IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 4 (April. 2018), ||VIII|| PP 16-22

Emergence of Defected Ground Structure and Its Effect on A Quasi Lumped Element Resonator Antenna

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Abstract: Nowadays, antennas used in wireless communication system need to be small size, light weight, low cost, wideband and low profile. Conventional microstrip patch antennas have limitations of large size, single operating frequency, narrow bandwidth, low gain and not more suitable for modern wireless communication systems. Microstrip patch antenna performance has been improved using Electromagnetic band gap (EBG), Photonic band gap (PBG), Defected Ground Structure (DGS) and recently was the introduction of the quasi lumped element resonator. The quasi lumped element resonator antenna has wider bandwidth, smaller size and moderate gain in comparison with the microstrip patch antenna. In this research, quasi lumped element resonator was used but with defected ground structure (DGS) for improved bandwidth, small size and lower return loss. The results showed that the quasi lumped element resonator antenna with DGS resonated at 5.8GHz which is better by 34.5 % compared to that without DGS. Also the antenna ground size was decreased by 3.04 % with DGS.

Keywords: Defected Ground Structure, Microwave Circuits, Antenna, Photonic Band Gap, Electromagnetic Band Gap

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Date of Submission: 14-04-2018 Date of acceptance: 30-04-2018

I. INTRODUCTION

Defected Ground Structure (DGS) are modifications to the ground plane of a microwave circuit in the form of an integration. It is a slot or an etched defect integrated with the ground plane of a microwave circuit. This microwave planar circuits have component parts and they are simply an arrangement of a top component made from a metal, typically copper in case of a microstrip patch antenna and separated by a substrate, with a metallic bottom thin layer of the same thickness with the top layer below the substrate. It is on this bottom layer (ground plane) that the defected ground structure is being worked on. A typical example of this work is found in filters, where it was under the microstrip line (Khandelwal *et al.*, 2017) and it led to the improvement of band stop characteristics, suppression of higher mode harmonics. All these were due to the modification of the filter circuit using defected ground structure. It was observed that the bandwidth of the antenna improved significantly with the use of some defects below the quasi lumped element resonator. This defected ground structure was initially proposed by Park et al., (1999) and a first description of it was as a single dumbbell shaped DGS. It can be explained as a modified form of the EBG with also a band stop property (Yang & Rahmat-Samii, 2009). The emergence of the DGS can be dated back to when the PBG structures were being studied in relations to electromagnetics (D. *et al.*, 2011) for which afterwards, they were then referred to as the EBG. The initial study of the PBG structures dates back to 1987 (John, 1987; Yablonovitch, 1987) but was restricted to optical frequencies and later became applicable for microwave and millimeter wave frequencies. DGS was recast to a paper in 1999, where the authors simplified the periodicity involved with an arrangement of metallic (Barlevy & Rahmat-Samii, 2001), dielectric (Özbay *et al.*, 1994) or metallodielectric (Contopanagos *et al.*, 1998; Yang & Rahmat-Samii, 2003), which was referred to as EBG to a structure with only a single unit cell without a period or repetition. That structure was referred by the researchers as PBG unit structure and in their subsequent article, the same structure was referred to DGS. Thus implying that the DGS is a simplified form of a printed EBG on a ground plane. DGS types can be distinguished by two classifications. These are the unit DGS structures and the periodic DGS structures. They are illustrated more in Figure 2. (D. *et al.*, 2011).

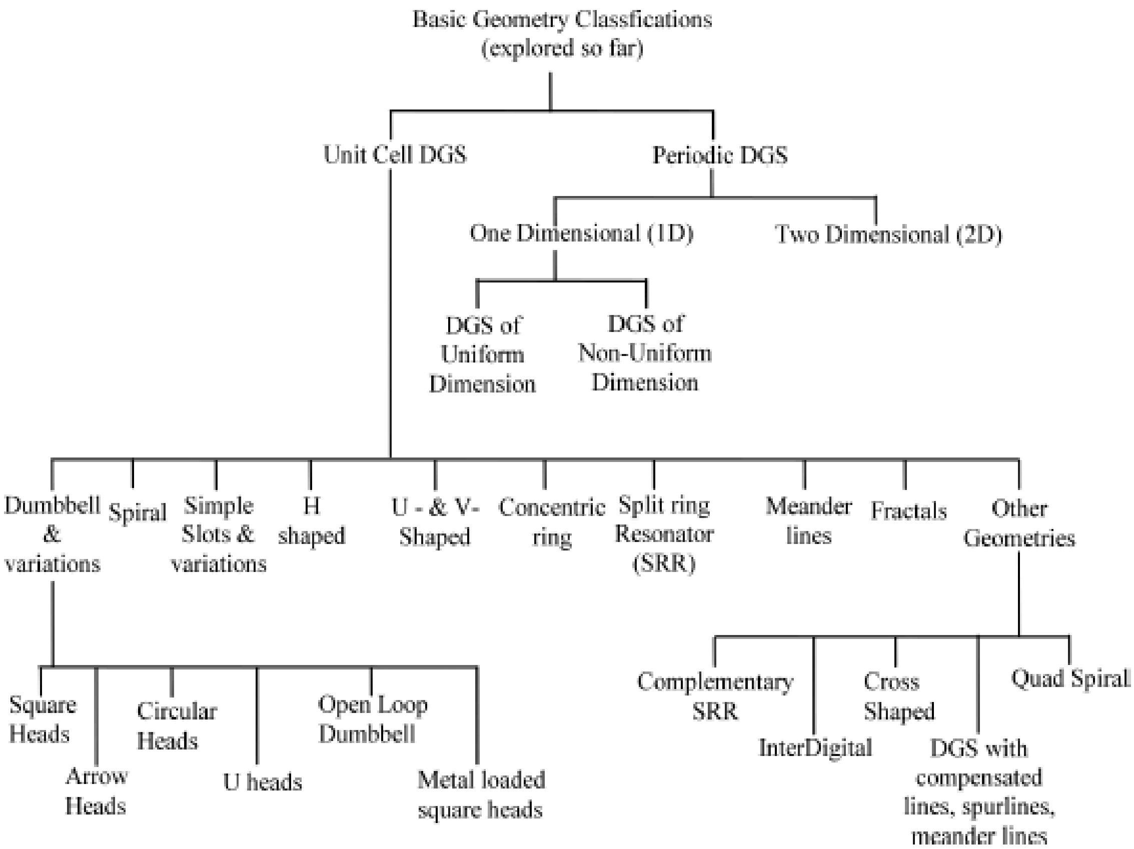


Figure 1: Basic Geometrical Classifications for DGS (D. *et al.*, 2011).

II. METHODOLOGY

In this section, the quasi lumped element resonator was designed based on the work of (Ain *et al.*, 2013). There is inclusion of circular dumbbell shaped defected ground structure on the ground plane of the antenna. The method taken to reach the design for the quasi lumped element resonator antenna is in two sections since there are two designs to be involved. This is as explained in sections 2.1 and 2.2 respectively.

2.1 DGS used with a Quasi Lumped Element Resonator Antenna

Quasi lumped element resonator antenna is a novel type of antenna introduced by Ain *et al.* (2013) for the purpose of doing the same functions of an antenna. The parameters used for computing the dimensions of the quasi lumped element resonator antenna as obtained from Ain *et al.*, (2013) are given in Table 2.1. The parameters are derived using Eqs (2.1)-(2.6). This is done by putting the equations together and finding the parameters that would result to a frequency of 5.8 GHz. This is because the antenna would be operating at 5.8 GHz. The circular head dumbbell shaped structures shown in Figure 3 was designed based on a periodic manner, and so each circular component has a diameter of 0.6 mm and a separation between the circles of length 0.6 mm, being dumbbell, each circle is connected by a rectangle of length 0.6 mm. The ground plane of the quasi lumped element resonator antenna was modified using 15 circular dumbbell DGS.

Table 1: Dimensions for the quasi lumped element resonator Antenna

Dimension of the antenna	Straight line inductor width	Inductor length (I_l)	Capacitor finger width (w_c)	Number of interdigital finger (N)	Distance between fingers (g_e)	Overlapping width of interdigital fingers (C_l)	Total antenn a size
Parameters (mm)	1.2	3.35	0.35	8	0.3	3.05	5.8 x 5.6

Figure 2, is the lay out of the quasi lumped element resonator antenna. the dimensions shown on this layout can be determined using Eqs, (2.1)-(2.8)

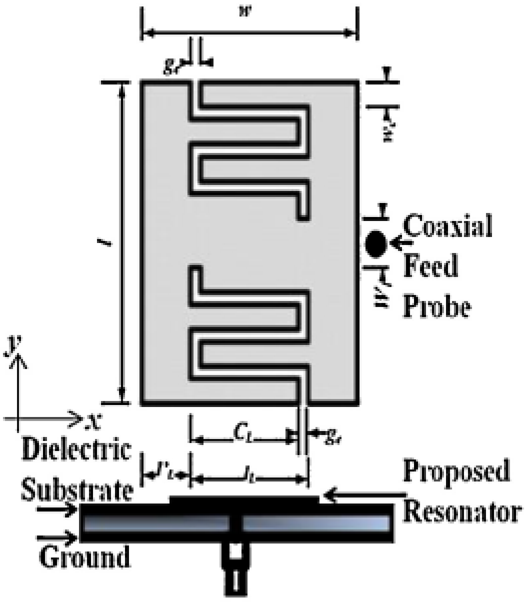


Figure 2: layout for the quasi lumped element resonator antenna in the x-y coordinates and y-z coordinates (Ain *et al.*, 2013)

The equation for determining the value of the inductance of the inductor is given in (Avenhaus, 1996) as:

$$L = 200*10^{-9}*I_L[\mathrm{In}(\frac{2I_L}{w_1+t})+(0.50049+\frac{w_1}{3I_L})] \quad (2.1)$$

where L is the inductance of the interdigital capacitor,

I_L is the inductor length,

W_1 is the inductor width,

t is the thickness of the resonator.

The capacitance of the interdigital capacitor can calculated using equation 2.2

$$C = \xi_0\left(\frac{\xi_r+1}{2}\right)[(N-\Delta)C_L \quad (2.2)$$

where C is the capacitance of the interdigital capacitor

ξ_0 is the permittivity of free spaced

ξ_r is the dielectric constant of the substrate

N is the number of fingers

Δ is the correction factor

C_L is the overlapping length of the interdigital capacitor fingers

The pad capacitance is calculated using equation 2.3

$$C_p = \left[\frac{2.85\xi_{eff}}{\mathrm{In}\left[1+(\frac{1}{2})(\frac{8h}{w_{eff}})\left[(\frac{8h}{w_{eff}})+\sqrt{(\frac{8h}{w_{eff}})^2+\pi^2}\right]\right]}\right]\times\left[\frac{l}{25.4*10^{-3}}\right] \quad (2.3)$$

where C_p is the pad capacitance

ξ_{eff} is the effective relative permittivity

h is the height of the substrate

w_{eff} is the effective corrected transmission line width

l is the pad length

The resonant frequency of the quasi lumped element resonator antenna is calculated using equation (2.4)

$$f = \frac{1}{2\pi\sqrt{L\left(\frac{C_{p1}C_{p2}}{C_{p1}+C_{p2}}+C\right)}} \quad (2.4)$$

where f is the resonant frequency of the antenna

L is the inductance of the inductor

C_{p1} is the pad capacitance

C is the capacitance of the interdigital capacitor

Parameters listed above that have not yet been included in the definition of terms in this work include w_{eff} and ξ_{eff} . They were stated as (Bogatin, 1988)

$$\xi_{eff} = \frac{e_r+1}{2}+\frac{e_r-1}{2}(1+\frac{10h}{w})^{-\frac{1}{2}} \quad (2.5)$$

$$w_{eff} = w + \left(\frac{4e}{\sqrt{\left(\frac{t}{h}\right)^2+\left(\frac{1}{\pi\left(\frac{w}{t}+1.10\right)}\right)^2}}\right) \quad (2.6)$$

where h, w, ξ_{eff} , w_{eff} and t mean the same things as explained above.

$L = (w_c+g_e)*N + (w_1-(2*g_e))$ (2.7)

while $w = 2*I'_L - I_L$ (2.8)

where g_e= space between fingers,

w_c = width of the conductors

w_1= width of the inductor

N = number of fingers

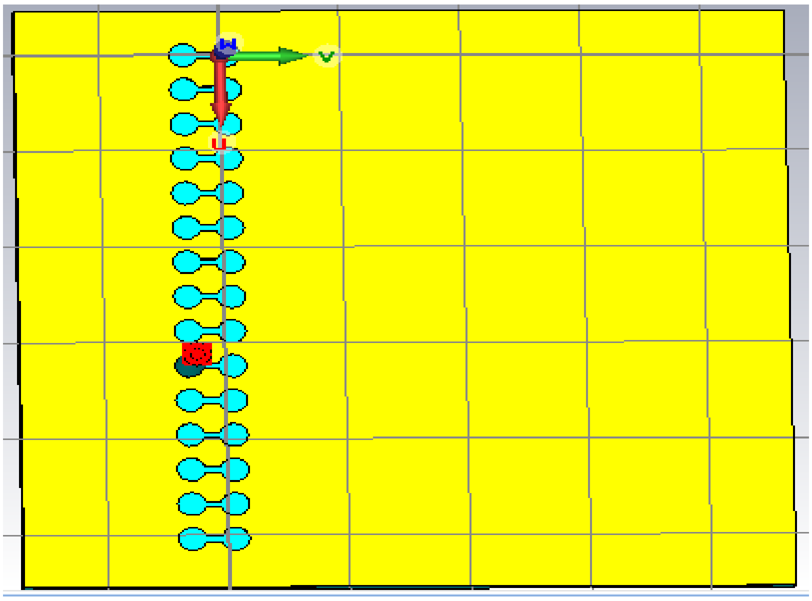
I'_L= pad width

2.2 Quasi lumped element resonator antenna without defected ground structure

For the quasi lumped element resonator antenna without defected ground structure, the dimensions of the quasi lumped element resonator antenna as shown in Figure 2.5 are derived using Eqs (2.1)- (2.8).

III. SIMULATION RESULTS AND DISCUSSION

Simulation of the antenna was carried out using CST Microwave studio 2015. The dimensions for the inductor length, the eight interdigital fingers, and other dimensions documented in Table 2.1 were used to design the antenna. Based on the dimensions for the circular head dumbbell defected ground structures, they were designed on the ground plane of the quasi lumped element resonator antenna. The dimension for the diameter of the circular dumbbell DGS was 0.6 mm and a separation between the circles of 0.6 mm, with a rectangle at the side of each circle of width 0.6 mm. It was observed that the ground plane for the antenna reduced in comparison to the original antenna.



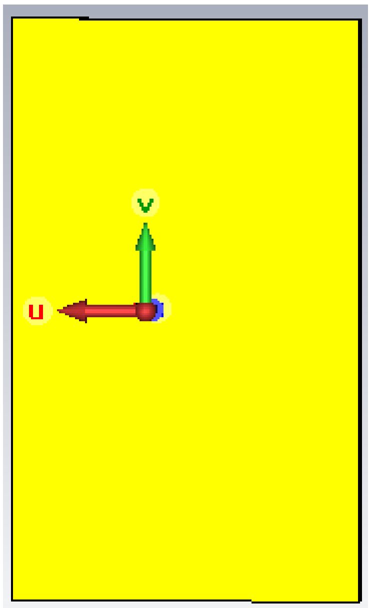


Figure 3: (a) ground plane for the quasi lumped element resonator antenna with circular head DGS and (b) ground plane of the quasi lumped element resonator antenna without DGS

The size of the ground plane became 1323.52 mm^2 when there was circular dumbbell defected ground structure on the antennas ground plane while it is 1365 mm^2 when there was no circular dumbbell defected ground structure on the ground plane of the antenna. This represents 3.04 % decrease in the size of the antenna. When the circular dumbbell shape was included with the design of the ground plane, the return loss and bandwidth and resonant frequency are shown in Figure 2.7. The antenna size when the antenna has circular head DGS and when it does not have DGS is documented in Table 2.3, with its corresponding resonant frequency, bandwidth and return loss.

Table 2: Shows ground plane size when circular head dumbbell DGS is integrated with the quasi lumped element resonator antenna and when it is not involved.

Parameter	with Circular head dumbbell DGS	Without Circular head dumbbell DGS
Resonant frequency (GHz)	5.8	5.8
Bandwidth (MHz)	564.5	370
Return loss (dB)	-31.361	-39.664
Antenna ground size (mm)	37.6 x35.2	65 x 21

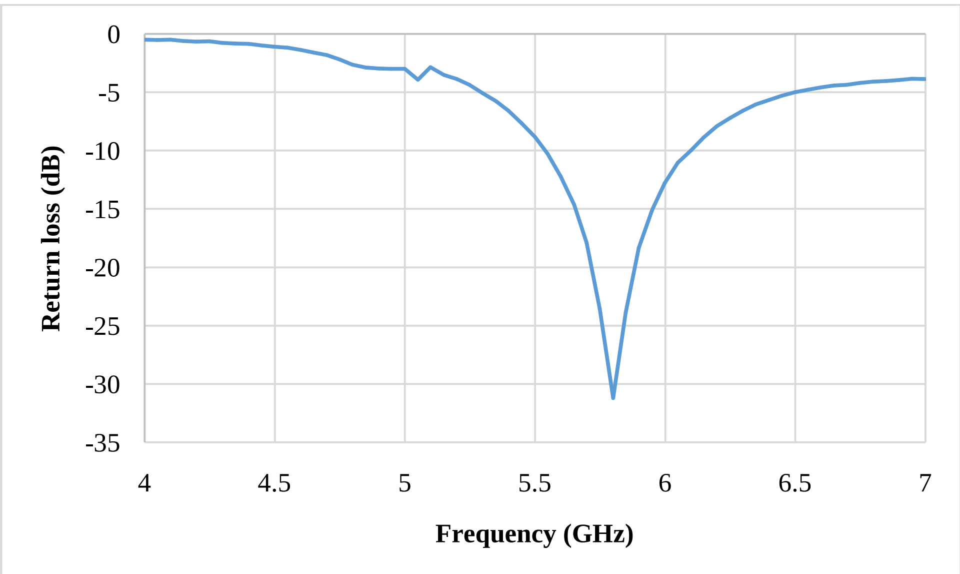


Figure 4: Quasi lumped Element resonator antenna with Circular Head DGS

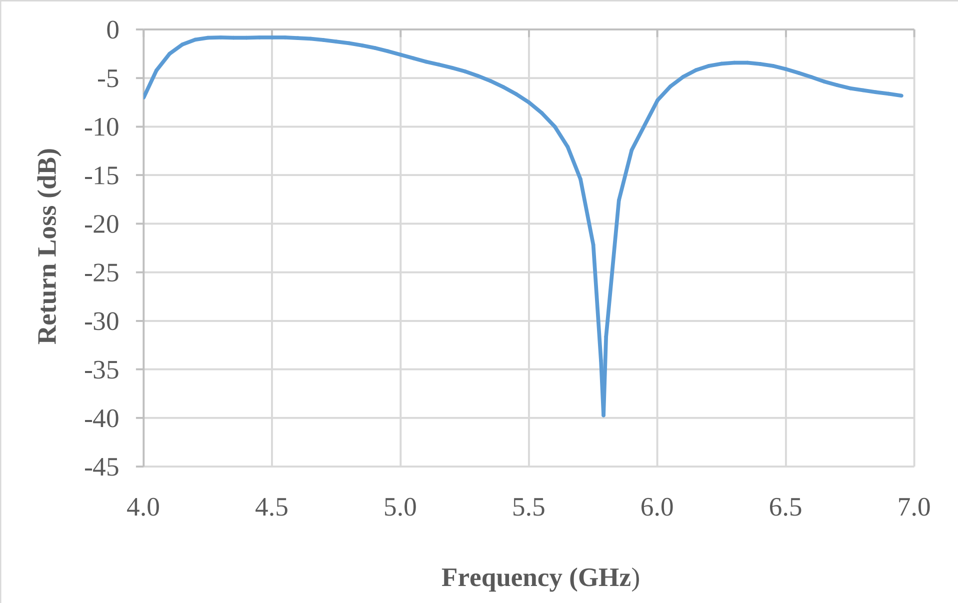


Figure 5: Quasi lumped Element resonator antenna without Circular dumbbell DGS

IV. CONCLUSION

In conclusion, it is noted that the defected ground structure can be used for improvement of bandwidth for a quasi lumped element resonator antenna and also a reduction in antenna size, since there is reduction in the ground plane of the antenna but with increase in power loss when the circular defected ground structure was used.

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T.M. Bello "Emergence of Defected Ground Structure and Its Effect on A Quasi Lumped Element Resonator Antenna”.” IOSR Journal of Engineering (IOSRJEN), vol. 08, no. 4, 2018, pp. 16-22.