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Novel Compact Spider Microstrip Antenna with New Defected Ground Structure

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ABSTRACT

Two novel Defected Ground Structures (DGS) were first proposed, which have better results than that of the dumbbell (published shape). Using the general model of DGS, its equivalent parameters were extracted. The two new proposed shapes of DGS were then used to design a novel compact spider microstrip antenna to minimize its area. The size of the developed antenna was reduced to about 90.5% of that of the conventional one. This antenna with two different novel shapes of DGS was designed and simulated by using the ready-made software package Zeland-IE3D. Finally, it was fabricated by using thin film and photolithographic technique and measured by using vector network analyzer. Good agreements were found between the simulated and measured results.

Keywords : DGS, Equivalent circuit model, Compact spider microstrip antenna

1 INTRODUCTION

The wireless communication services have been available, which use many frequency spectrum allocations, e.g., WIMAX (Worldwide Inter operability Microwave Access), BWA (Broadband Wireless Access) and WIFI (Wireless Fidelity). For these applications, microstrip antennas are preferred because of their advantages such as low profile, light weight and easy design with multi frequency bands. However, a common disadvantage of microstrip antennas is surface wave, which is excited whenever the substrate has dielectric permittivity ($\varepsilon_r > 1$) [1]. To suppress surface waves, several studies are conducted including defected ground structure (DGS). DGS is realized by etching the ground plane with a certain lattice shape which disturbs the current distribution of the antenna. Many shapes of DGS have been studied such as concentric ring [2], circle [3], spiral [4], dumbbells [5-8], elliptical [9] and U, V slots [10]. DGS gives an extra degree of freedom in microwave circuit design and can be used for a wide range of applications. Meanwhile, for antenna applications, DGS is mainly applied to the feeding technique. The concept of Defected Ground Structures (DGS) evolved in recent years primarily from the studies of Photonic Band Gap (PBG) structures in electromagnetics. DGS refers to some compact geometries known as a unit cell etched out as a single defect or in a periodic configuration with a small period number on the ground plane of a microwave printed circuit board. This configuration provides a feature of stopping wave propagation through the substrate over a frequency range [11].

2 DGS DESCRIPTION AND FREQUENCY CHARACTERISTICS

2.1 DGS Equivalent Circuit Model

A defected ground structure (DGS) for the microstrip line was proposed in [12]. The DGS unit structure can provide the bandgap characteristic in some frequency bands with only one or more unit lattices as shown in Fig.1. The equivalent-circuit parameters are extracted by using a simple circuit analysis method as shown in Fig.2. By employing the extracted parameters and circuit analysis theory, the bandgap effect for the provided defected ground unit structure can be explained. By using the derived extracted equivalent circuit model and parameters, the low-pass filter is designed and simulated.

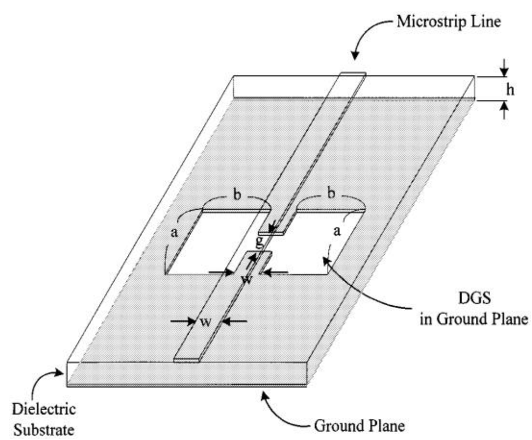


Fig. 1Three dimensional view of the DGS unit section, which is etched in the ground plane

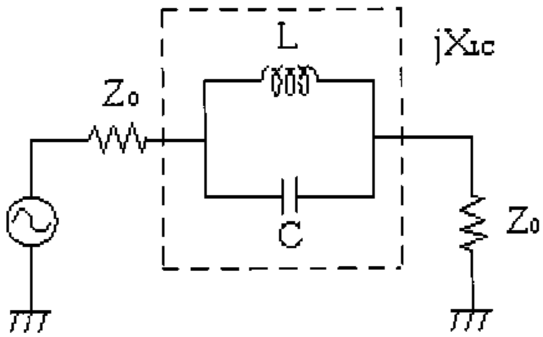


Fig. 2 Equivalent circuit of the DGS unit

2.2 Parameters Extraction

The parameters of the equivalent circuit can be obtained by using eqs. (1, 2) where f_0 is the attenuation pole location, f_c is the 3-dB cutoff frequency, Z_o is the characteristic impedance and g_1 is given by the prototype value of the Butterworth-type low pass filter. It is found that the values of the equivalent lumped element circuit model are 0.3397 pF, 9.86 nH respectively.

$$C = \frac{\omega_c}{Z_0\, g_1(\omega_0^2 - \omega_c^2)} \qquad (1)$$

$$L = \frac{1}{4\pi^2 f_0^{\,2}\, C} \qquad (2)$$

2.3 Design Specifications

The lattice dimensions of the dumbbell DGS unit section were a = b = 12mm and the gap distance g = 0.6mm by using FR-4 substrate material with thickness h=1.6mm, dielectric constant ε_r = 4.65 and tangent loss (tanδ= 0.02). The extracted equivalent circuit parameters for the dumbbell DGS unit section is illustrated in Table 1 and the simulating result is shown in Fig.3 respectively.

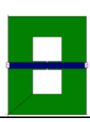
DGS	DGS area (mm^2)	Fo (GHz)	Fc (GHz)	C (pF)	L (nH)
	336	≈2.75	≈1.27	≈0.3397	≈9.86

Table 1 .Extracted equivalent circuit parameters for the DGS

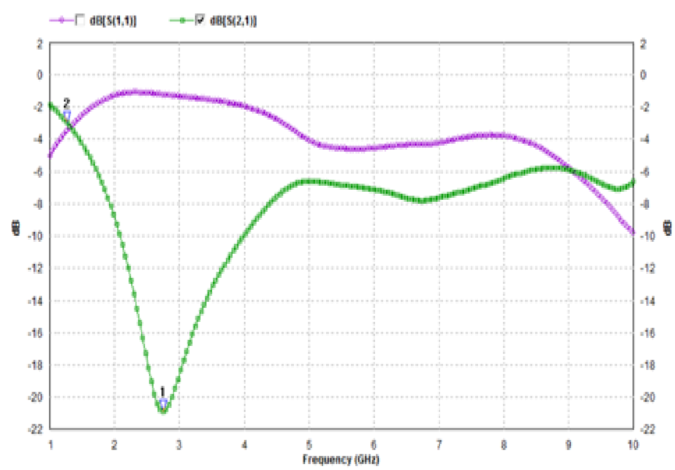
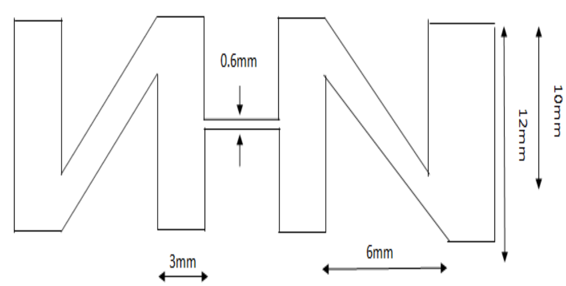


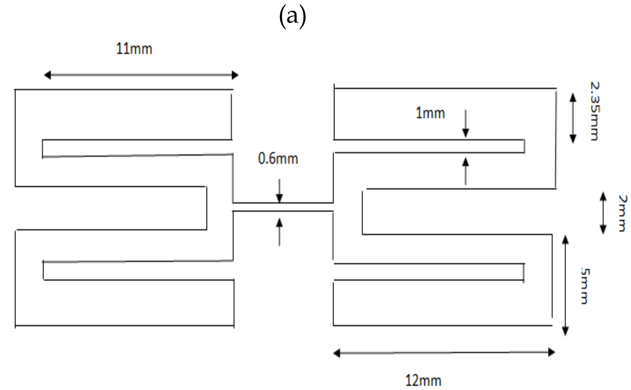
Fig. 3 Frequency response simulation of dumbbell-shape DGS

2.4 Novel DGS Shapes Description and Frequency Characteristics

We suggest two novel DGS (N-shape, Meander-shape) as shown in Fig. 4(a, b respectively) with total area $4\lambda_g$. Simulated frequency responses are shown in Fig. 5(a, b respectively).

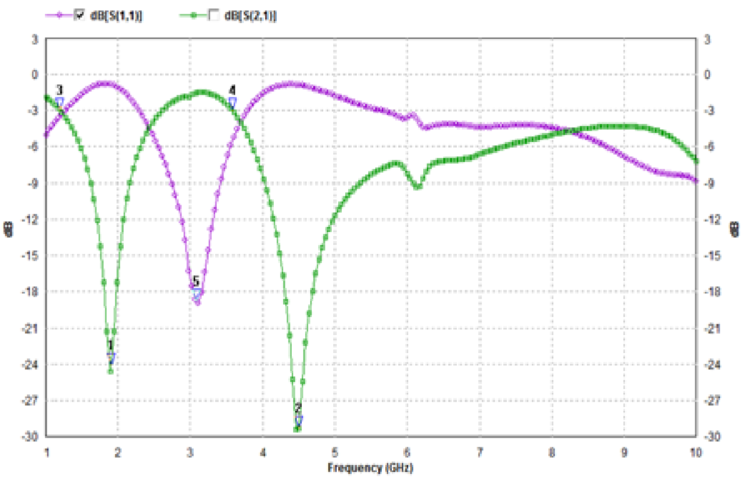


(a)

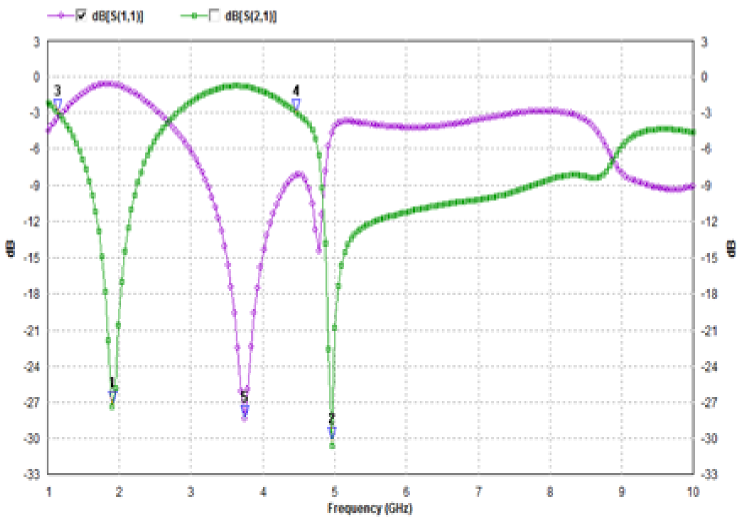


(b)

Fig. 4 Novel DGS shapes (a) N-shape DGS, (b) Meander-shape DGS



(a)



(b)

Fig. 5 Simulated frequency responses of novel DGS shapes (a) Frequency response of the N-shape DGS, (b) Frequency response of the Meander-shape DGS.

The comparison between the novel DGS shapes and the published dumbbell DGS for the same etched area in the ground plane of the microstrip transmission line and by using the same substrate material is shown in Table 2 and the simulated frequency responses are shown in Fig. 6. For the three shapes, it is found that the two novel DGS shapes provide a size reduction about 41% compared to the published dumbbell shape for the same attenuation pole location (Fo = 2.75 GHz).

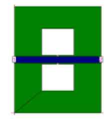
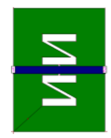
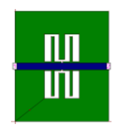
DGS shape	DGS photograph	Fo (GHz)	Fc (GHz)
Dumbbell		≈2.75	≈1.27
N-shape		≈1.9	≈1.2
Meander		≈1.91	≈1.14

Table 2 .Comparison between the two novel DGS and the published dumbbell

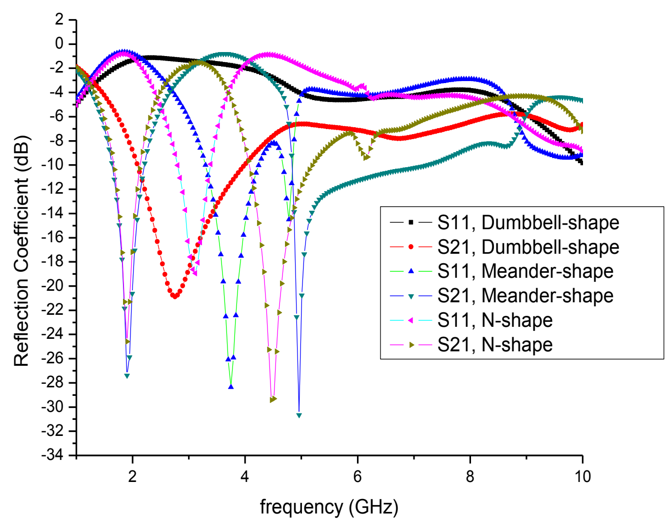


Fig.6 Frequency responses of the two novel DGS and the published dumbbell shapes

2.5 Circuit Model for the Proposed DGS Shapes

It is found that as shown in Fig.5, our novel DGS shapes have multi-stopband in frequencies so we use a general equivalent circuit model for DGS including multi-stopband in frequencies [13]. The proposed circuit model is shown in Fig.7 which consider the first and second resonance modes where f_{01} and f_{02} are the first and second resonant frequencies respectively, and f_T denotes the a transit frequency. Thus, a unit cell DGS, either in microstrip or CPW, is modeled by the two LC resonators, i.e., $L_1$and C_1, $L_2$and C_2, in connection with a T-network consists of C_p, LS_1, and LS_2. The T-network is essential here to represent the interaction between the two resonators. Below the transit frequency f_T the first resonator dominates the frequency characteristics, whereas the second resonator is dominant for the frequency above f_T.

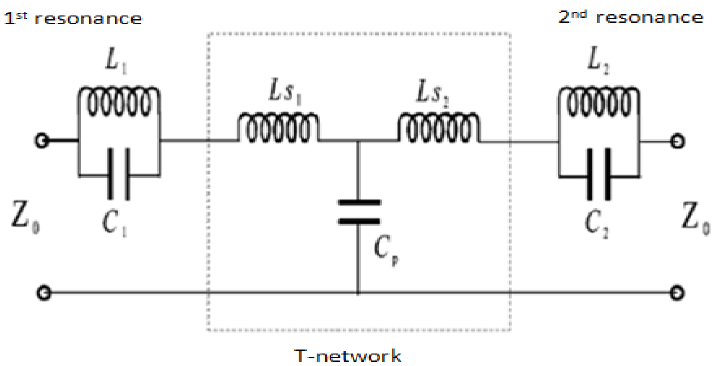


Fig.7 General equivalent circuit model of DGS

The parameters of the equivalent circuit for novel DGS shapes (N-shape, Meander shape) are calculated by using eqs. (3, 4) and parameters extraction values are shown in Table 3. Where f_{01} = 1.9GHz, f_{02} = 4.5GHz, f_T=3.1GHz (for N-shape DGS) and f_{01} =1.91GHz, f_{02} =5 GHz, f_T = 3.74GHz (for Meander-shape DGS).

$$C_i = \frac{1}{Z_0}\frac{1}{4\pi\Delta f_{3dB\_i}}, \qquad L_i = \frac{1}{(2\pi f_{0i})^2\, C_i} \qquad \text{For } i = 1,2 \qquad (3)$$

$$C_p = -\frac{1}{2\pi f_T X_{21}}, \quad L_{s_i} = \frac{X_{ii} - X_{21}}{2\pi f_T} + \frac{L_i}{\left(\frac{f_T}{F_{0i}}\right)^2 - 1} \qquad \text{For } i=1,2 \qquad (4)$$

Parameters extraction	N-shape DGS	Meander-shape DGS
C_1 (pF)	1.33	1.4
C_2 (pF)	0.44	0.35
L_1 (nH)	5.3	5
L_2 (nH)	2.84	2.9
Ls_1 (nH)	-1.6	0.062
C_P (pF)	-0.88	-0.83
Ls_2 (nH)	-10	-8.3

Table 3 .Parameters extraction for the novel DGS shapes

3 A Novel Compact spider Microstrip Antenna with Two Novel DGS

3.1 Compact Spider Microstrip Antenna Design

The proposed compact spider microstrip antenna is designed, simulated by using the ready-made software package Zeland-IE3D to resonate at 4G by using FR-4 substrate with the following parameters; dielectric constant (ε_r =4.65), thickness (h=1.6mm), dielectric loss tangent (tanδ=0.02). The compact spider microstrip antenna has a total area of 8.36λ_g and shown in Fig.8. The simulation of the compact spider microstrip antenna is shown in Fig. 9.

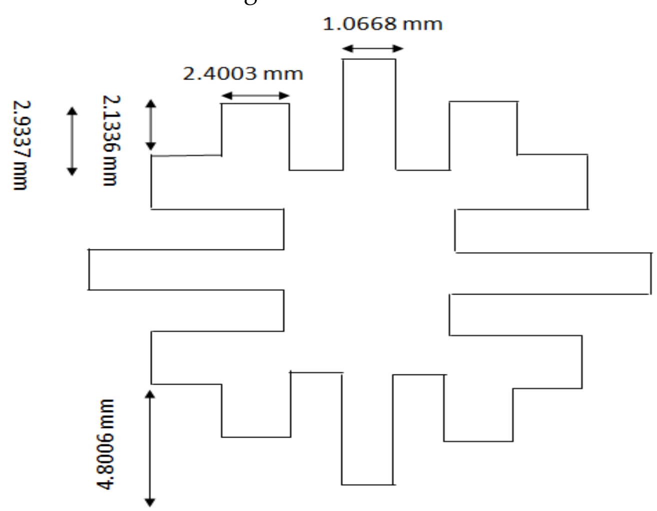


Fig.8 Novel compact spider microstrip antenna

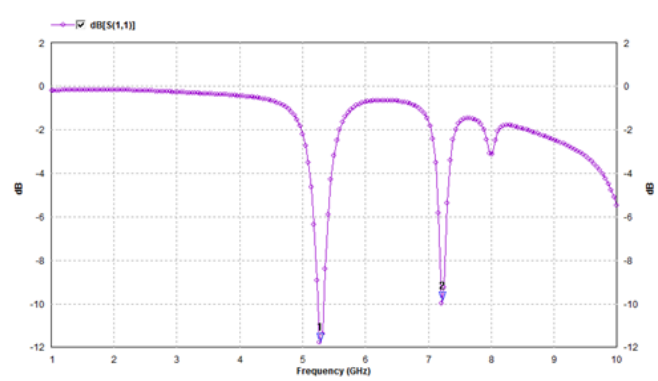
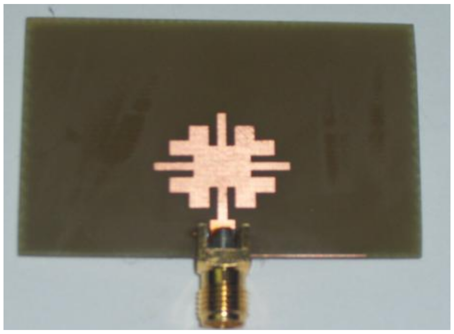


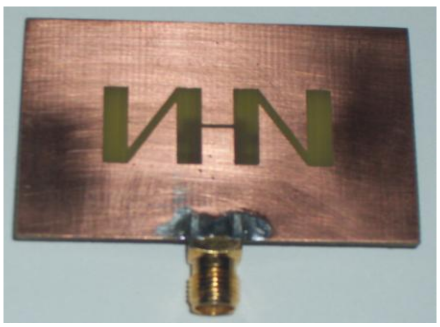
Fig.9 Simulation result of reflection coefficent (S_{11}) against resonance Frequency

3.2 Fabricated novel compact spider microstrip antenna with the two new DGS

We apply the two novel DGS shapes in the ground plane of the fabricated novel compact spider microstrip antenna in order to reduce its size as shown in Fig.10



(a) Top view

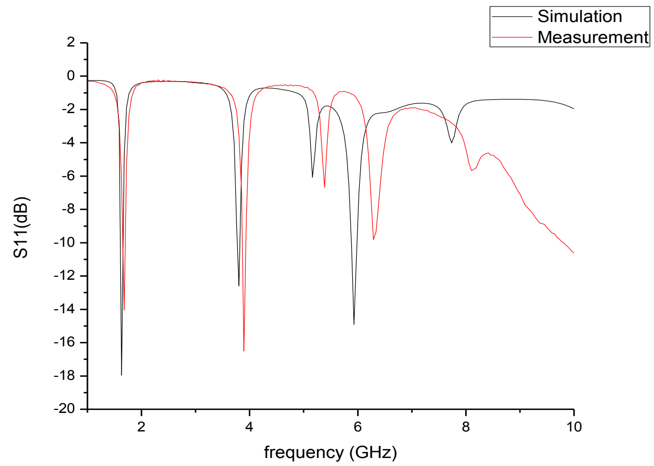


(b) Bottom view with N-DGS shape

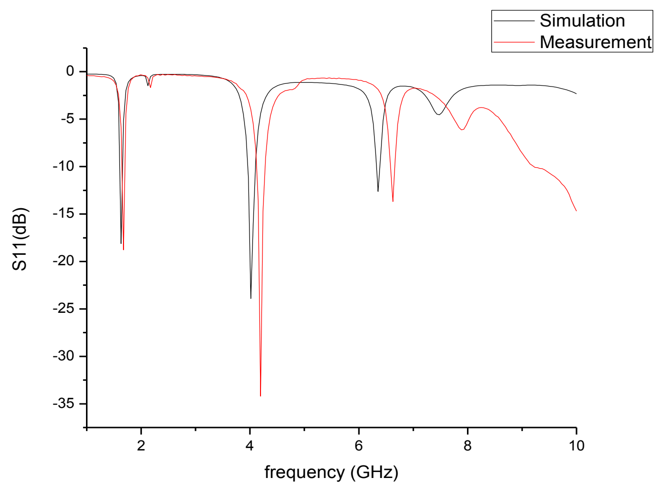
(c) Bottom view with Meander-DGS shape

Fig.10 Fabricated novel compact spider microstrip antenna with the two new DGS

The simulation and measurement results of the compact spider microstrip antenna with the N, Meander-DGS shapes are shown in Fig.11 (a, b respectively). Good agreements were found between the simulated and measurement results.



(a)



(b)

Fig.11 Simulation and measurement results of the novel compact spider microstrip antenna with (a) N-shape DGS, (b) Meander-shape DGS

4 Conclusion

In this paper, we firstly introduced two different new shapes of DGS which described their equivalent circuit model and parameters extraction. The two novel DGS shapes achieve a size reduction about 41% compared to the published dumbbell shape for the same attenuation pole location (Fo) and provide two sharp stopband frequencies which are useful in the filter applications. Then we applied the new DGS shapes to minimize the size of a novel compact microstrip antenna to about 9 times compared to the conventional microstrip patch antenna resulting in a resonant frequency of 1.63 GHz. Secondly, we obtained negative values of equivalent circuit DGS lumped elements, represented by equivalent inductors and capacitors, which result in negative values for permittivity (ε) and permeability (μ). In other words, development of a new technology that produces new materials which do not reflect the microwave frequencies (Meta Materials).

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