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Improvement in Cutoff Frequency of Microstrip Butterworth Low Pass Filter using DGS Technique

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Abstract: ***This paper presents the design, analysis and fabrication of Butterworth Low pass filter with sharp rejection response using defected ground surface technique. The work is carried out to design a low pass filter with cut-off frequency 2.5 GHz to achieved the broad frequency response; the first step is to make a rectangle of 10x10mm at ground surface and the equivalent circuit for the DGS, subsequently followed to consequent L-C parameters extraction using analysis of S parameters response (EM simulation). The designed Butterworth low pass filter is realized and optimized using DGS (Defected Ground Structure) to attain a compact size, satisfactory transition sharpness along with low insertion loss in pass band and wide rejection in the stop band. The fabricated device showed the good conformity with theoretical and VNA measured result.***

Index Terms: ***Low Pass Filter, Micro strip Filter, Butter worth, Filter, DGS***

I. INTRODUCTION

Filters have applications in various fields of engineeringand commonly used in various electronic devices to isolate noise or interference signal from surrounding environment. For instance, radio transmitter use filters to block harmonics release which may be interfering with other communication devices. A Microwave filter [10] is used to manage the frequency response at a certain point and have different types based on frequency range, e.g. low pass filter [10,12] pass the lower frequency components (smaller than cutoff frequency) to pass while rejecting the higher frequency components.

Latest development in modern wireless communication systems has urged for new high-quality miniature filters design to support modern devices

II.Desining Of Butter worth Low pass filter [10]

Desining specification of 5th order Butterworth Low pass filter using Insertion loss method are shown in table 1.

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TABLE1: DESIGNED FILTER PARAMETERS AND VALUES

S.No.	Components	Value
1.	No. Of Element (N)	5
2.	$R_S = R_L$	50Ω.
3.	Cutoff frequency f_c	2.5GHz
4.	Substrate: GML	1000
5.	Permittivity of substrate ϵ_r	3.2
6.	Height h	0.762mm
7.	Size of substrate	50x50mm

A. Technical Parameter of Butterworth LPF:

1. Insertion Loss/Attenuation loss: -

$$N\ (No.of\ \ Element) = 10LOG(1 + w/w_c)^{2N}$$

2. CalculatingConductance: -

$$g_{k=2\sin\left[\frac{(2k-1)\pi}{2N}\right]}\quad where: -K$$
$$= 0,1,2 \ldots \ldots N$$

3. Inductance &Capacitance: -

$$InductanceL = R_o L_{p(g)}/w_c$$
$$Capacitancec = \frac{C_p(g)}{R_o w_c}$$

4. Electrical length of capacitor & inductor

$$\beta L_{capacitor} = \frac{C_n Z_L}{R_o} * \frac{180}{\pi}$$
$$\beta L_{inductor} = \frac{L_n R_o}{Z_h} * \frac{180}{\pi}$$

Where: - C_n=Normalized value of capacitor
Z_L=Lower impedance
R_o=Source resistance

B. IMPLEMENTATION, ANALYSIS & SIMULATION OF LOW PASS FILTER:

For design the low pass Butterworth filter [1, 2] using above mentioned formulae [10], we have followed the following steps-

Step 1: – Prototype design:

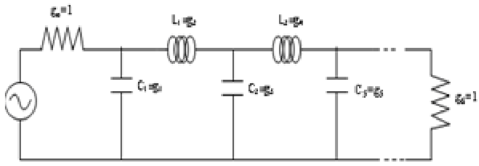

Figure 1: Schematic of LPF filter

Where:
$g_0 = 1$, $g_1 = 0.6180$, $g_2 = 1.6180$, $g3 = 2.000$, $g_4 = 1.6180$, $g_5 = 0.6180$, $g_6 = 1$

Step 2:– Impedance and frequency scaling:

The original resistance R_n, inductance L_n and capacitance C_n are modified by the following formulae by effect of new load impedance of R_o and cut-off frequency of ω_o.

$$R = R_0 R_n$$

$$L = \frac{(R_0 * L_n)}{\omega_0}$$

$$C = \frac{c_n}{R_0 * \omega_0}$$

Using the transformation with $R_o = 50\Omega$ and $\omega_o = 2\pi(2.5\times10^9)$ the new values are: -

C1= **0.7872 pF**; L2=**5.1528nH**

C3=**2.5477 pF**; L4=**5.1528 nH**

C5=**0.7872 pF**

Step 3: Converting into distributed elements:

The ratio Z_H/Z_L should be as high as much possible, which is restricted by the practicaldesign, which can be implemented on a printed circuit board. Typical values are Z_H=120 to 150Ω and Z_L=20Ω to 15Ω, as a typical LPF design generally consists of irregular series inductors and shunt capacitors in a ladder configuration, here the design is implemented the filter on a PCB board by using variable high and low characteristic impedance section transmission lines [5]. Proposed design considered Z_L=20Ω and Z_H=120Ω. The common relationship between inductance and capacitance with transmission line length are as follows (at the cutoff frequency ω_c):

$$\beta L_{capacitor} = \frac{C_n Z_L}{R_o} * \frac{180}{\pi}$$

$$\beta L_{inductor} = \frac{L_n R_o}{Z_h} * \frac{180}{\pi}$$

$$\text{Physical length } l_{C1} = (\text{Electrical length}/360) * \left(C/f_c\sqrt{\varepsilon_r}\right)$$

C_1 = 2.820 mm; L_2 = 8.503 mm; C_3 = 9.126 mm

L_4 = 8.503 mm; C_5 = 2.820 mm

Table 2: Overall values of Microstrip Low-Pass Filter

Element	Element Normalised Value (g_k)	Actual Element Value	Element Value Width (*W*) mm	Length (*L*) mm
C1	0.6180	0.7872 pF	6.3524	2.820
L2	1.6180	5.1528nH	0.5387	8.503
C3	2.000	2.5477 pF	6.3524	9.126
L4	1.6180	5.1528 nH	0.5387	8.503
C5	0.6180	0.7872 pF	6.3524	2.820

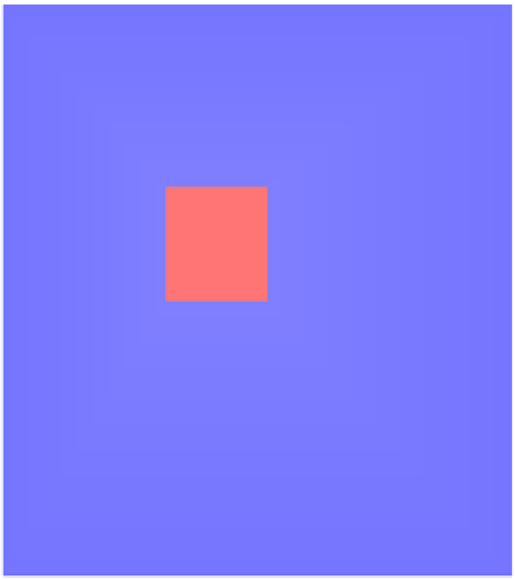

Figure 2 :- Front Side of the Conductor Pattern

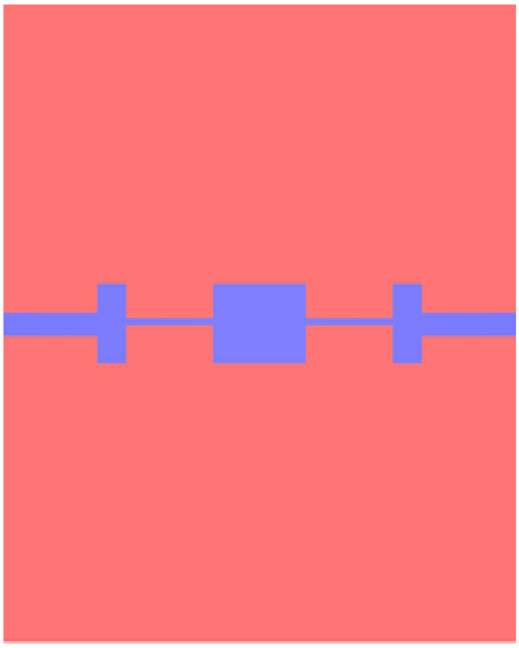

Figure 3 :-BackSide of the Conductor Pattern

To Sharp Rejection Using Defected Ground Structure [1,2]

The objective of structure like micro strip line with a centered slot at the ground plane has excellent applications in low pass filters for spurious band suppression which is called as Defected Ground Structure (DGS) [2, 3]. DGS adds an extra degree of freedom in microwave circuit design and opens the door to a wide range of application. It also added the slow-wave and band-stop features by varying the equivalent inductance and capacitance of the transmission line [13]. A compact Butter worth LPF [1, 2] with DGS and analyze the consequence of DGS parameter on the LPF. The size of DGS is 10x10 mm in ground side of LPF. The front and back side of conductor prototype are shown in figure 2 and 3 respectively.

III. SIMULATION RESULT

A. The response of the proposed design (with and without DGS) simulations results are shown in figure 4 and 5.

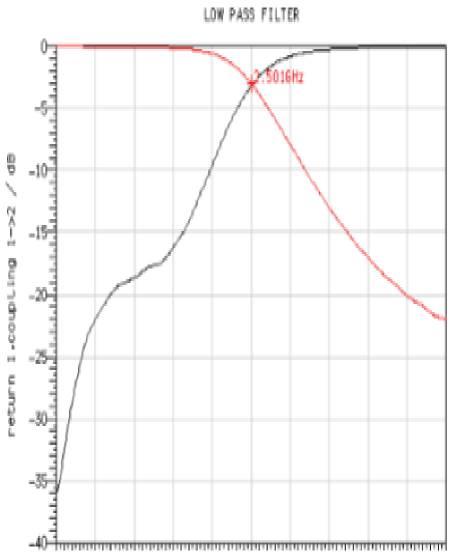

Figure 4: Responses of LPF with DGS (2.5 GHz)

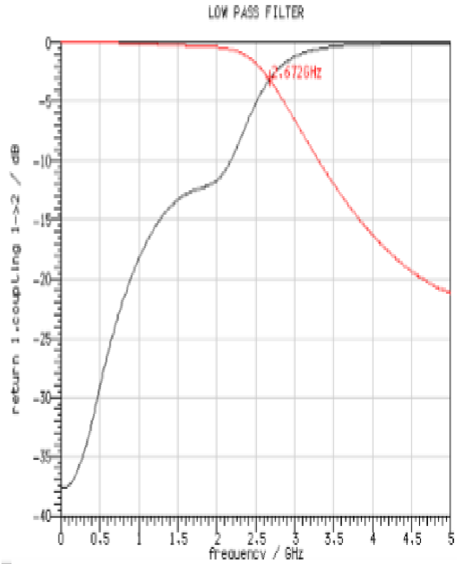

Figure 5: Responses of LPF with DGS (2.672 GHz)

B. Measured Result Through Vna

The response of the designed filter measured through vector network analyzer are shown in figure 6 and 7, and attained the cutoff frequency 2.44 GH_Z for without DGS and 2.672 GH_Z with DGS.

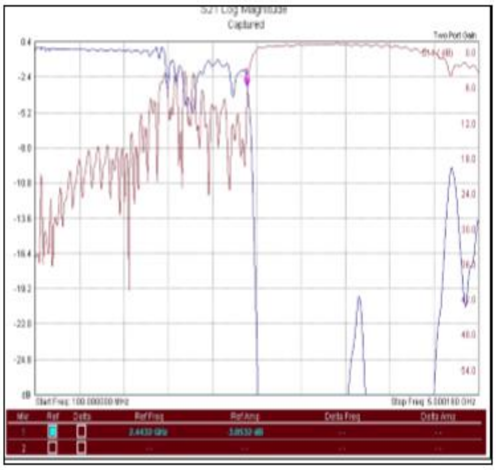

Figure 6: Result of LPF without DGS. (2.44 GH_Z)

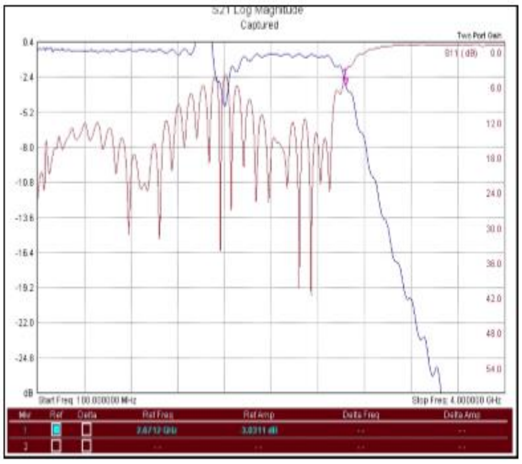

Figure 7: Responses of LPF with DGS (2.672 GHz)

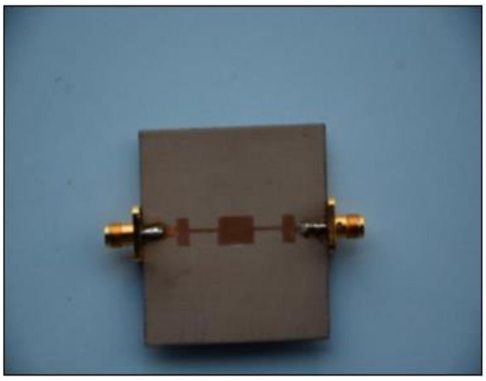

Figure 8: Front side of Fabricated Design

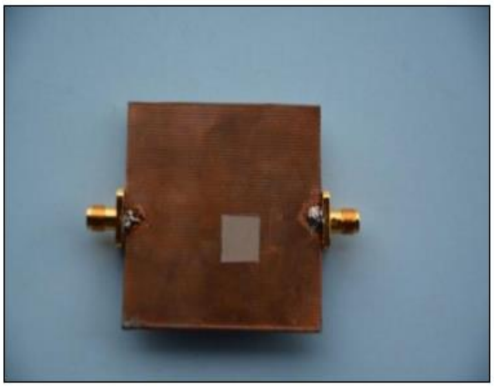

Figure 9: Back side of Fabricated Design

IV. FABRICATION RESULT

After Fabrication, authors measured the result of design whether it has attained the proposed specifications or not. The table 2 showed the comparison between simulations andmeasured result and it attains the target requirements. The fabricated design is shown in figure 8 and 9 for both side patterns.

Table 4: Comparison Results

Parameter	**Simulated Results/ Measured Results**	
	Before DGS	After DGS
Cut Off Frequency	2.5GHz/ **2.44 GHz**	2.672GHz/ **2.671 GHz**

V. CONCLUSION

The proposed work of Butterworth low pass filter with DGS was designedand fabricated. The presented 2.5GHz butter worth low pass filter have attained in the improvement up to 2. 672GHz.The results obtained by manually by distributed parameters valuesusing formulae does not gave the satisfactory results as there was a large shift in the cut-off frequency because of various stray inductances and fringing capacitances in the filter design. But in the values of distributed parameters obtained after end corrections gave the results very close to the desire results. Thereafter to get the exact results, the designed was optimized [9] and it showed that by decreasing the inductance and corresponding length shifted the frequency to the right. The results obtained by Micro strip simulation arealmost same with fabricated device, while the measured results showed a slight shift in cut-off frequency due to fabrication errors.

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