

Performance Analysis of High Pass Filter and Band Pass Filter Using DGS

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Abstract- The performance of a high pass filter (HPF) and a band pass filter (BPF) with and without defected ground structure (DGS) was analyzed in this specific work. The Defected ground structure includes rectangular and circular etched shapes in ground plane. Calculation and comparison of the response of both filters was done separately. Parameters of the proposed configuration were calculated at the centre frequency of 1.5 GHz and also proposed designs were fabricated with dielectric constant of 4.4, loss tangent of 0.02 and substrate height of 1.6mm. Results were simulated using computer simulation technology software (CST) and fabricated structures tested on a spectrum analyzer. The undesired sidebands and fluctuations of response were reduced by using defected ground structure (DGS). Also the cut off point of the high pass filter is shifted to a higher frequency and an improvement in selectivity is achieved in the case of band pass filter (BPF).

Index Terms- High Pass Filter (HPF), Band Pass Filter (BPF), SMA (submarine version-A) Connector, Defected Ground Structure (DGS), Computer Simulation Technology Software (CST), Printed Circuit Board (PCB), Spectrum Analyzer.

I. INTRODUCTION

For designing high performance and compact filters, a defected ground structure has been widely used. A Defect on ground can change the propagation properties of a transmission line by changing the current distribution and applied field between the ground plane and upper surface. There are various different structures for implementing DGS [1]. By using these different DGS structures filters, power divider, power amplifier etc was implemented [2]-[9]. PBG (photonic bandgap) and EBG (electromagnetic bandgap) structure are also a type of DGS, which is created by etching different periodic shapes in the ground plane. However, it is so difficult to use PBG structure for the design of the microwave or millimetre wave components due to the difficulties of the modulating and radiation from the periodic etched defects.

So many etched shapes for the microstrip could be used as a unit DGS. An LC unit circuit can represent the unit DGS circuit. They provide inductive and capacitive elements connected in series [10]. Which remove undesired output response fluctuations; move the high pass filter frequency limit to a higher value and the selectivity of a particular band is also improved in the case of BPF [11]. DGS has property of rejecting electromagnetic wave in certain frequency and direction, and most important function of these structures is the filtering of frequency bands, and harmonics of the filter in microwave

circuit. In this proposed work an arbitrary shape of DGS is used to improve the parameters of the filters like return loss, transmission coefficient etc. And also the dimension of these different shapes varies to find efficient response. A lot of different shapes of DGS were tested and the more efficient one is introduced in this work.

II. IMPLEMENTATION OF 6TH ORDER HIGH PASS FILTER

The proposed high pass filter (HPF) consists of shunt short circuited stubs of electrical length θ_c at some specified frequency f_c (usually the cut off frequency of HPF). These elements were separated by unit elements (UE) of length $2\theta_c$ shown in the figure 1 [12]. In theory this type of filter has very wide band response for small θ_c but this requires a high value of impedance in the short circuited stub (SC-Stub).

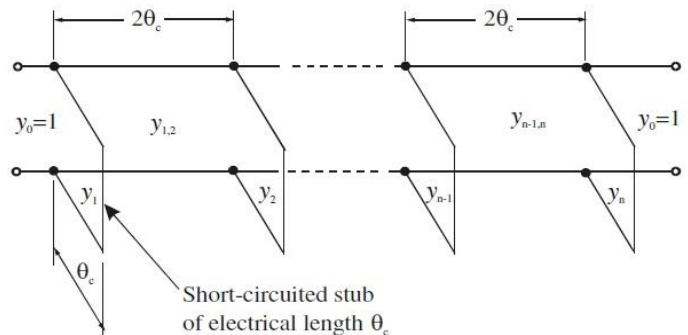


Figure 1: Optimum distributed highpass filter [12].

To design high pass filter let us consider the cut off frequency $f_c=1.5\text{GHz}$ and 0.1dB Ripple in passband up to 5GHz. As in figure the electrical length θ_c can be determined by equation (1) [12]:

$$\left(\frac{\pi}{\theta_c} - 1\right) f_c = 5 \quad (1)$$

By this, $\theta_c = 30^\circ$ and for proposed 6th order filter shown in figure 2 have element values given in table 1. For given terminating impedance Z_0 the associated impedance values can be determined by equation (2) and (3) [12]

$$Z_i = Z_0/Y_i \quad (2)$$

$$Z_{i,i+1} = Z_0/Y_{i,i+1} \quad (3)$$

For $i=1, 2, \dots, 6$

Synthesis of W/h [12]

$$\frac{W}{h} = \frac{8 e^A}{e^{2A} - 2} \quad (4)$$

With
$$A = \frac{Z_c}{60} \left[\frac{\epsilon_r + 1}{2} \right]^{0.5} + \frac{\epsilon_r + 1}{\epsilon_r + 1} \left[0.23 + \frac{0.11}{\epsilon_r} \right]^{0.5}$$
 (5)

Where

$Z_c = Z_0 = 50\Omega$ and ϵ_r (dielectric constant) = 4.4, W = width, h = height of dielectric which is taken as 1.6mm.

Effective dielectric constant of dielectric material given by equation (6) and (7) [12]

For $W/h \leq 1$:

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W} \right)^{-0.5}$$
 (6)

For $W/h > 1$

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\left(1 + 12 \frac{h}{W} \right)^{-0.5} + 0.04 \left(1 - \frac{W}{h} \right)^2 \right]$$
 (7)

Whereas guided wavelength is given by equation (8)

$$\lambda_g = \frac{300}{f(\text{GHz}) \sqrt{\epsilon_{re}}} \quad (8)$$

ϵ_{re} = Effective dielectric constant, $f = 1.5$ GHz

Lengths of the elements (l) were determined by equation (9) [12]

$$\Theta_c = \beta * l \quad (9)$$

Where β is the phase constant.

For designing HPF use of circular and rectangular shape DGS were proposed. The radius of circle is taken as 7.5 mm and length and width of rectangle is taken as 5mm and 14mm respectively.

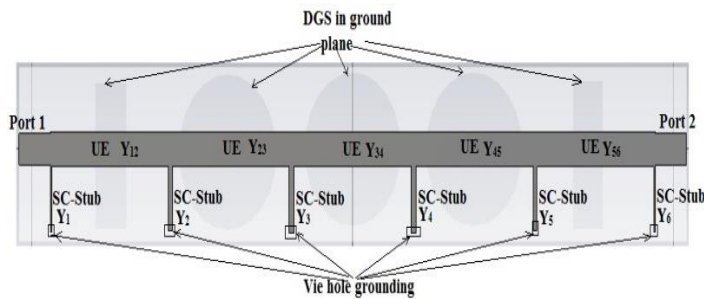


Figure 2: Proposed 6th order high Pass Filter with DGS.

Table 1: Element values of the proposed configuration.

s.n o.	Element	Admittance values In mho	Impedance values In ohm	Length of the element (mm)	Width of the element (mm)
1	Unit element (UE)	$Y_{1,2}=Y_{5,6}=1.0672,$ $Y_{2,3}=Y_{4,5}=1.04395,$ $Y_{3,4}=1.03794$	$Z_{1,2}=Z_{5,6}=46.85,$ $Z_{2,3}=Z_{4,5}=47.895,$ $Z_{3,4}=48.172$	$l_{1,2}=l_{5,6}=18.186,$ $l_{2,3}=l_{4,5}=18.213,$ $l_{3,4}=18.2195$	$w_{1,2}=w_{5,6}=3.4016,$ $w_{2,3}=w_{4,5}=3.2828,$ $w_{3,4}=3.25456$

2	Short Circuited Stub	$Y_1=Y_6=0.35346,$ $Y_2=Y_5=0.46383,$ $Y_3=Y_4=0.52615$	$Z_1=Z_6=141.46,$ $Z_2=Z_5=107.798,$ $Z_3=Z_4=95.03$	$l_1=l_6=9.8141,$ $l_2=l_5=9.64,$ $l_3=l_4=9.554$	$w_1=w_6=0.22672,$ $w_2=w_5=0.57184,$ $w_3=w_4=0.8144$
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III. IMPLEMENTATION OF 5TH ORDER BAND PASS FILTER

The bandpass filter can be design using short circuited stub shown in figure 3 [12]. The shunt short-circuited stubs are $\frac{\lambda_{g0}}{4}$ long with connecting lines which are also $\frac{\lambda_{g0}}{4}$ long. λ_{g0} is the guided wavelength in the medium of propagation at the midband frequency of f_0 . The performance of an n degree filter depends on the characteristic admittances of short circuited stubs Y_i ($i=1$ to n) and also on the connecting line characteristic admittances $Y_{i,i+1}$ ($i=1$ to $n-1$).

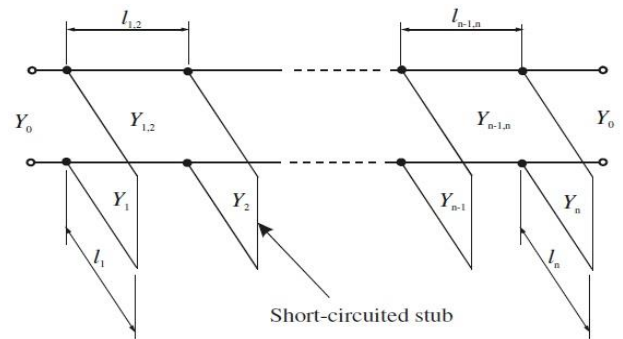


Figure 3: Bandpass filter with quarter-wavelength short-circuited stubs [12].

The bandpass filter (BPF) was designed with centre frequency of $f_0=1.5$ GHz. Electromagnetic equations [12] used for the design of BPF are mention below-

The fractional bandwidth (FBW) of the BPF is given by equation (10)

$$FBW = \frac{f_2 - f_1}{f_0} \quad \text{with } f_0 = \frac{f_1 + f_2}{2} \quad (10)$$

where $f_0=1.5$ GHz, $f_1=1$ GHz, $f_2=2$ GHz and also constants are given by equation (11)

$$\theta = \frac{\pi}{2} \left(1 - \frac{FBW}{2} \right) \quad \text{and } h=2 \quad (11)$$

Calculation of admittances are given by following equations (12-19)

$$\frac{l_{1,2}}{Y_0} = g_0 \sqrt{\frac{hg_1}{g_2}} \quad (12)$$

$$\frac{l_{n-1,n}}{Y_0} = g_0 \sqrt{\frac{hg_1 g_{n+1}}{g_0 g_{n-1}}} \quad (13)$$

$$\frac{l_{i,i+1}}{Y_0} = \frac{hg_0 g_1}{\sqrt{g_i g_{i+1}}} \quad (14)$$

$$N_{i,i+1} = \sqrt{\left(\frac{J_{i,i+1}}{Y_0}\right)^2 + \left(\frac{hg_0g_1 \tan \theta}{2}\right)^2} \quad (15)$$

$$Y_1 = g_0 Y_0 \left(1 - \frac{h}{2}\right) g_1 \tan \theta + Y_0 \left(N_{1,2} - \frac{J_{1,2}}{Y_0}\right) \quad (16)$$

$$Y_n = Y_0 \left(g_n g_{n+1} - g_0 g_1 \frac{h}{2}\right) \tan \theta + Y_0 \left(N_{n-1,n} - \frac{J_{n-1,n}}{Y_0}\right) \quad (17)$$

$$Y_i = Y_0 \left(N_{i-1,i} + N_{i,i+1} - \frac{J_{i-1,i}}{Y_0} - \frac{J_{i,i+1}}{Y_0}\right) \quad (18)$$

$$Y_{i,i+1} = Y_0 \left(\frac{J_{i,i+1}}{Y_0}\right) \quad (19)$$

For i= 1 to n-1

Equations (5) to (8) were used for the calculation of width of the impedance and guided wavelength.

Length of the admittances were given by equation (20)

$$l = \frac{\text{guided wavelength}(\lambda_{g0})}{4} \quad (20)$$

Where g_i are the element values of a ladder-type lowpass prototype filter, given for a cut off $\Omega_c = 1$. h is a dimensionless constant which may be any value for proper admittance level. To design such type filter take order of the filter as 5 shown in figure 4. The prototype parameters were - $g_0 = g_6 = 1$, $g_1 = 1.1468$, $g_2 = 1.3712$, $g_3 = 1.9750$, $g_4 = 1.3712$, $g_5 = 1.1468$. Fractional bandwidth (FBW) = 0.67 (obtained from equation (9)) and a 50 ohm terminal line impedance were chosen. The computed design parameters are summarized in Table 2.

For designing BPF use of circular and rectangular shape DGS were proposed. The radius of circle is taken as 13.5 mm and length and width of rectangle is taken as 11mm and 26mm respectively.

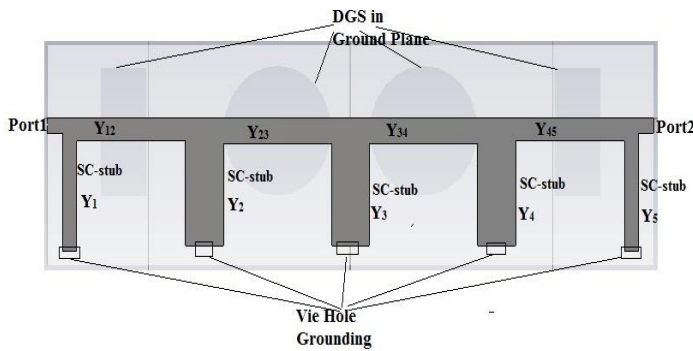


Figure 4: Proposed 5th order BPF with DGS.

Table 2: Microstrip design parameters for 5th order Band Stop Filter.

s.n o.	Element	Admittance values In mho	Impedance values In ohm	Length of the element (mm)	Width of the element (mm)
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1	Connecting lines	$Y_{1,2}=Y_{4,5}=$ 0.0258, $Y_{2,3}=Y_{3,4}=$ 0.02787	$Z_{1,2}=Z_{4,5}=$ 38.66, $Z_{2,3}=Z_{3,4}=$ 35.87	$l_{1,2}=l_{4,5}=$ 26.9332, $l_{2,3}=l_{3,4}=$ 26.8028	$w_{1,2}=w_{4,5}$ = 4.585, $w_{2,3}=w_{3,4}$ = 5.1273
2	Short Circuited Stub	$Y_1=Y_5=$ 0.02156, $Y_2=Y_4=$ 0.0422, $Y_3=$ 0.0413	$Z_1=Z_5=$ 46.365, $Z_2=Z_4=$ 23.68, $Z_3=24.2060$	$l_1=l_5=$ 27.261, $l_2=l_4=$ 26.076, $l_3=26.1145$	$w_1=w_5=$ 3.46, $w_2=w_4=$ 9.455, $w_3=9.15$

IV. RESULTS

1. 6th order High Pass Filter

The fabricated layout of the 6th order high pass filter is shown in the figure 5 and figure 7. FR4 lossy material with dielectric constant of 4.4, substrate height of 1.6mm and loss tangent 0.02 were used for the fabricated design. The graphs obtain after the simulation (CST Software [13]) and measured value (spectrum analyzer) of the HPF without using DGS are shown in figure 6. CST Microwave studio is software for electromagnetic analysis and design in high frequency range. The most flexible tool of CST is the transient solver, which is used to simulate any design. And spectrum analyzer is a practical instrument which is used to test the PCB layout in 0 to 3 GHz frequency range. So the results were calculated in 0-3GHz frequency range only. Above this frequency range the results were calculated only CST software.

The graph shown in figure 6 shows the cut off frequency is at 1.5GHz means that the signals were passing after this frequency. Also before 1.5 GHz the signal shows attenuation of -35dB to -40dB (means perfect stop band). Return loss after 1.5GHz is below -10 dB which shows perfect impedance matching after that frequency.

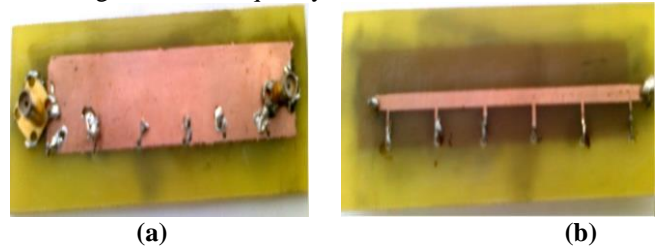


Figure 5: (a) Bottom view of the HPF (b) Top view of HPF.

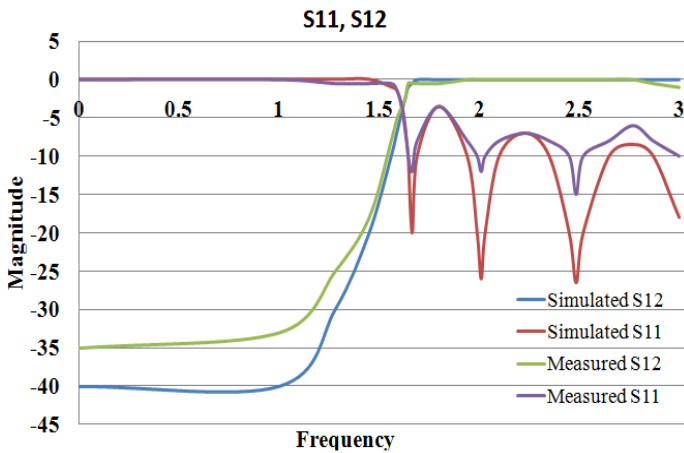


Figure 6: Graph of the HPF without DGS.

Another layout which is made by using DGS (etched rectangular and circle shape on ground plane) is shown in figure 7 and the graph of this proposed configuration is shown in figure 8. The graph shown in figure 8 after applying DGS the cut off point has been shifted to a higher frequency near 2 GHz, which shows that the signal above 2 GHz were passed with negligible attenuation and signals below 2GHz is attenuation by up to 40 dB. By comparing both the results (figure 6 and figure 8), it has been found that the cut off point changes after applying DGS and also reduced sidebands and fluctuation of the output is achieved. So for the application where we require to increase in passband using same size filter the use of DGS is advantageous. It shows that further improvement in the cut off point will be achieved by using DGS in this design of high pass filter.

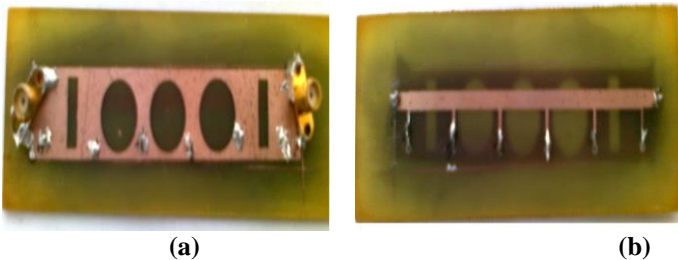


Figure 7: Layout of the fabricated device (a) Bottom view with DGS on ground plane (b) Top view of the HPF

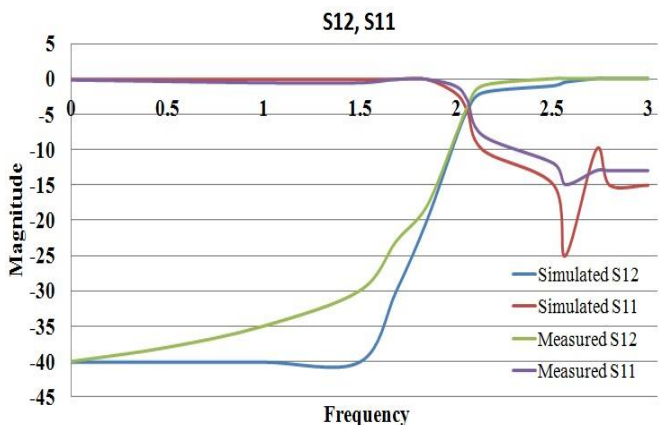


Figure 8: Graph of the HPF with DGS.

2. 5th Order Band Pass Filter

The fabricated layout of the BPF without DGS is shown in the figure 9. It uses same material as used in HPF. The graphs obtained after the simulation (CST Software [11]) and measured values (spectrum analyzer) are shown in figure 10. The graph shows the pass band of 0.85GHz to 1.88GHz is achieved. Attenuation in that range is 0 db and return loss is below -10 dB showing that the filter is efficiently working in this range. Except this band the filter is having stopband in which the attenuation is below -40 dB and return loss is near 0 dB axis.

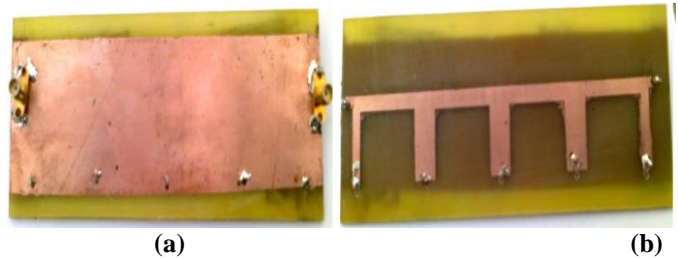


Figure 9 (a) Bottom view of the BPF without DGS (b) Top view of BPF.

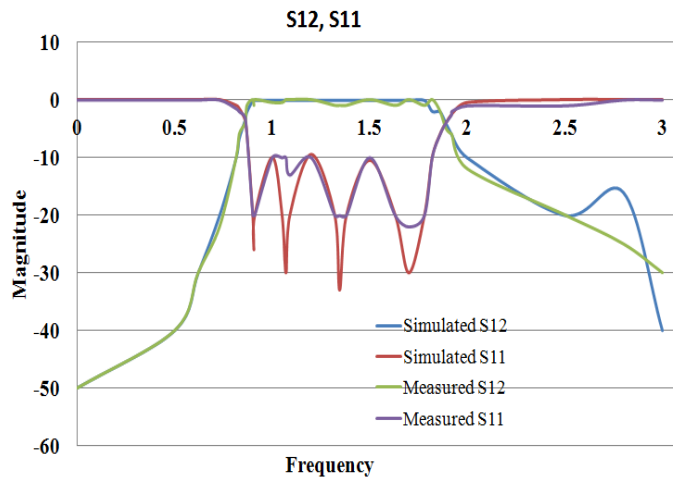


Figure 10: Graph of the BPF without using DGS.

The same configuration was designed with DGS as shown in figure 11 (etched circle and rectangle in ground plane). The graph obtained on CST and Spectrum Analyzer shown in figure 12. The graph shows the pass band of 1.05 GHz to 1.4 GHz is achieved. Attenuation in that range is nearly -2 db and return loss is below -10 dB showing that the filter is efficiently working in this range. Except this band the filter is having stopband in which the attenuation ranges in between -10 dB to -40 dB and return loss is near 0 dB axis.

By comparing both the results (figure 10 and figure 12), it has been found that the passband has been reduced, meaning that the selectivity of the filter was improved for this particular band. So in communication where large number of channels are used to transmit data; the effect of inter channel interference reduces the quality of receive data in large band. In that case the use of DGS in filters implementations is necessary to avoid large band. A particular band is selected by using DGS. By this it is found that for designing a filter to pass a particular band the use of DGS will be advantageous.

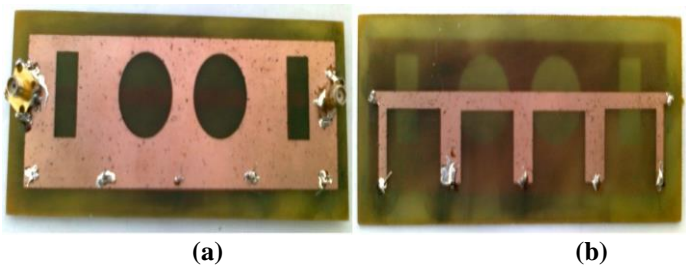


Figure 11: Layout of the proposed design (a) Bottom with etched circle and rectangle (b) Top view of the BPF

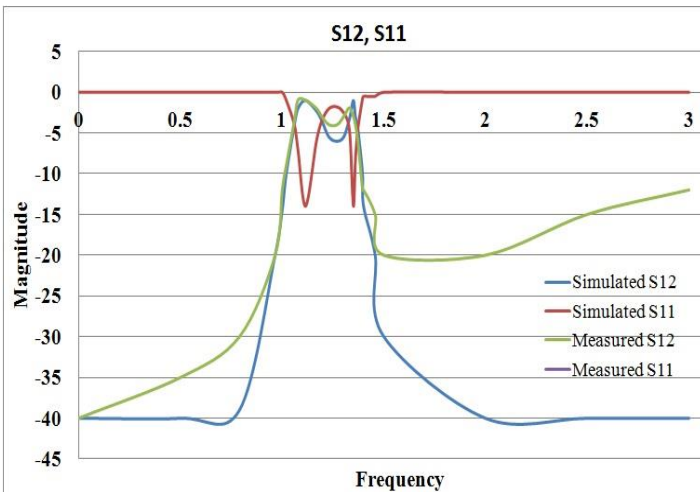


Figure 12: Graph of BPF with DGS.

V. CONCLUSION

The proposed design was implemented and analyzed at the centre frequency $f_c=1.5\text{GHz}$ (same for HPF and BPF), and passband frequencies of $f_1=1\text{GHz}$, $f_2=2\text{GHz}$ (for BPF). It has been found that measured results are in good agreement with the simulated value. In the case of the HPF the cut off point has been shifted to a higher frequency and sideband fluctuation was removed. In the case of the BPF with DGS the reduction in passband as compared to a filter implemented without using DGS was also achieved. So for the application where shifting of cut off, reduced level of fluctuation of response (in case of HPF) and reduction in passband (in case of BPF) is needed, then use of DGS for designing filter should be proposed.

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