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Compact Elliptical Function Low Pass Filter with New E- Shape Defected Ground Pattern

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Abstract

An Eliptical Function low pass filter with 1.6 GHz frequency is developed and then it is made compact. Then to improve the filter performance a Defected Ground Pattern DGP is applied at the bottom layer of substrate FR-4. DGP dimensions are optimized to have good results. A comparison is also made between in filter's performance with and without DGP.

I. Introduction

Microwave communications have progressed very rapidly in recent years, and many microwave devices are becoming smaller and smaller. To meet the miniaturization requirement Filters are also required to be of small size. Filters are indispensible components of Microwave communication systems. In Microwave applications the transmission lines are treated as part of filter and often a low pass filter is built up as stepped impedance transmission line filter. With the increased attention given to micro- and millimeter-wave communication systems, high performance filters with compact size are highly attractive [1], [2] and [3]. Due to the advantages of small size and easy fabrication, the microstrip has been gaining much attention. The microstrip low pass filters can be designed using Butterworth, Chebyshev or elliptical functions. Elliptical function is used in this work because of its advantages of sharper rate of cut-off frequency for a given no. of reactive elements, easy fabrication, low cost and high performance.

In this letter, first an elliptical function low pass filter featuring sharp roll-off is designed and then the filter is made compact. Finally a new E-Shape DGP is applied to the filter design and its dimensions are varied to have optimized results. The filter design is simulated on IE3D software.

II. Design Procedure

In this letter the filter is designed with Elliptical function and have stepped- impedance structure for microstrip realization. Designing procedure starts with a Prototype Low Pass filter designing in which LPF is normalized with source and load resistance of 1Ω and cut-off frequency of 1 Radian/s. The order of the network corresponds to the number of reactive elements. The degree of elliptical function prototype LPF for a particular specification may be found from transfer function or design tables. After prototype filter designing Frequency and Element transformation is done to have practical filter. [7].

Frequency transformation is also called frequency mapping required to map a response (in low pass prototype frequency domain Ω) to in ω (in which practical filter response is measured). It affects all reactive elements but not any resistive elements. Element transformation is done by Impedance scaling. Impedance scaling removes $g_0 = 1$ normalization and adjust filter to work for any value of source impedance denoted by Z_0. The impedance scaling factor for any value of source impedance is denoted by Z_0.

III. Design and Measurement Results of a Six-Pole LPF

A six-pole filter is designed with cut-off frequency 2 GHz, pass band ripple L_{Ar} = 0.1dB, Zo = 50Ω, Ωs = 1.3024, L_{As} = 43.4113 on a FR-4 substrate with $\varepsilon_r = 4.5$ and H = 1.5. Z_{OL} and Z_{OC} are taken as 93 Ω and 24 Ω. The design parameter table is given in table 1.

Table 1 Design parameter table

Characteristic impedance Z	Z_{oC}=24	Z_o=50	Z_{oL}=93
Microstrip width w	W_c=8.16	W_O=2.82	W_L=0.78
Guided wavelength λ_g	λ_{gC} = 77.5	λ_{go}=81.42	λ_{gL}=85

After performing Frequency and Element Transformation and Calculation, the physical lengths obtained are:

l_{L1} = 5.80 mm l_{L2} = 9.13 mm
l_{L3} = 9.32 mm l_{L4} = 8.17 mm
l_{L5} = 8.58 mm $l_{C2'}$ = 1.70 mm
$l_{C4'}$ = 3.18 mm $l_{C6'}$ = 7.66 mm

The filter is designed and simulated on IE3D software. The figure 1 shows the filter design without any DGP structure.

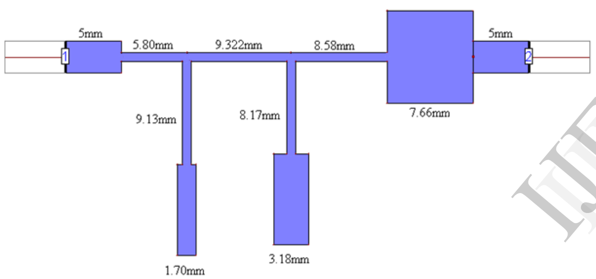

Figure 1 Elliptical function low pass filter

Now the filter is made compact so that it takes less area on substrate and also to make the design cost effective. It can be observed from figure 2,

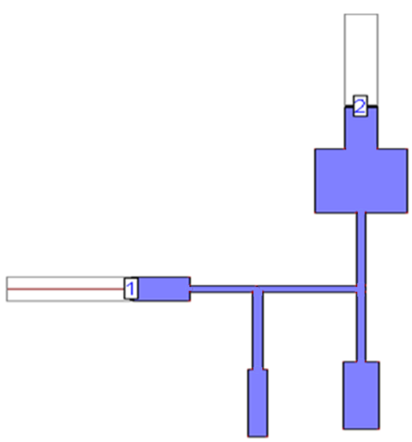

Figure 2 Compact elliptical function low pass filter

after making filter compact approximately 50 % length reduction is achieved. The filter design is made compact keeping in mind that its basic geometry should not get changed.

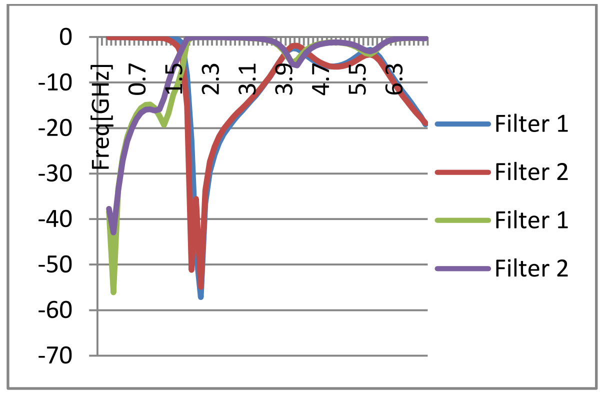

Figure 3 Comparisons of original filter and compact filter

The figure 3 gives comparison of original filter (given as Filter 1 in figure) and the same filter with compact size (given as Filter 2 in figure). It can be observed that compactness in filter design is achieved without any much change in its response. The minor changes are due to radiative losses at the ends but these can be ignored. it is also observed that transition from pass band to stop band is very sharp but in the stop band there is spurious transmission of signal. The aim is to suppress these spurious signals and to make stop band better. To suppress these spurious signals or harmonics DGP is applied to the filter.

IV. Defected Ground Pattern (DGP)

Defected ground Pattern (DGP) for planar transmission lines has drawn wide interest in applications for microwave, microstrip filter, antenna and millimetre-wave circuit design. DGP is realized by etching off a defected pattern from the ground plane of the substrate below the microstrip line [4], [5] and [6]. Etching disturbs the shield current distribution in the ground plane. This disturbance can change the characteristics of a transmission line such as line capacitance and inductance. Also changing the dimensions of DGP can change the characteristics of filter and improves the results. A DGP filter with elliptic function response has attenuation poles and zeros at finite frequencies and show high selectivity characteristics. Recently, few DGP with quasi elliptic responses have been reported [8]-[11].

In this letter a new E-shape DGP shown in figure 4 is introduced. Two DGP with period D = 8 mm, L1=7 mm, L2 = 5 mm, L3 = 7 mm, a = 1.4 mm and g = 0.3 mm is applied at the bottom surface of substrate and design is simulated on the software.

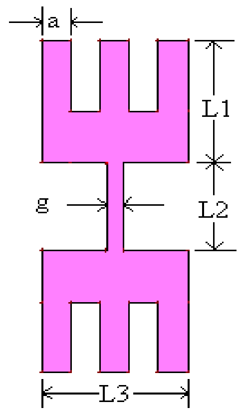

Figure 4 E-shape DGP

The filter design is given in figure 5 and simulated response is given figure 6. It can be observed that after applying DGP structure there is suppression in harmonics as it has came down to a level of -10 dB from -2.43 dB. There is a decrease of 7.57 dB in harmonics and also up to 5 GHz the output is below -10 dB but the pass band ripple has been increased to -0.76 dB. The cutoff frequency f_c is 1.6 GHz. The return loss is -0.68 dB at 3.7 GHz.

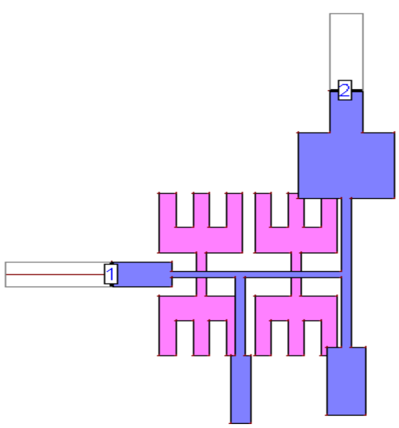

Figure 5 Compact filter design with two E-shape DGP

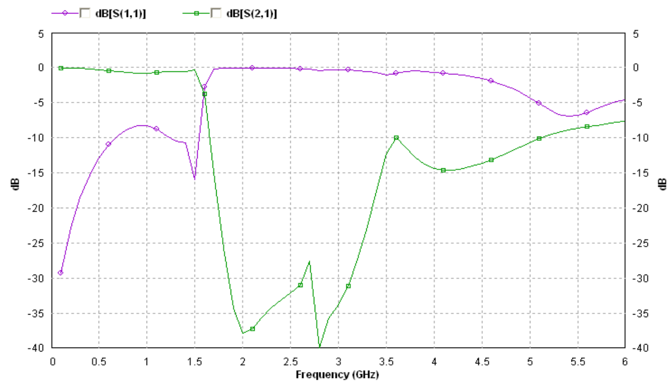

Figure 6 Simulated response of Compact Elliptical filter with E-shape DGP

V. Parametric Analysis of DGP

The result of the filter given in figure 6 can be optimized by performing modifications on the DGP dimensions. Different dimensions gap width (g), gap length (L2), DGP period (D) and parameters t of DGP are varied one by one keeping all other dimensions unchanged and then an analysis is done from filter responses given in figure 7- 14 to have the dimensions with best results.

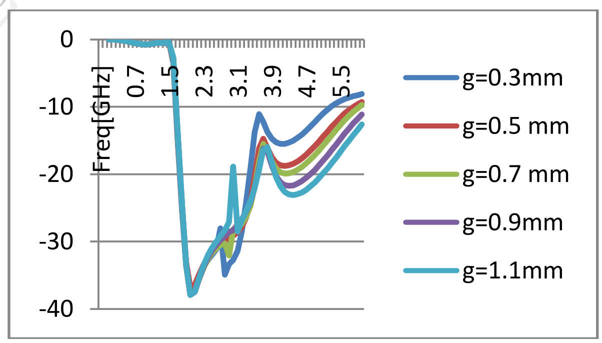

Figure 7 S_{21} Simulated response for different values of gap width (g)

It is observed from figure 7 that as g is increased harmonics suppression becomes better, stop becomes little wider but cut-off frequency 1.6 GHz and pass band ripples L_{Ar} -0.74 dB remains same. Results are better with gap width g = 0.9 comparatively. Figure 8 shows the S_{11} simulated response for different values of gap width (g). It is observed that the return loss is decreasing. It has decreased from -1 dB to -0.31 dB. It can be seen that for g = 0.9 mm a wide response is obtained so this value is fixed for further optimization and rest of the dimensions will be modified.

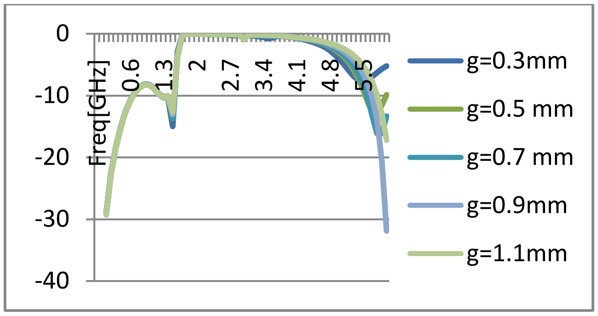

Figure 8 S_{11} simulated response for different values of gap width (g)

Now gap length L2 is varied and all other dimensions are kept unchanged. From the figure 9 it is observed as L2 is increased there is increase in pass band ripple, a minor decrease in cut-off frequency *fc*. The harmonic suppression also change with gap length and have best suppression at L2 = 5 mm. It can be seen from figure 9 and 10 for L2 = 5 mm the results are better than other values of L2, so now L2 = 5 mm is fixed for further optimization.

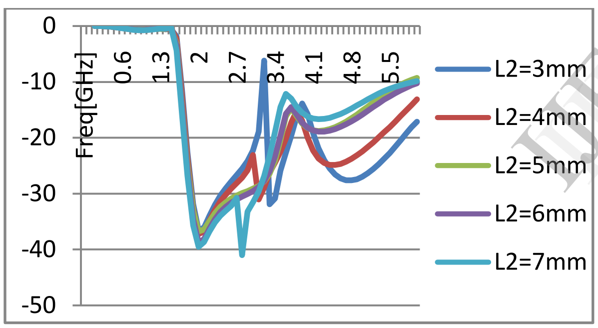

Figure 9 S_{21} Simulated response for different values of gap length (L)

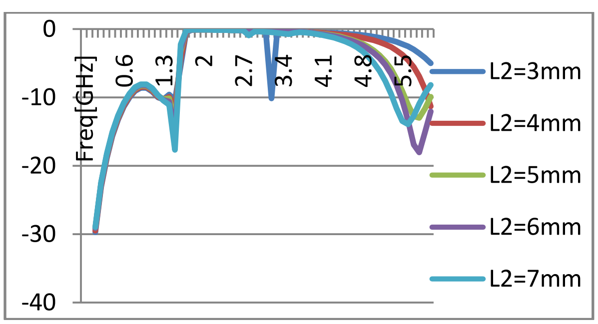

Figure 10 S_{11} Simulated response for different values of gap length (L)

Now the distance between two DGP D is varied keeping all other dimensions constant. It is observed from figures 11 and 12 that as DGP period increases cut-off frequency *fc* decreases, stop band becomes little narrow, pass band becomes poorer, insertion loss decreases and return loss also shows decrement. It can be observed from figures that for D = 8 mm the results are better, so D is taken 8 mm for further optimization.

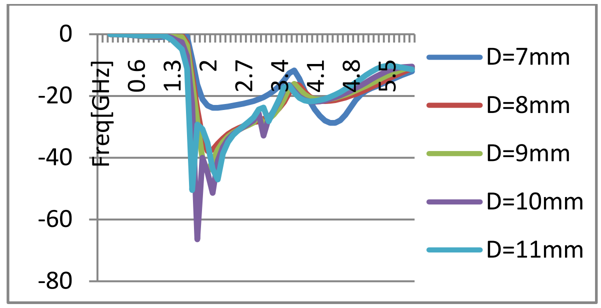

Figure 11 S_{21} Simulated response for different values of DGP period (D)

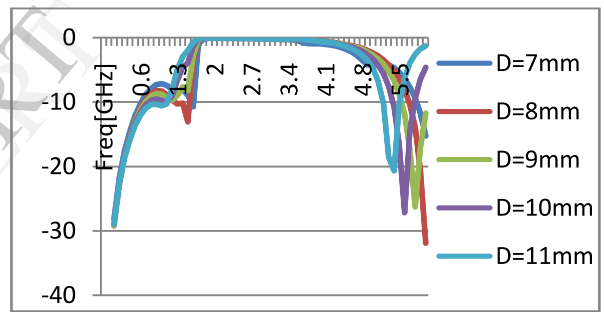

Figure 12 S_{11} Simulated response for different values of DGP period (D)

The simulated response for various values of t is given in figure 13 and 14. It can be noticed from the figure that as t is increased from 1 mm to 4 mm there are

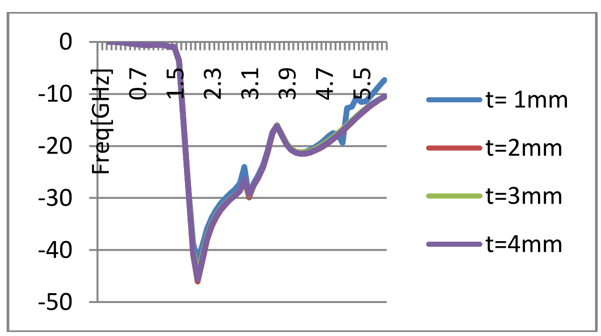

Figure 13 S_{21} Simulated response for different valuest

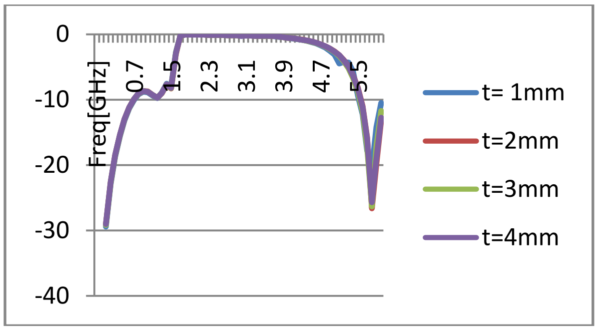

Figure 14 S_{11} Simulated response for different values of t

minor variations in the parameters like cut-off frequency *fc*, harmonic suppression and stop band width but there is significant variation in pass band ripples. The overall results are observed to be better with t = 3 mm. Hence the final optimized proposed filter design with DGP dimensions L1=7 mm, L2 = 5 mm, L3 = 7 mm, g= 0.9 mm, D = 8 mm, t = 3 mm and a = 1.4 mm is given in figure 15.

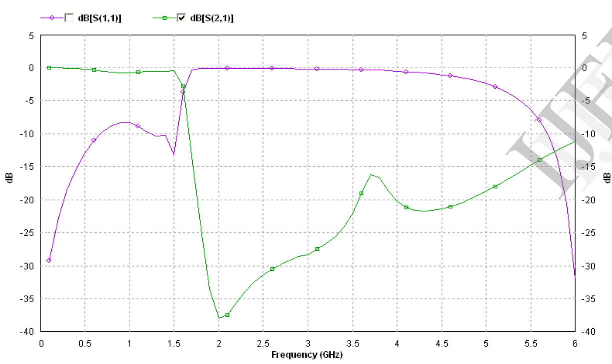

Figure 15 Simulated response of optimized filter with E-shape DGP

It can be seen from figure 15 that it is having insertion loss L_A of -16.23 dB at 3.7 GHz frequency, and a return loss L_R of -0.31 dB at 3.7 GHz and pass band ripple L_{Ar} -0.74 dB, cut-off frequency of 1.6 GHz and stop band up to 5.3 GHz frequency.

Now a comparison between compact elliptical filter without DGP (Filter 1) and with DGP (filter 2) is shown in figure 16 and it can be observed that a decrease of approximately 14 dB is achieved in optimized filter design.

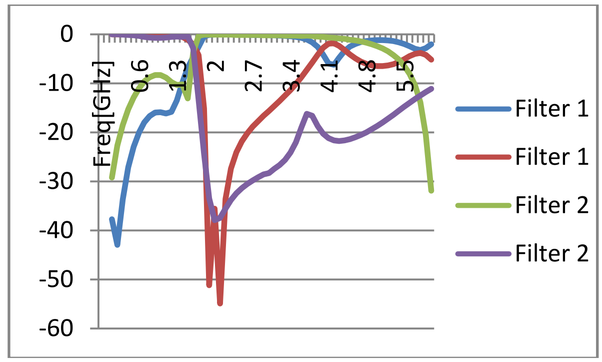

Figure 16 S_{11} and S_{21} response of filter without DGP and with DGP.

V. Conclusion

In this paper an Elliptical low pass filter of 1.6 GHz frequency is designed and simulated. The filter is made compact. An E-shape DGP structure at ground layer is added which helped in suppressing harmonics at different frequency. It can be observed from waveforms that transition from pass band to stop band is very sharp.

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