Implementation of Lowpass Filter using Microstrip Stub and Defected Ground Structure

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ABSTRACT
One compact microstrip low-pass filter using conventional elliptical headed dumbbell shaped defected ground structure (DGS) is proposed in this work. An equivalent circuit model is provided to depict the DGS unit. The proposed structure with main dimension parameters has been analyzed as a design guide, which can be used to fabricate the filter. The H-shape open stub has been introduced which increases the equivalent parallel capacitance to improve the out-band suppression. The proposed LPF shows low cut-off frequency response, low insertion loss, sharp transition and fairly good rejection in stop-band. Finally, one 5th order equivalent Butterworth filter has been designed using 5 arrays of DGS units. The five array DGS filter, including stubs provides the rejection in stop-band from 2.8GHz to higher frequencies. Defected ground structures (DGS) have shown increasing potential for implementation in different applications: MIC, MMIC, and RFIC. They provide sharp, distinct electromagnetic band-gap and high slow wave factor, which lead to smaller size circuits and lots of engineering challenges to fulfill the requirements of modern communication systems.

Keywords
microstrip; defected ground structure; elliptical; lowpass filter; open stub.

1. INTRODUCTION

A defected structure etched in the metallic ground plane of a microstrip line is an attractive solution for achieving finite pass band, rejection band, and slow-wave characteristics. The defected structure effectively disturbs the shield current distribution in the ground plane and thus, introduces high line inductance and capacitance of the microstrip line. Thus, it obtains wide stop band and compact size, which meet emerging application challenges.

Dumbbell shaped defected ground structure (DGS) is explored first time by Ahn applied to design a lowpass filter [1- 3]. Unit cell has been described as a one-pole Butterworth filter, where the capacitance comes only from the transverse slot width and the inductance comes only from the loop. The study of dumbbell DGS with various head shape have appeared in the literature recently and they are used to design filters, couplers, dividers, amplifiers [4–10], etc.

In this article, a symmetric DGS pattern with reference to transmission line is proposed. Its unit cell consists of two elliptical headed slots connected with a rectangular slot under microstrip line transversely. The investigated DGS unit produces a stop band characteristics and shows 1st order Butterworth response. A 5th order lowpass filter has been implemented with the array of five DGS units and additional open stubs have been introduced for spurious suppression.

2. FREQUENCY CHARACTERISTICS AND TUNNING OF DGS

The DGS is fabricated on the Arlong based PTFE substrate with dielectric constant 3.2, 0.79 mm thickness and 0.0025 loss tangent. The layout is shown in Fig. 1(a). Different dimensions of the elliptical headed dumbbell shaped DGS cell are a = 2mm, b = 1mm, g =0.2 mm and L = 12mm which is eatched undreneath a 50Ω microstrip transmission line with width, W = 1.92mm. The structure is simulated with MoM based IE3D EM software and the S-parameters are plotted in Fig. 1(b).

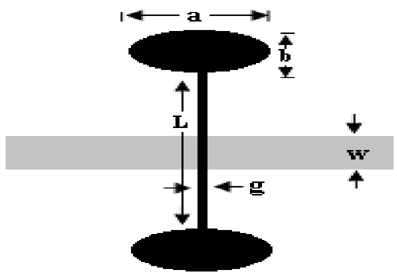

Fig. 1(a): Elliptical headed dumbbell shaped DGS unit

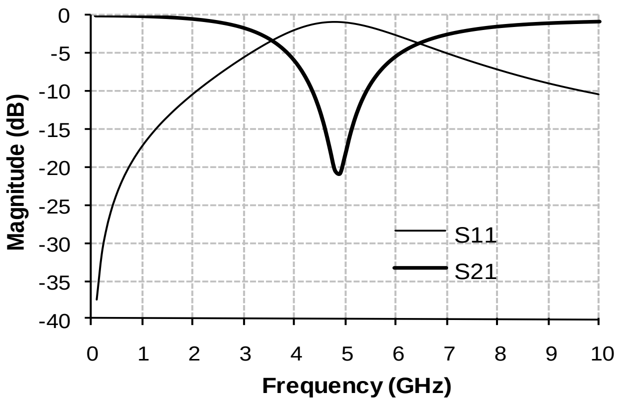

Fig. 1(b): scattering parameters

The unit DGS cell provides some inductance and some capacitance values and behaves as L-C resonant or tank circuit. From the characteristic response it can be observed that the proposed DGS provides resonance frequency or one attenuation pole, fp at 4.88 GHz and 3-dB cut off or one attenuation zero, fc at 3.5 GHz.

The DGS behaves as L-C resonant or tank circuit. But the unit cell of the DGS can be modeled most efficiently by a parallel combination of R, L and C resonant circuit connected to transmission at its both sides [Fig. 2]. The equivalent R, L and C values can be obtained using the expressions as follows:

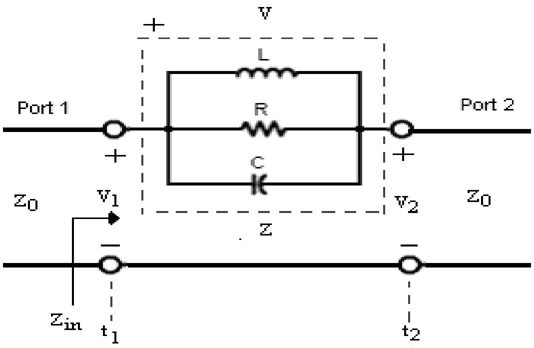

Figure 2: Equivalent-circuit model

$$C = \frac{\omega_c}{2Z_0(\omega_0^{\,2} - \omega_c^{\,2})} \quad \text{……………………….(1)}$$

$$L = \frac{1}{4\pi^2 f_0^{\,2} C} \quad \text{……………………..……(2)}$$

$$R(\omega) = \frac{2Z_0}{\sqrt{\frac{1}{|S_{11}(\omega)^2|} - (2Z_0(\omega C - \frac{1}{\omega L}))^2 - 1}}$$

……………………(3)

Throughout the paper the conductor and dielectric loss assumed to be very small. The total power loss due to lossy conductor, dielectric material and radiation must be same as the power dissipated in the equivalent resistors (R). Since, the conductor and dielectric losses are assumed to be neglected, thus, the total power loss due to the radiation effect only. The radiation rate can be calculated from the equivalent circuit easily as follows:

Let , $V^{/}$ is the incident voltage and V_1 be the total voltage at the left reference plate t1, V be the voltage across the parallel resonant circuit and V_2 be the transmitted voltage at the right reference plate t2. Z is the impedance of the parallel R, L and C resonant circuit. Then the radiated power, P_r can be calculated by

$$P_r = \frac{|V|^2}{2R} = \frac{|V_1 - V_2|^2}{2R} = \frac{2|V^{/}|^2 \left|\frac{Z}{Z+2Z_0}\right|^2}{R}$$

… ……………………..…(4)

The radiation rate, η can be expressed as

$$\eta = \frac{P_r}{P_{in}} = 4\left|\frac{Z}{Z+2Z_0}\right|^2 \frac{Z_0}{R} \quad \text{…………………(5)}$$

where, P_{in} is the input power given by

$$P_{in} = |V^{/}|^2 / (2Z_0) \quad \text{………………..……..……(6)}$$

At the resonant frequency $(\omega \to \omega_0 = 1/\sqrt{LC})$, $Z \to R$ and η is given by

$$\eta = \frac{1}{\frac{R}{4Z_0} + \frac{Z_0}{R} + 1} \quad \text{………………..……………..(7)}$$

a function of R/Z_0. From equation (7), the radiation rate η can be shown to have its maximum value of 0.5 when R/Z_0 = 2. It is also seen that when R goes to infinity or open then equivalent circuit will be a LC tank or resonance circuit, the radiation rate η becomes zero or it should be lossless.

Throughout the paper, it is considered that rediation loss is neglected i.e. R is not taken into consideration. Therefore, the proposed DGS unit can be represented simply by L-C tank or resonant equivalent circuit and behaves as 1st order Butterworth prototype filter with element values L= 2.08 nH and C = 511.8 fF as follows:

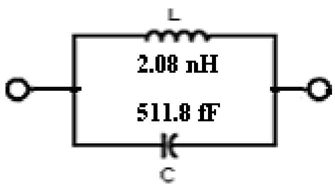

Fig. 3(a): Equivalent Circuit of single DGS cell

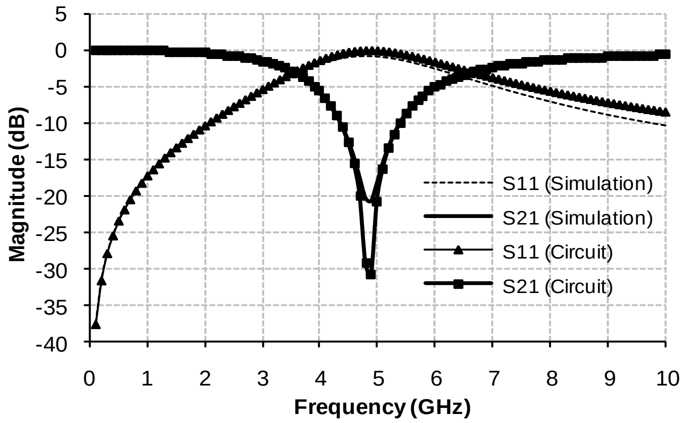

Fig. 3(b): scattering parameters

The equivalent circuit is shown in Fig. 3(a) and corresponding characterestic response has been extracted. The above Fig. 3(b) shows that there is a good agreement between simulated and circuit model responses.

3. TUNNING AND PARAMETRIC STUDY OF DGS UNIT

The resonance frequency can be tuned with the variation of any one parameter of the DGS unit keeping other parameters constant. Here the length of the mojor axis of ellipse 'a' has been varied and remaining other dimensions are constant.The following Table I and Figures 4a–4d shows the variation of different parameters with different values of major axis 'a'.

TABLE I: Variation of Different Parameters with Different Values of Major Axis Length 'a':

Major axis, a (mm)	Attenuation Pole, fp (GHz)	Attenuation Zero, fc (GHz)	Inductance, L (nH)	Capacitance, C(pF)
2	5.782	4.236	1.671	453.4
4	4.88	3.52	2.08	511.8
6	4.3	3.02	2.531	541.3
8	3.854	2.672	3.041	560.8

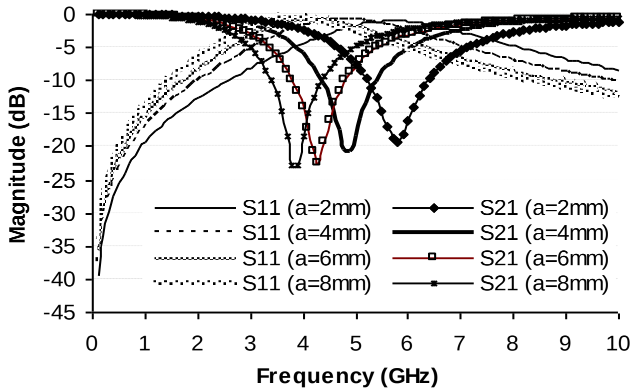

Fig. 4(a)Variation of S-Parameters with 'a'

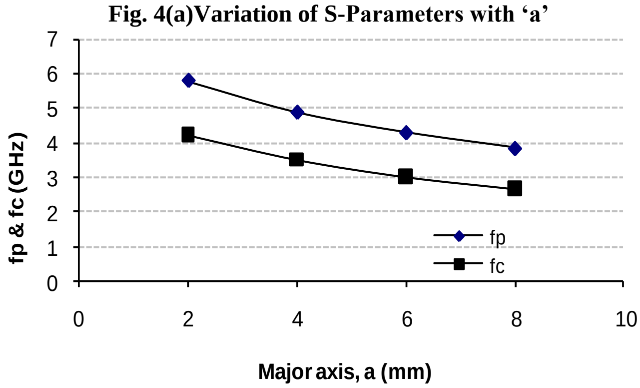

Fig. 4(b) variation of fc & fp with 'a'

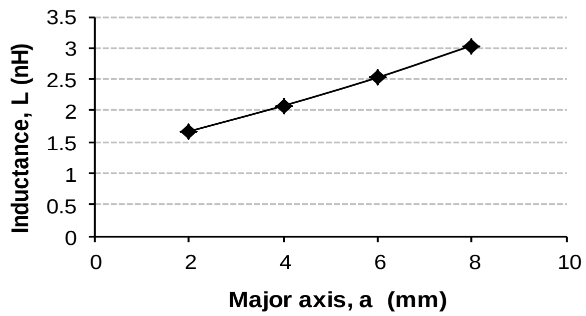

Fig. 4(c) variation of Inductance (L) with 'a'

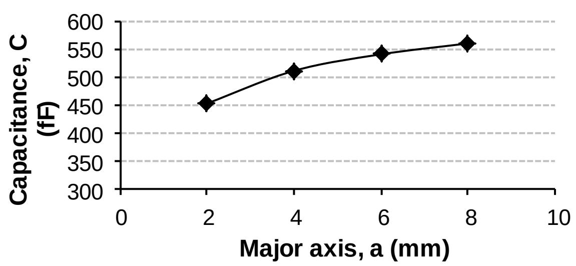

Fig. 4(d) variation of Capacitance (C) with 'a'

From the above Fig. 4(a) it is found that the resonance frequency decreases with the increment of the major axis length 'a'. This is due to increment of dumbbell head area or loop length or total electrical path length with the increment of 'a' which is responsible for increment of inductance, 'L' as shown in Fig. 4(c) but the capacitance, 'C' depends on transverse slot length and width of the DGS unit which is remained almost unchanged as shown in Fig. 4(d). Therefore, the fp and fc change inversely with 'a' as shown in Fig. 4(b).

From the above curve (Fig. 4(b)) and with the help of curve fitting it is possible to find the value of the require major axis length (a) of the DGS for the specified value of the attenuation pole frequency, fp, utilizing the following equation:

$$Y = -0.0929X^3 + 2.2209X^2 - 17.955X + 49.532 \qquad \text{………………………………..(8)}$$

where, Y is the calculated length of the major axis 'a' and X is the given value of the resonance frequency 'fp'.

Similarly, from the same curve (Fig. 4(b)) and with the help of curve fitting it is possible to find the value of the require major axis length (a) of the DGS for the specified value of the attenuation zero frequency, fc, utilizing the following equation:

$$Y = -0.6828X^3 + 8.3505X^2 - 36.665X + 59.377 \qquad \text{… ……………………………….(9)}$$

where, Y is the calculated length of the major axis 'a' and X is the given value of 3-dB cut-off frequency 'fc'.

In the same way user can obtained their requirement with the variation of any other parameters.

4. IMPLEMENTATION OF LOWPASS FILTER

One dumbbell DGS with a=5mm, b=4mm, L=15mm and g=0.2mm is taken which provides a stop band at 3 GHz. The technique matches a network by connecting a single open or short circuited transmission line, i.e the stub, in series or parallel with the load. The DGS can be used for low-pass filter design and spurious pass band suppression using $\lambda/4$ wavelength long open stub as shown in Fig. 5(a) and the comparative S- parameters are shown in Fig. 5(b).

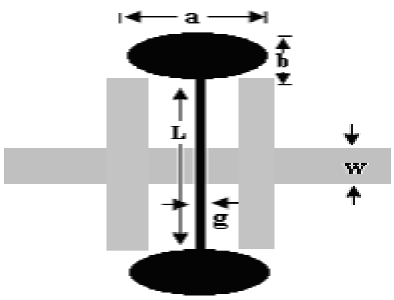

Fig. 5(a) DGS with stub

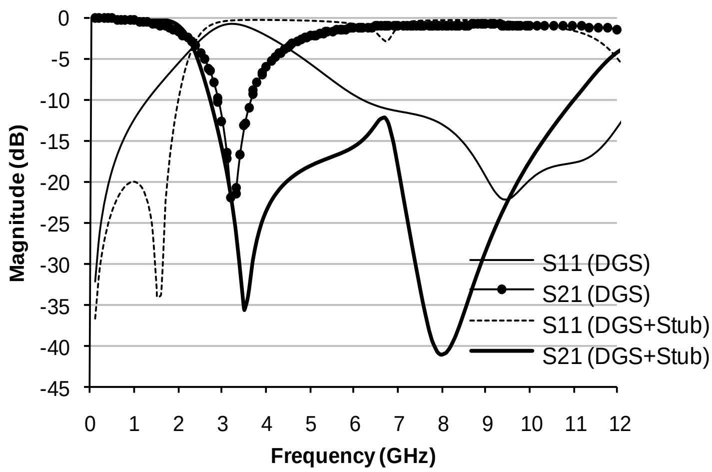

Fig. 5(b) Scattering parameters

From the above Fig. 5(b) it is shown that DGS provides stop band but DGS with stub provides lowpass filtering response. However, this structure has the disadvantage of insufficient suppression of harmonics around 6.8GHz, 12GHz and higher frequencies. These spurious can be removed with the increment of DGS units and stubs in array. The responses of single, three and five DGS units with four, eight and twelve open stubs respectively is shown in Fig. 6.

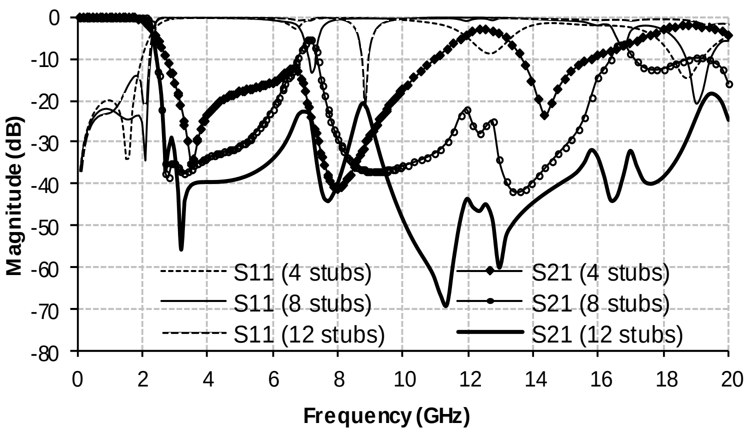

Fig. 6 Scattering Parameters

Above analysis shows that with the increasing number of dumb-bell shape defected ground structure and number of stub, selectivity and sharpness factor of filter is increased and rejection band is increased with reduction of harmonics.

Therefore, one 5th order good lowpass filter can be designed with the array of five DGS structures as shown in Fig. 7. The different dimensions of major axis of ellipse are 5mm, 4.6mm and 4mm respectively, minor axises are 4mm, 3.6mm and 3mm respectively and the transverse lengths are 15mm,12mm and 10mm respectively with width 0.2mm. The open stub lengths are 6mm, 4mm and 3mm respectively seperated by 4mm.and the distance between two adjucent 6mm stub is 2mm.

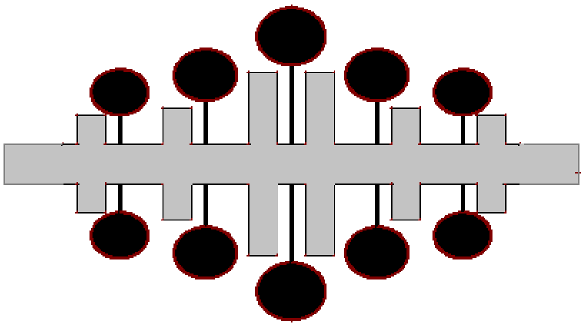

Fig. 7 Proposed structure

The structure has been designed on PTFE substrate and simulated with MoM based IE3D EM simulator. The simulated S-parameters of the structure is shown in Fig. 8.

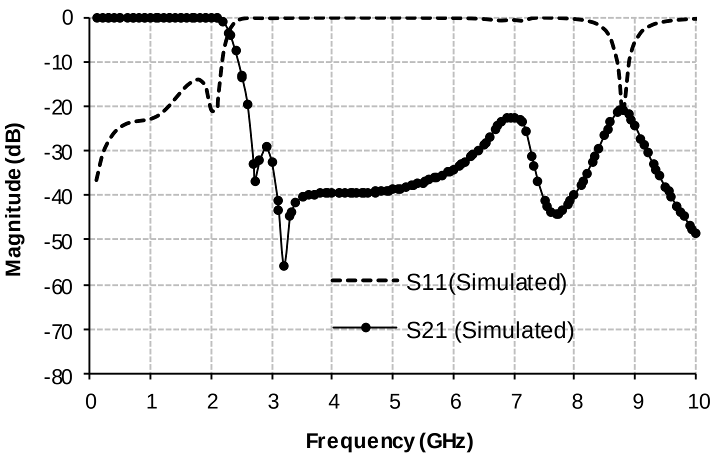

Fig. 8 Scattering Parameters

It is observed from the Fig. 8 that the proposed structure provides good lowpass filtering response with attenuation pole at 2.875 GHz, attenuation zero at 2.32 GHz, negligible passband insertion loss, sharp transition between passband and stopband with sharpness factor 122 dB/GHz and wide attenuation stop band.

5. CONCLUSION

Several compact and high performance filters and other circuit components have been realized by using the generic structure called the defected ground structure. It will also lead to the lower power handling capability of the filter and DGSs have found to be potentially great applicability to design filters, couplers, power dividers, amplifiers and other circuits at present time. The open stub increases the equivalent parallel capacitance to improve the out-band suppression. The novel symmetric DGS have been proposed here with stubs. The both measured and simulated results show pole and zero filter responses, which enabled to provide extremely sharp transition band, no passband insertion loss and wide stop band. Finally as the said filters are very compact in size and have all advantages of planar filters, applicable in modern microwave and millimeter wave communication systems.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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