Compact Wide Band Printed Filter with Improved Out-of-Band Performance

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Abstract ─ This paper presents a new configuration of a compact wide-band Bandpass Filter (BPF). The filter is realized using embedded stub configuration along with Defected Ground Structure (DGS) and folded stubs. The proposed configuration not only offers a compact structure but also shows a wide passband and improved out-of-band performance. A prototype model is developed and its characteristics are measured. Good agreement is obtained between simulation and measured results. The results show improved wide-band behavior, insertion loss lower than 0.6 dB and 49.16 % of size reduction.

Key-Words - Bandpass filter, compact bandpass filter, defected ground structure and embedded stub.

I. INTRODUCTION

The microwave filters play a very important role in wireless and satellite communication transceiver systems. It is an important passive component in the communication system that rejects unwanted signals in the specified band of interest. Planar microwave wideband BPF's have received greater attention due to several advantages, such as low cost, small size and ease of fabrication. The performance of the filter highly depends on its passband and out-of-band performances. In the past, several techniques have been developed to analyze these filters with improved passband and out-of-band characteristics. In [1] a microstrip wideband BPF with increased fractional bandwidth is reported. Using a ring-resonator a higher filter bandwidth is achieved [2] and Ultra Wideband (UWB) characteristic is realized by combining low pass filter with high pass filter [3]. With the help of Multiple-Mode Resonator (MMR), various wideband and UWB BPF are developed [4-10]. A wideband filter with an extended out-of-band has been constituted by internally installing an Electromagnetic Bandgap (EBG) transmission line into a traditional highpass filter with short-circuited stubs [11]. Wideband microstrip BPF is also reported using Sierpinski fractal stub-based resonator where a greater fractional bandwidth is achieved [12]. Further, a compact wideband BPF using modified non-bianisotropic split-ring resonators is developed [13] and a dual-wideband filter design is implemented with the stepped-impedance resonators using different concepts, such as frequency mapping approach and defected stepped impedance resonator [14-15]. With the application of coupling mechanism, miniaturized wideband BPF's are also reported [16-17]. Using the aperture-coupled technique, a three-layer UWB BPF is studied in [18], which involves a complicated design procedure. In [19], a technique deploying an EBG structure is proposed and wide-stopband behavior is reported with increased circuit size. Several other triple-mode UWB filters have been reported based on varied MMR's, such as stub-loaded MMR [20], one open stub and one short stub loaded MMR [21]. In fact, with the help of MMR in fiber grating, other kinds of filters in optical-electrical fields have been used to realize optical switching because of its high nonlinearity and low insertion loss [22-25]. A novel miniaturized parallel coupled-line BPF with suppression of second, third and fourth harmonic frequencies are realized in [26]. A microstrip BPF based on Folded Tri-Section Stepped Impedance Resonator (FTSIR) and DGS is reported in [27]. A compact microstrip BPF with bandwidth control is developed by employing DGS resonators [28]. In [29], a novel compact LPF and BPF based on DGS using two Complementary Split Ring Resonators (CSRR) are presented. A compact UWB bandpass filter with two controllable highly selective notched

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bands are reported in [30]. An embedded stub is proposed to implement microwave bandstop filter with narrow bandwidth and sharp rejection rate [31].

In this paper a new compact wideband filter is proposed using DGS along with embedded stubs and folded stub configuration to improve the out-of-band performance of the filter.

II. BAND PASS FILTER IMPLEMENTATION AND SIMULATION RESULTS

Conventional BPF configuration employs cascaded short circuited stubs of electrical length θC at some specified frequency fC, separated by connecting lines (unit elements) of electrical length 2θC [11] as shown in Fig. 1. The electrical length θC can be determined from:

$$\left(\frac{\pi}{\theta_C}-1\right)f_C = f_H \,. \tag{1}$$

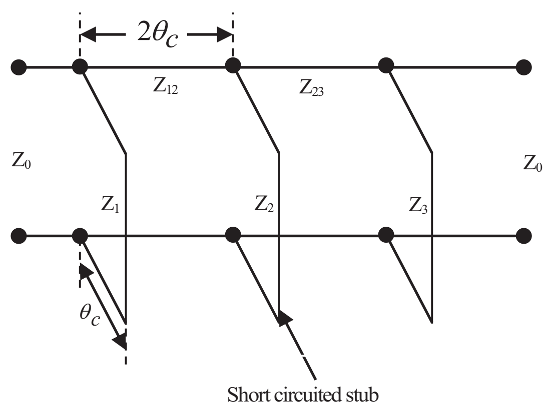


Fig. 1. General circuit model for the conventional wideband BPF.

For fC = 1.4 GHz and fH = 5.4 GHz, the electrical length, θC = 0.647 radians or 370. Next, the filter parameters are obtained for n = 3 (three short circuited stubs) and 0.1 dB ripple, as y1 = y3 = 0.40, y1,2 = y2,3 = 1.05 and y2 = 0.48, where yi, yi,j and yj,i are the element values of optimum distributed high pass filter, where i = j = 1,2,3. The corresponding impedances are calculated as Z1 = Z3 = 124.68 Ω, Z1,2 = Z2,3 = 47.45 Ω and Z2 = 103.53 Ω [11]. All the vias dimensions are 0.5 mm in diameter. The overall electrical length of the conventional filter is 4θC, where the unit elements have electrical length = 2θC.

The lengths of the input and output transmission lines are selected depending on the length of the short circuited stub. Since the proposed configuration employs the shorted stubs embedded in the transmission lines, the length of the input and output transmission lines are selected as λg/8.

Table 1: Dimensions of the filter

Filter elements	Impedance (Ω)	Length (mm)	Width (mm)
Microstrip line side stubs, $Z_1 = Z_3$	124.68	15.82	0.82
Microstrip line centre stub, Z_2	103.53	15.70	1.30
Unit element (UE), $Z_{12} = Z_{23}$	47.45	30.28	5.22

The filter is designed on a RT/duroid 5880 substrate with a dielectric constant of 2.2, thickness h = 1.57 mm and loss tangent 0.0009. The Method of Moments based IE3D simulation software tool from Zealand, USA, is used for the purpose of simulation. The conventional BPF is shown in Fig. 2 and the dimensions are specified as shown in Table 1. The characteristics of the filters are obtained in terms of S-parameters, as shown in Fig. 3.

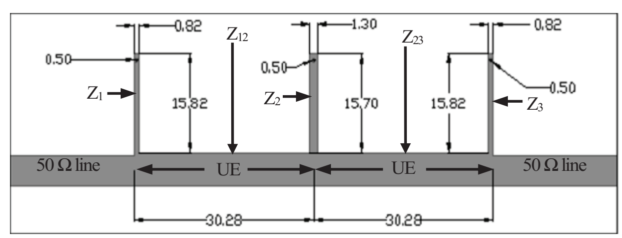


Fig. 2. Conventional BPF with Z12 = Z23 = 47.45 Ω.

The impedance of the unit elements Z12 = Z23 = 47.45 Ω of conventional BPF is replaced with the impedance of 50 Ω, to maintain uniformity. This does not alter the characteristics of the filter significantly as shown in Fig. 3. It is observed that the out-of-band characteristic needs improvement. Next, the conventional BPF is analyzed with DGS configuration, with an intention to improve the out-of-band characteristic and also to reduce the total length of the filter

A parametric study is carried out to determine the proper dimension of the lattice (DGS) [32- 33] for generating the attenuation pole at the desired location over the out-of-band. Following the procedure as in [32-33] for the location of attenuation pole at 8.9 GHz, the lattice dimension is obtained as x = 4 mm, y = 2 mm and g = 0.5 mm. The incorporation of DGS helps in two ways. First, it generates an attenuation pole at the desired location, thus offering an improved out-of-band characteristic. Secondly, it also miniaturizes the length of the filter, as the length of the unit elements are now half of the original length. Hence, a unit element of electrical length 2θC of conventional BPF is now replaced by the unit element of electrical length θC after incorporating a DGS, as shown in Fig. 4.

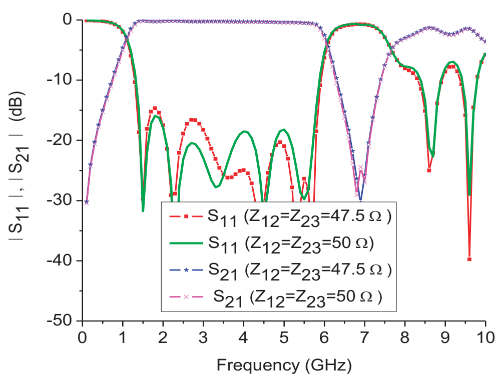


Fig. 3. Simulated result for S-parameters.

The filter configuration is further modified by folding the central shorted stub in L-shape configuration and embedding the two shorted side stubs in 50 ohm transmission lines, thus offering a compact configuration, as shown in Fig. 5 (a); where W1 = 1.42 mm, W2 = 0.58 mm and W3 = 0.56 mm.

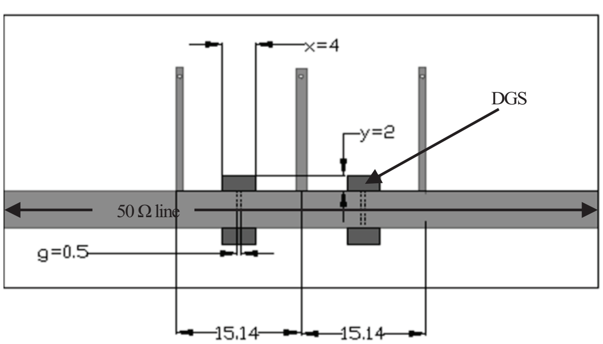
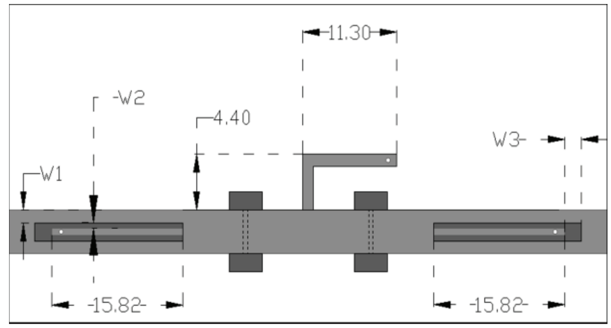
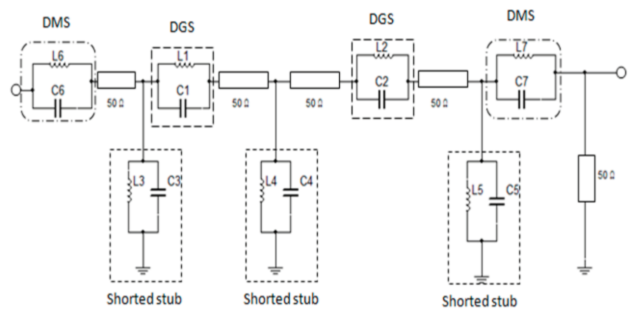


Fig. 4. Wide BPF with DGS.



(a)



(b)

Fig. 5. (a) Proposed compact embedded filter and (b) equivalent circuit of proposed compact embedded filter.

The equivalent circuit representation of the proposed compact embedded filter is shown in Fig. 5 (b), where the DGS and DMS configurations are represented as a parallel combination of L and C, connected in series with 50 ohm microstrip line and the shorted stub is represented as parallel L and C, connected in shunt.

A. Effect of slot/gap parameters (W_1, W_2)

Four set of values of slot W1 and gap W2 are selected as follows: (I) W2 = 0.38 mm and W1 = 1.62 mm; (II) W2 = 0.58 mm and W1 = 1.42 mm; (III) W2 = 0.78 mm and W1 = 1.22 mm; (IV) W2 = 0.98 mm and W1 = 1.02 mm.

The simulated results of the variation of the slot W1 and gap W2 are shown in Fig. 6.

For the (I) data set, improved performance in the passband is observed. However, due to the limitations in our PCB fabrication facility, the (II) data set is considered as the existing fabrication facility does not support the strip/slot dimensions less than 0.5 mm.

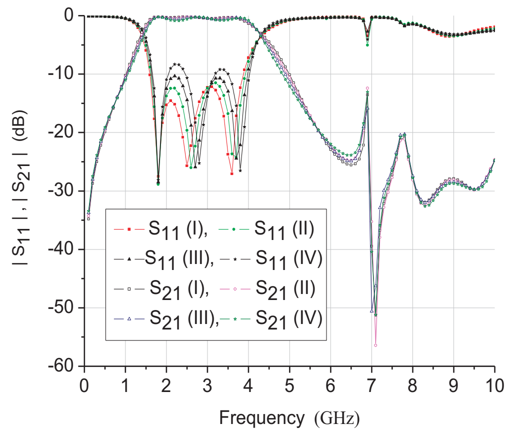


Fig. 6. Simulated result of S-parameters for different W1 and W2.

B. Effect of gap parameters (W3)

For constant W2 = 0.58 mm, three set of values of gap W3 are taken; as (I) W3 = 0.36 mm, (II) W3 = 0.56 mm and (III) W3 = 0.76 mm. It is seen that the results do not show any significant change with respect to W3, as shown in Fig. 7. Therefore, W3 is chosen as 0.56 mm. The characteristics of the two configurations, Figs. 4 and 5 (a) are compared in Fig. 8.

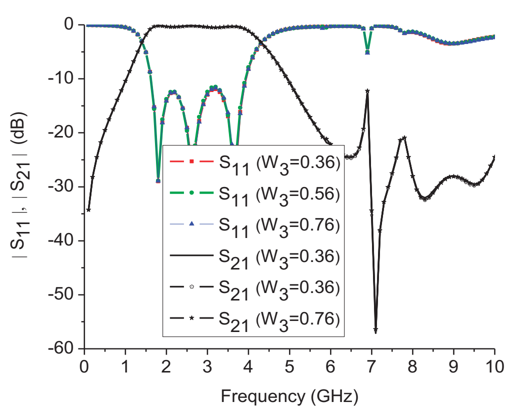


Fig. 7. Simulated result of S-parameters for gap W3.

It is evident from Fig. 8, that employing the DGS improves the out-of-band characteristics. However, a reduction in the bandwidth of the filter in the passband is observed when the stubs are outside. This may be attributed to the larger electrical length offered in case of DGS, which in turn limits the passband [26-27]. However, this problem of bandwidth reduction is overcome when the stubs are embedded in I/P and O/P transmission lines (Fig. 5 (a)), as depicted in Fig. 8. The reason behind this improvement is reduction in effective electrical length in case of embedded stubs. A passband of more than 2.5 GHz and a very wide rejection bandwidth is obtained in the out-of-band region. Size reduction of approximately 49.16% is achieved in the proposed compact filter. Figure 9 shows the filter response in terms of group delay, which shows almost a constant group delay in the passband as desired.

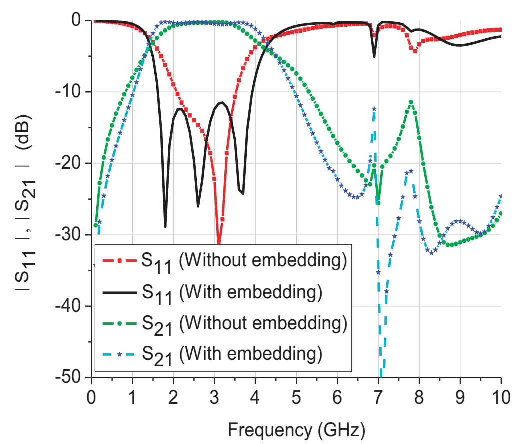


Fig. 8. Simulated result of the filter with DGS; with and without embedded stub.

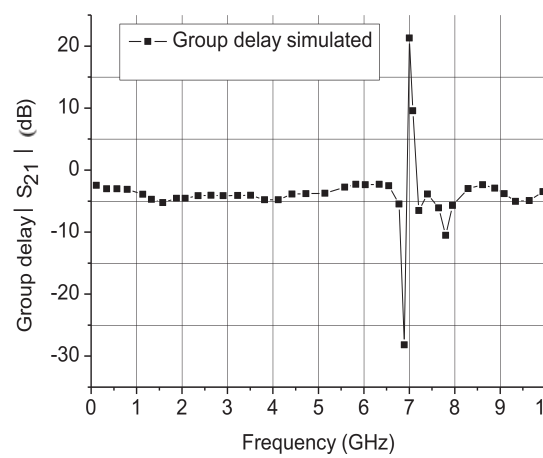


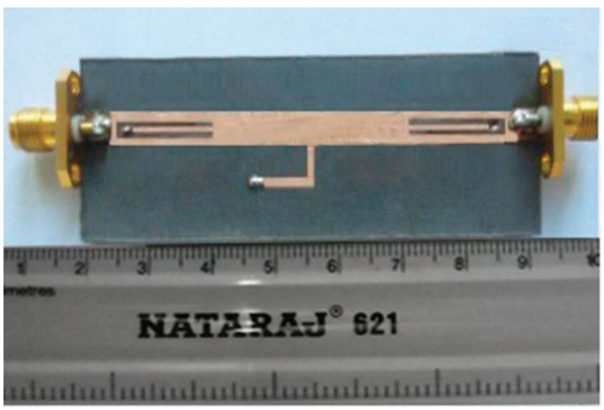
Fig. 9. Simulated result of the proposed compact embedded BPF.

Table 2: Performance of filters

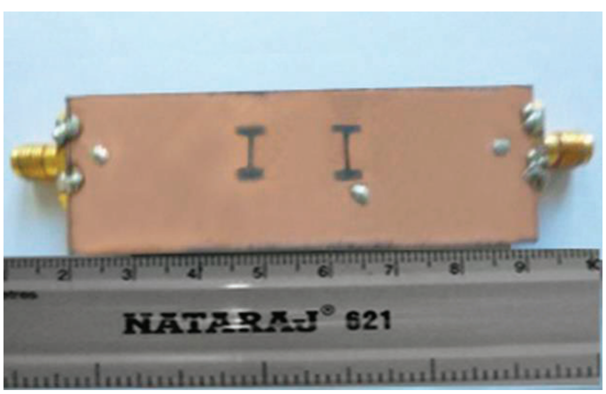
Configuration	10 dB passband (GHz)	10 dB rejection bandwidth in out-of-band (GHz)	Area occupied (length×width) in mm2
Conventional BPF (length of 50 Ω line = λg/8)	1.3 to 5.8 = 4.5	6.2 to 7.6 = 1.4	102.54×20.85 = 2137.96
Conventional BPF (length of 50 Ω line = λg/16)	1.3 to 5.8 = 4.5	6.2 to 7.6 = 1.4	83.03×20.85 = 1731.17
Proposed BPF (without embedding)	2.28 to 3.75 = 1.47	5.2 to 10 = 4.8	102.54×20.85 = 2137.96
Proposed compact embedded BPF	1.6 to 4.1 = 2.5	4.88 to 10 = 5.12	102.54×10.54 = 1086.77

III. EXPERIMENTAL RESULTS

The prototype filter is fabricated and the photograph of the top and bottom view of the filter is shown in Figs. 10 (a) and 10 (b).



(a) Top view



(b) Bottom view

Fig. 10. Prototype of the proposed compact embedded structure.

Finally, the response of the fabricated filter is measured using PNA series Vector Network Analyzer and the response is compared with the simulated result, as shown in Fig. 11.

A comparison of the simulated response with the measured response, shows a good agreement. The performance of the filter in passband and out-of-band for three configurations under investigation, is tabulated in Table 2.

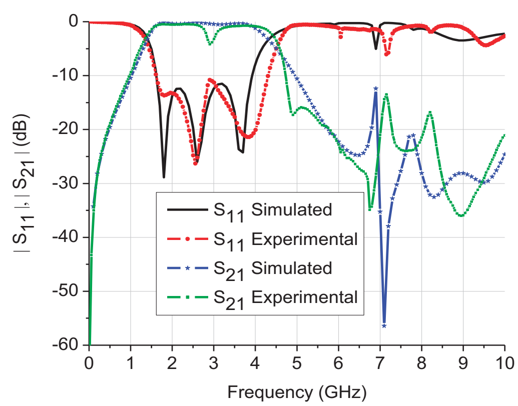


Fig. 11. Experimental and simulated result of the proposed compact embedded filter.

IV. CONCLUSION

A compact wideband filter is implemented based on the concept of embedded stub and DGS. The proposed structure is realized in two steps. First, the conventional wideband filter is miniaturized in terms of the length of unit element by the application of DGS, then further reduction is obtained by embedding the shorting side stubs in the microstrip line and folding the central shorted stub in L-shape. The proposed compact embedded bandpass filter structure shows a size reduction of 49.16 % along with a good passband and improved out-of-band rejection bandwidth.

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