance providing high pass filter response and via holes for shorting the microstrip line increases the inductance. The advantage of the proposed design is no stubs or hi-lo impedance were used. Defected Microstrip Structure (DMS) is inserted into stub loaded Stepped Impedance Resonator (SIR) to realize a series of multi-band resonators [3]. The use of coupling structures provides greater flexibility to adjust the resonant frequency. In quarter-wavelength resonators can be applied in the design of various components like filters, diplexers and antennas [4]. Based on quarter-wavelength resonators, compact filters were realized. The configurations of the proposed filters were analyzed, which consist of quarter-wavelength resonators with open-/short-circuited stubs and cross coupled-lines. The center frequencies of two pass band can be tuned by adjusting the lengths of the quarter-wavelength resonators and stubs, respectively.

3. Design of the Multi-Band Band Pass Filter

In general, the design specifications of the filter include the center frequency, fractional bandwidth and pass band ripple. In this paper, the filter is designed for center frequency of 2 GHz with fractional bandwidth of 50 %. The allowable pass band ripple is 0.1 dB. The designed filter uses 5th order Chebyshev filter coefficients. The substrate is chosen as RT duroid 6010 with high dielectric constant (10.2) and having small thickness (0.635 mm) which leads to the reduction in size of the design. The required specifications are considered for the design with the prototype parameters for 5th order as $g_0=g_6=1$, $g_1=g_5=1.1468$, $g_2=g_4=1.3712$, $g_3=1.975$

The multi-band BPF is mainly designed using half-wavelength open stubs in order to avoid the via holes in case of quarter-wavelength shorted stubs. The design equations for open circuited stubs are found using the characteristic admittance of the transmission line.

$$Y_{i\alpha} = \frac{Y_i(\alpha_i \tan^2\theta)}{(\alpha_i+1)\tan^2\theta} \qquad (1)$$

With this admittance value, using the microstrip line equations, width and length of the transmission lines and the open stubs are calculated. The dimensions of the open stubs and the connecting lines are being tabulated.

Table 1 Connecting Lines Dimensions

i	Y_{ia} (mho)	W_i (mm)	$\lambda_{g0}/2$ (mm)
1	0.0146	0.2815	14.7194
2	0.0287	1.1565	13.9397
3	0.0283	1.1258	13.9566
4	0.0287	1.1565	13.9397
5	0.0146	0.2815	14.7194

Table 2 Open Stubs Dimensions

i	$Y_{i,\,i+1}$ (mho)	$W_{i,\,i+1}$ (mm)	$\lambda_{g0(I,\,i+1)}/4$ (mm)
1	0.02587	0.9694	14.0495
2	0.02787	1.0998	13.9712
3	0.02787	1.0998	13.9712
4	0.02587	0.9694	14.0495
5	0.02	0.5957	14.3373

In the above Table 1 and 2, i correspond to the position of the connecting lines/stubs. The simulation is done using Advanced Design System 2016.01 and the layout of the filter design is as shown in the Figure 2.

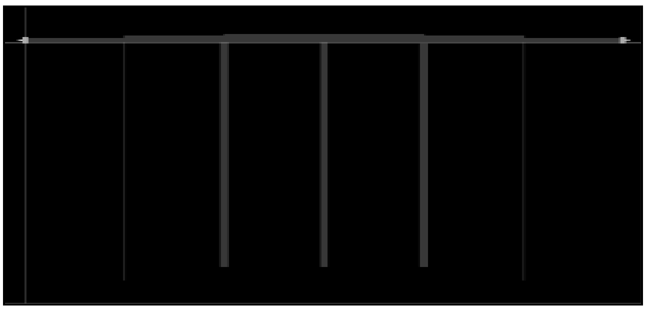

Figure 2 Layout of the Multi-band BPF Design

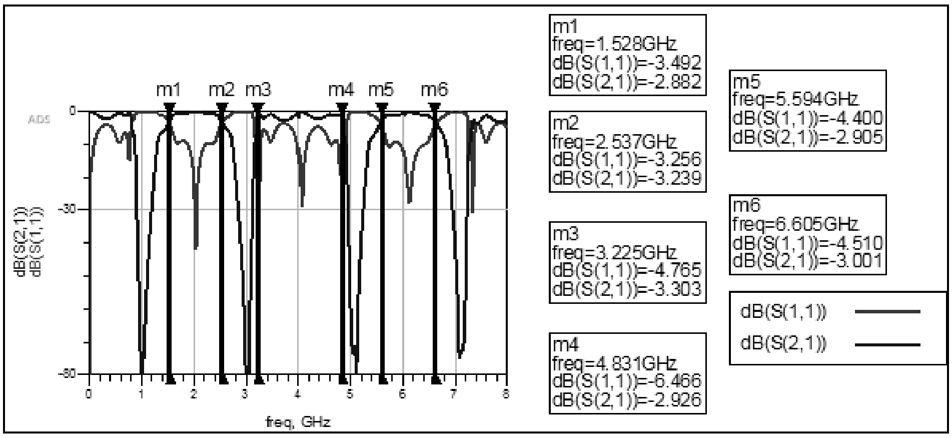

Figure 3 Response of the Multi-band BPF Design

From the response, it is inferred that at the cut-off frequency of 2 GHz, the obtained return loss is 40 dB and the pass band range is 1.528 GHz – 2.537 GHz (i.e.) bandwidth of 1 GHz. The second band due to the presence of open stubs is obtained at $2f_0$ (i.e.) 4 GHz with the bandwidth of 1.5 GHz and second transmission zero is at $3f_0$ GHz. The second band has undesired ripples which have to be minimized. The third band is obtained at 3 (i.e.) 6 GHz with the bandwidth of 1.1 GHz.

4. Proposed Filter Design

In the proposed filter design, the concept of DGS is implemented. The concept of DGS is originated from photonic band gap structures (PBG) in the optical field. The DGS is realized by etching simple shape in the ground plane of microstrip line. The etched pattern disturbs the current path in the ground plane which changes the performance of microstrip line. The DGS has two main characteristics: one is slow wave effect and the other is band stop characteristics. A DGS cell is equivalent to LC circuit. The classic microwave low pass filter (LPF) is implemented either by all shunt stubs or by series connected high-low (Hi-Lo) stepped impedance microstrip line sections. However, these designs suffer from some disadvantages such as the fabrication difficulties associated with the high impedance lines and the appearance of spurious bands. In order to overcome these disadvantages, a method has been proposed, which uses both DGS resonators and a compensated microstrip line to design the desired LPF. The slot in the ground plane acts as a parallel resonant circuit; it can be modeled by an LC circuit. The values of L, C and R can be computed using. At resonance frequency, the relationship between LC and ω0 is defined. In the design, four rectangular slots are etched in the ground plane. The ground plane is left undisturbed in the place of the stubs, so that there is no radiation from the ground plane. The DGS helps to attain the better stop band characteristics.

Figure 4 shows the Multi-band BPF design along with the defected ground structure. The response of the designed filter is shown in the following Figure 5. From the response, it is inferred that at the near cut-off frequency of 2 GHz, the obtained return loss is 35 dB and the pass band range is 1.533 GHz – 2.844 GHz (i.e.) bandwidth of 1.31 GHz. The second band due to the presence of open stubs is obtained at 2(i.e.) 4 GHz with the wide bandwidth and second transmission zero is at 3 GHz. The second band has undesired ripples which have to be minimized and hence the desired pass band lies in the range of 3.87 GHz – 4.42 GHz having the bandwidth of 0.55 GHz.

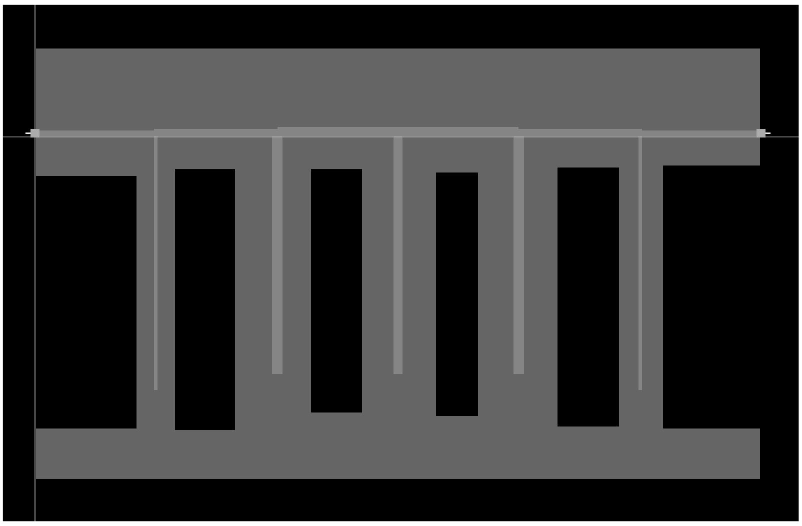

Figure 4 Layout of the Proposed Filter Design with DGS

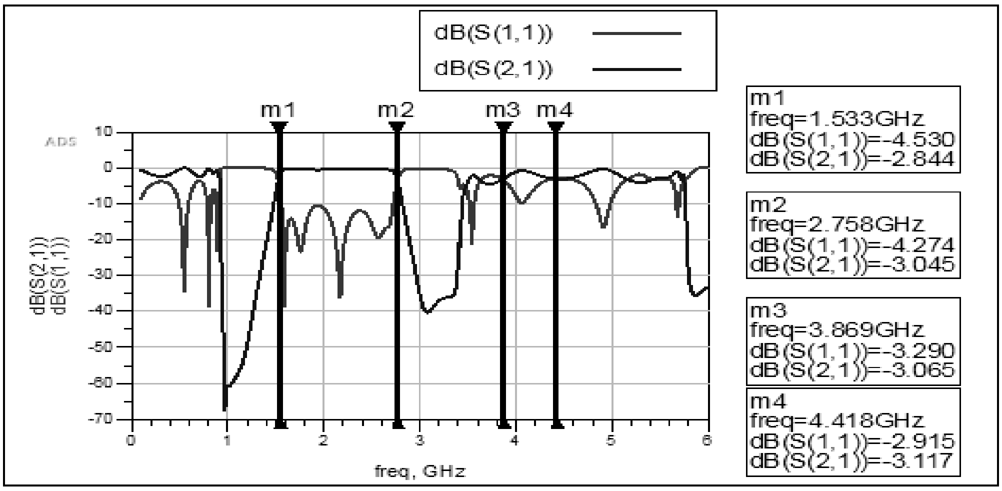

Figure 5 Response of the Proposed Filter Design

5. Experimental Results

The designed Multi-band BPF with DGS is fabricated using the RT Duroid 6010 substrate of thickness 0.635 mm. The snapshots of fabricated design and the measured results of thee designed filter is as shown in the following Figures. Figure 6 shows the top surface of the fabrication which has the 5th order band pass filter with five stubs along with the connecting lines. The bottom surface of the design has finite ground in which copper layer has been coated to act as ground. The designed band pass filter is tested using the Vector Network Analyzer N9915A and the obtained return loss and insertion loss of the filter have been shown in the following figures. The frequency response of the filter has been observed in the frequency range of 1 GHz-6 GHz. The plot of in dB with respect to frequency is used to determine the return loss at the desired center frequency. The plot of in dB with respect to frequency is used to determine the insertion loss in the filter and also the pass bands of the filter.

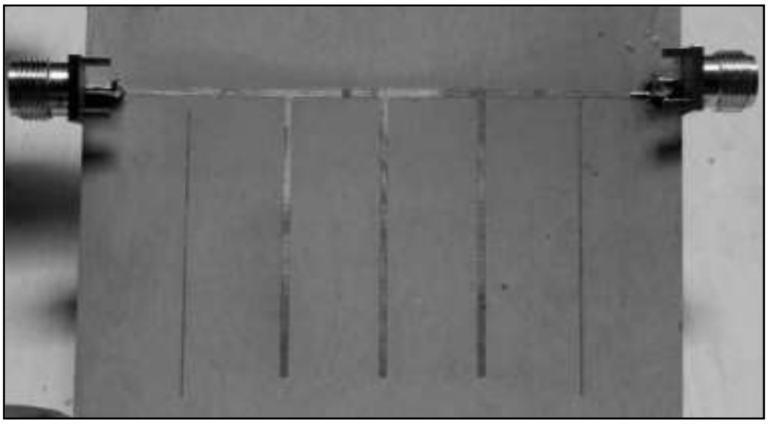

Figure 6 Top Surface of the Designed Filter

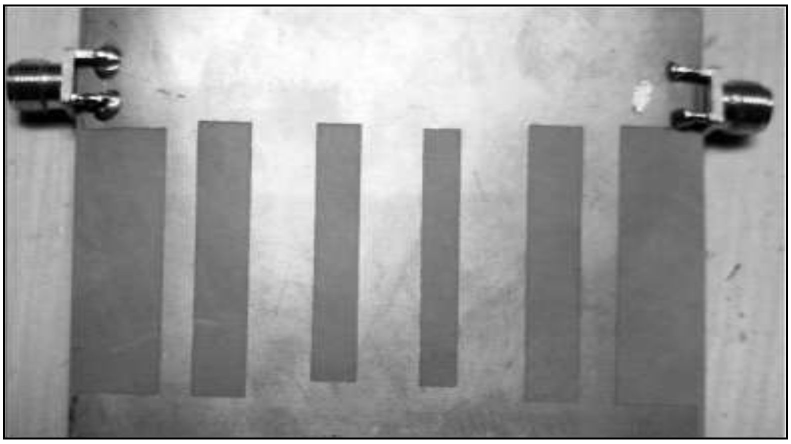

Figure 7 Designed Filter Bottom Surface

Figure 8 Testing the Filter

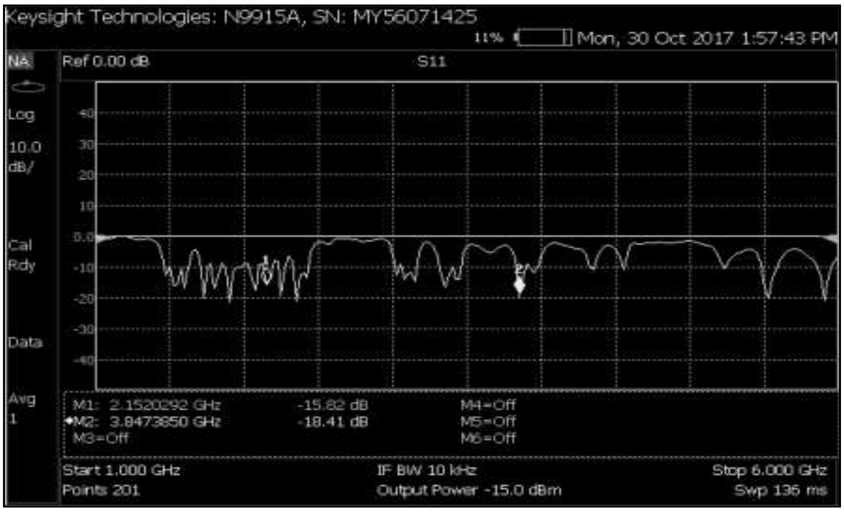

Figure 9 Versus Frequency Plot

It is inferred from the above Figure 9, that the return loss of 15.82 dB is obtained at 2.15 GHz (shifted from center frequency of 2 GHz) indicating that 2.618 % of input power gets reflected and the return loss of 18.41 dB is obtained at 3.85 GHz (shifted from center frequency of 4 GHz) indicating that 1.442 % of input power is reflected.

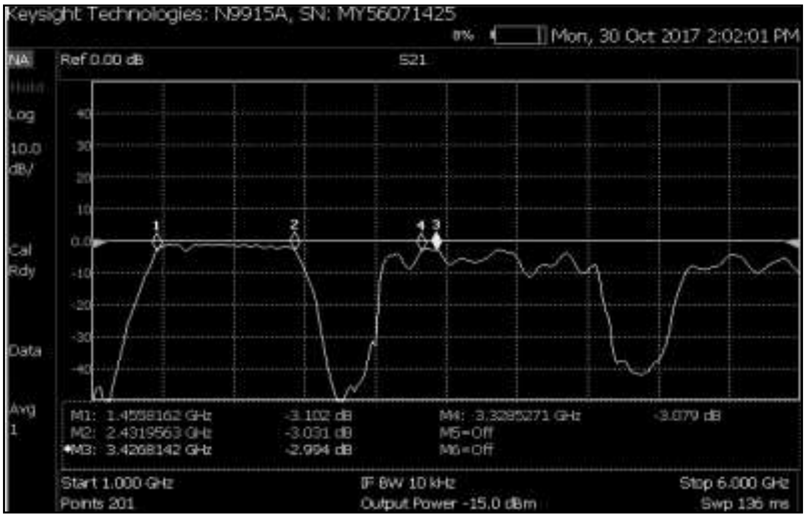

Figure 10 Versus Frequency Plot

From the above Figure 10, it is inferred that the first pass band occur in the frequency range of 1.4581 GHz – 2.4319 GHz with less than 0.3 dB insertion loss and having the bandwidth of 974 MHz. The second pass band occurs in the frequency range of 3.328 GHz – 3.426 GHz coving the minimum bandwidth of 100 MHz which has to be improved.

6. Conclusion

The multi-band band pass filter has been designed using open stubs instead of short stubs as it avoids the holes in the design. The defected ground structure is used in the designed filter. The designed filter has the advantage of compact size. Its size is 80 x 50, which can fit into any wireless devices. The designed filter exhibits multiple bands which support many of the wireless standards such as GSM, Wi-Fi, LTE, RFID, etc. The future work can be extended to minimize the pass band ripple in the second band of designed filter and to attain tunability in the designed band pass filter.

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