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LOW PASS TRI-SECTION STEPPED IMPEDANCE FILTER WITH WIDE STOPBAND USING DGS

Neeraja. P[1*], Usha Kiran K[2]
[1*] M.tech Communication Engineering,Vellore Institute of Technology, Chennai
[2]Vellore Institute of Technology, Chennai
Correspondence Author*:* neeraja.p2013@vit.ac.in

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Abstract
In this paper, a low pass tri-section stepped impedance filter with wide stop band using I-shaped DGS is presented. A bandwidth of 13 GHz is obtained at stopband. The maximum insertion loss is 0.3 dB and minimum return loss is 60 dB in the pass band. The minimum insertion loss is 47 dB and maximum return loss is 0.3 dB in stop band.

Introduction
Low pass filters are very important part of communication systems, especially mobile modules, to reject unwanted higher frequencies. They are often followed by a bandpass filter so as to select the specific frequency range from the low frequency provided by the low pass filter.
Recently a paper on design of compact low pass filter with wide stopband using tri -section Stepped Impedance Resonator was proposed. The paper discusses about achieving a wideband by changing the impedance ratios of a three sections stepped impedance filter[1]. Another recent paper discusses the design of a tri-section folded SIR filter. It proposes how to reduce the length of a tri-section SIR filter by folding it[2]. Y.Z.Zhu and X.J.Zhang et al., propose the general idea of compact T shaped line filter with ultra wide stopband. The series quarter wavelength line in conventional filters are replaced by open stub T shaped lines, resulting in ultra wide stopband[3]. Wang H.C Yang et al., discuss the design of a compact microstrip low pass filter with ultra wide stopband using SIR. Here semi circular microstrip is used to reduce the size of the filter and open circuited stubs are used to provide selectivity [4]. Kalpana Ramesh Chaturvedi et al., propose a wide stopband 6 pole stepped impedance low pass filter using double equilateral U shaped defected ground structure. It provides dual finite attenuation poles that can be independently controlled by DGS lengths[5]. Govind Singh Takur et al., propose the performance of low pass filter and bandstop filter using DGS[6].J.Y.WU and Y.H.Tseng et al.,propose the design of a compact microstrip lowpass filter using thin slots. Back to back C shaped DGS structures are used to obtain a wide stopband[7].
In this paper, a low pass tri-section stepped impedance filter with wide stopband using I-shaped DGS structure is proposed for GSM 900 for mobile communication. The filter is designed at 1 GHz cutoff. By changing the impedances, a wide stopband is achieved. And by applying the I-shaped DGS further increase in bandwidth is achieved.

Tri-section stepped impedance resonator
Filters are very important part of communication system. They will select the required frequencies and reject all other frequencies. Low pass filters are of utmost importance because they usually make the first filter in communication modules. They will filter out the lower frequencies up to the designed cutoff and reject all the higher frequencies. They are usually followed by a band-pass filter so as to select the particular frequency ranges among the selected lower frequencies.
Stepped impedance filters are created by cascading different impedance sections of microstrip so as to achieve a stepped structure. It is popular because it is very easy to design and is very cheap.
In tri-section stepped impedance filter, three different impedance sections are cascaded. The higher impedance section will have a lower area and it therefore acts as an inductor. The lower impedance section will have a higher area and it acts as a capacitor. The intermediate section act as an inductor with respect to the lower impedance section, while it acts as a capacitor with respect to the higher impedance section. So by changing its impedance with respect to the other two will therefore also change the overall inductance and capacitance of the system. Thus by only changing the ratios of the impedances of the sections, one can achieve different characteristics of the filter. So here by changing the impedance ratios, higher bandwidth is tried to obtain.
Further increase in bandwidth is obtained by applying I-shaped DGS structure. DGS is nothing but Defected Ground Structure. ie., a slot is created in the ground plane so that the current distribution changes. Changing the current distribution changes the L and C parameters, there by adding new resonance. So the second passband is pushed to higher frequencies, thereby increasing the stopband bandwidth.

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Design of tri-section stepped impedance resonator

This section discusses the methodologies and equations that are to be followed for the design of a stepped impedance filter. The basic structure of a tri-section stepped impedance filter is given in Fig.1.

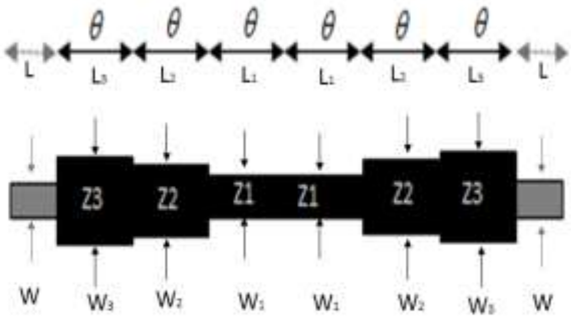

Fig 1. Basic structure of a tri-section stepped impedance filter.

Impedance ratios

The main parameters under consideration here are the two impedance ratios. These two ratios are K_1 and K_2 where

$$K_1 = \frac{Z_3}{Z_2} \quad \text{and} \qquad (1)$$

$$K_2 = \frac{Z_2}{Z_1} \qquad (2)$$

Here Z_1, Z_2 and Z_3 are the impedances of the three sections.

For design purpose, the value of Z_2 is assumed so as to achieve the values of Z_1 and Z_3 from equations (1) and (2).

Width of the microstrip sections

Now for each of the three impedances Z_1, Z_2 and Z_3, the corresponding width is calculated using the following equations (4) or (5)

for $\frac{w}{d} < 2$;

$$\frac{w}{d} = \left\{ \frac{8e^A}{e^{2A} - 2} \right\} \qquad (3)$$

Where $A = \frac{Z_0}{60} \frac{\sqrt{\varepsilon_r + 1}}{2} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}\left(.23 + \frac{.11}{\varepsilon_r} \right)$ (4)

Or

for $\frac{w}{d} > 2$;

$$\frac{w}{d} = \frac{2}{\Pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(B - 1) + .39 - \frac{.61}{\varepsilon_r} \right) \right] \qquad (5)$$

where

$$B = \frac{377\Pi}{2Z_0\sqrt{\varepsilon_r}} \qquad (6)$$

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Where l is the physical length per section, w is the width of the element, d is the thickness off the substrate, Z_0 is the characteristics impedance and ε_r is the relative dielectric constant.

Length of the microstrip sections

The electrical length (in radians) can be calculated from equation (7), if the impedance parameters are known.

$$\theta = \tan^{-1}\left(\sqrt{\frac{k_1 k_2}{k_1 + k_2 + 1}}\right) \quad (7)$$

where θ is the electrical length per section. i.e., the length of each section is θ. There are a total of six sections in tri-section stepped impedance filter. So the total electrical length (in radians) is 6 θ.

To convert it into physical length (in mm), equation (8) can be used.

$$l = \frac{\theta}{\beta}\frac{\Pi}{180} \quad (8)$$

where

$$\beta = k_0\sqrt{\varepsilon_e} \quad (9)$$

$$k_0 = \frac{2\Pi f_0}{c} \quad (10)$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}.\frac{1}{\sqrt{1 + 12\frac{d}{w}}} \quad (11)$$

where f_0 is the cutoff frequency and ε_e is the effective dielectric constant.

Proposed structure

The proposed low pass filter is designed at a cutoff frequency of 1GHz. It is built on a substrate having a dilectric constant ε_r of 2.17 and thickness .78 mm. The filter has a loss tangent 0.0002.Copper conductors have 0.1mm thickness. The impedance Z_2 is taken as 20 Ω.The table 1. Shows the measurements of each elements when the impedance ratios K_1 and K_2 are .90 and .10 respectively.

Table1.The measurements of all elements when K_1=.9 & K_2=.1

Length(mm)		Width(mm)	
L	55.1260	W	2.4243
L_1	7.0654	W_1	9.0745
L_2	7.0888	W_2	8.117
L_3	7.7940	W_3	0.0829

Maximum bandwidth in the stopband is obtained when K_1=.9 and K_2=.1. The lengths and widths of each sections with impedances Z_1, Z_2 and Z_3 are 7.0654mm, 7.0888mm and 7.7940mm and 9.0745mm, 8.1170mm and 0.0829mm respectively. The model structure of the proposed structure in HFSS is shown in Fig. 2

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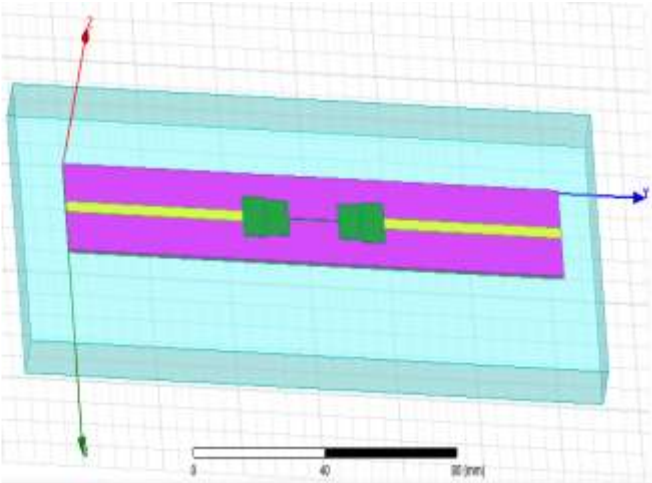

Fig 2. Tri-section stepped impedance filter structure modelled using HFSS

A bandwidth of 4.5GHz is achieved. The maximum insertion loss is .3dB and minimum return loss is 18dB in the pass band. The minimum insertion loss is 20dB and maximum return loss is .3dB. The simulation result in HFSS is shown in Fig. 3.

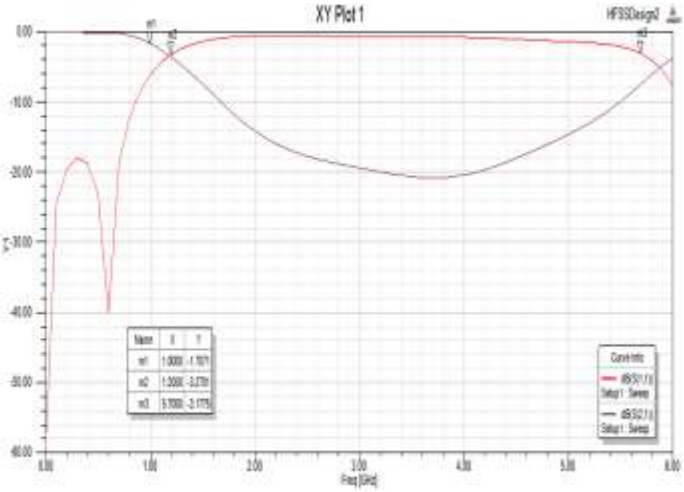

Fig 3. Simulation results using HFSS

Comparison of the stop band bandwidth obtained using different impedance ratios are tabulated in Table 2.

Table2.Comparison of stopband bandwidth by different impedance ratios

Sl. No	K1	K2	Bandwidth(GHz)
1	1.5	1.5	NA
2	.2	.8	NA
3	.5	.5	1.4
4	.8	.2	2.7
5	.96	.17	3
6	.9	.1	4.5

From table 2, it is clear that highest bandwidth for stopband is obtaines when K_1=.9 and K_2 =.1

Now an I-shaped DGS is applied on this structure, so as to increase the stopband bandwidth. Addition of DGS structure adds new resonant frequencies in the structure, pushing the higher stopband frequencies further away. The I-shape is applied on the region with maximum Electric field radiation as shown in Fig.4.

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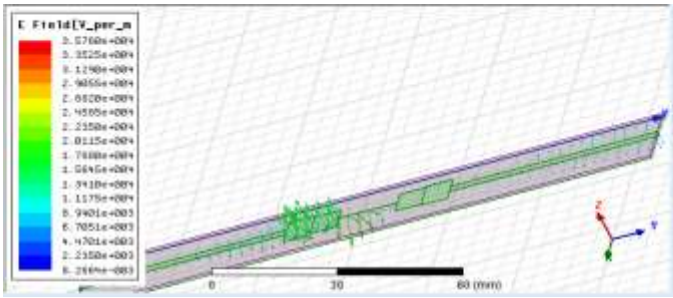

Fig 4. Plot of E-Field

The direction of the EM radiation is altered after the application of the I-slot as shown in the Fig.5. Now the radiation is along the edges of the slot.

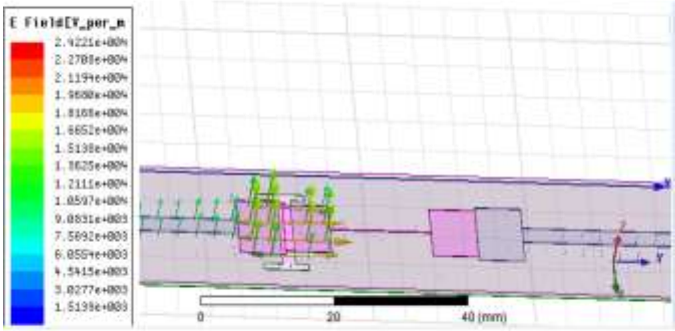

Fig 5. Plot of E-Field along the I-Shape

The dimensions of the structure is given below in Fig.6. The I-shaped DGS has the dimensions as follows: w=7,l=1,g=2,s=11.

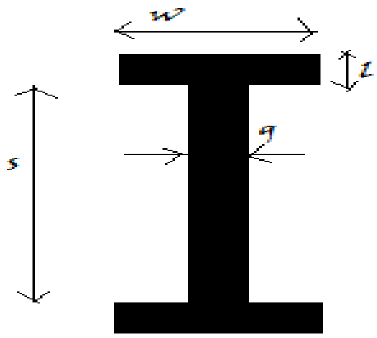

Fig 6. I-shaped slot structure

The filter structure modelled using HFSS is given below in Fig 7.

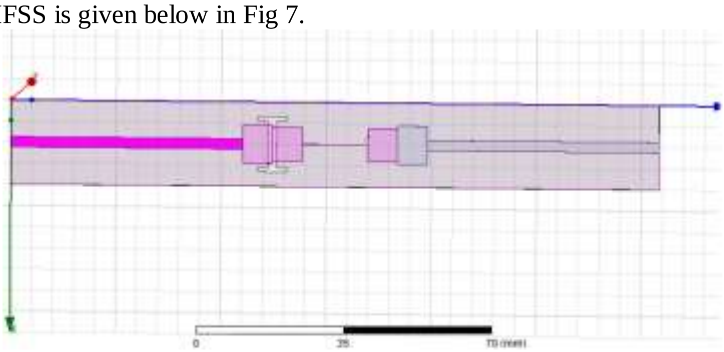

Fig 7. Tri-section stepped impedance filter structure with I- shaped DGS modelled using HFSS

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The HFSS simulation result of the structure is given in Fig 8. Gain v/s frequency is plotted.

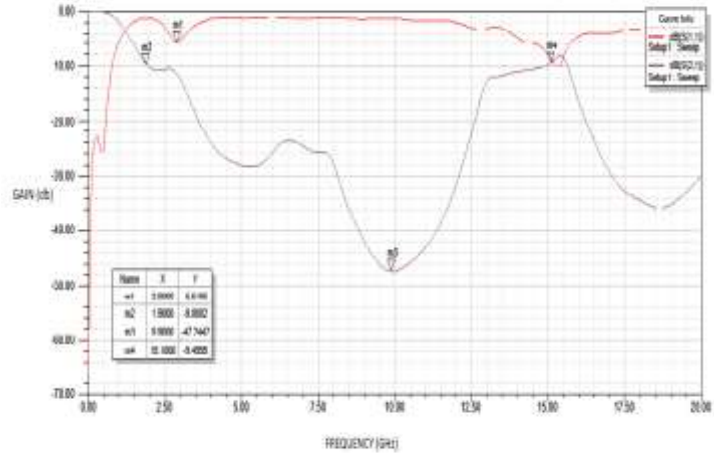

Fig 8. Simulation results using HFSS

Conclusion

A low pass tri-section stepped impedance filter is designed at 1GHz cutoff frequency using DGS. Wider stopband characteristics is observed. A stopband of 13 GHz bandwidth is obtained, whereas the conventional tri-section stepped impedance filter only provided 4.5 GHz bandwidth in the stopband. The maximum insertion loss is 0.3 dB and minimum return loss is 60 dB in the pass band. The minimum insertion loss is 47 dB and maximum return loss is 0.3 dB in the stopband**.**

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