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Research Article

Application of Defected Ground Structure to Suppress Out-of-Band Harmonics for WLAN Microstrip Antenna

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An application of defected ground structure (DGS) to reduce out-of-band harmonics has been presented. A compact, proximity feed fractal slotted microstrip antenna for wireless local area network (WLAN) applications has been designed. The proposed 3rd iteration reduces antenna size by 43% as compared to rectangular conventional antenna and by introducing H shape DGS, the size of an antenna is further reduced by 3%. The DGS introduces stop band characteristics and suppresses higher harmonics, which are out of the band generated by 1st, 2nd, and 3rd iterations. H shape DGS is etched below the 50 Ω feed line and transmission coefficient parameters (S_{21}) are obtained by CST Microwave Studio software. The values of equivalent L and C model have been extracted using a trial version of the diplexer filter design software. The stop band characteristic of the equivalent LC model also has been simulated by the Advance Digital System software, which gives almost the same response as compared to the simulation of CST Microwave Studio V. 12. The proposed antenna operates from 2.4 GHz to 2.49 GHz, which covers WLAN band and has a gain of 4.46 dB at 2.45 GHz resonance frequency.

1. Introduction

Printed antennas have been widely used because of their advantages like low profile, easy fabrication, low cost, small size, and so forth [1, 2]. To reduce the size of the antenna without much more adverse effect on bandwidth and the gain of an antenna, various methods have been proposed like using dielectric substrates with high permittivity [3], applying magneto inductive waveguide loading [4], and using notches or slots on patch antenna [5]. By embedding specific slot (fractal slot) on microstrip antenna, surface current path increases, which lowers the resonant frequency of an antenna, and thus antenna size reduction can be possible [6]. To improve radiation efficiency of the antenna, it becomes necessary to suppress higher harmonics, which cause loss of power. Higher harmonics also produce spurious radiation. To suppress higher harmonics, various techniques like PBG (photonic band gap structure) [7–10], Filter, and EBG (electromagnetic band gap structure) [11, 12] have been proposed. The conducting metal etched off in specific shape from the ground plane provides wide rejection band covering some frequency range [13–17]. The structure of this type is known as *defected ground structure* (DGS). The main advantages of DGS is that it introduces slow wave effect. This effect produced because of the DGS equivalent L and C components. The transmission line witH-DGS gives a higher effective impedance and also introduces high slow wave effect, which provides rejection band in some frequency range. The microstrip line witH-DGS has a large electrical length as compared to conventional microstrip for the same physical length. Thus, DGS helps to lower resonance frequency and therefore to reduce the size of an antenna [18].

In this paper, an application of the DGS to suppress higher harmonics and thus to improve radiation efficiency of the planar antenna is demonstrated. Moreover, this paper also shows the significant role of the fractal geometry for size miniaturization of the radiating element of the patch antenna.

2. Antenna Geometry and Operational Mechanism

The geometry of the proximity coupled patch antenna is presented in Figure 1. The argon material, which has a relative

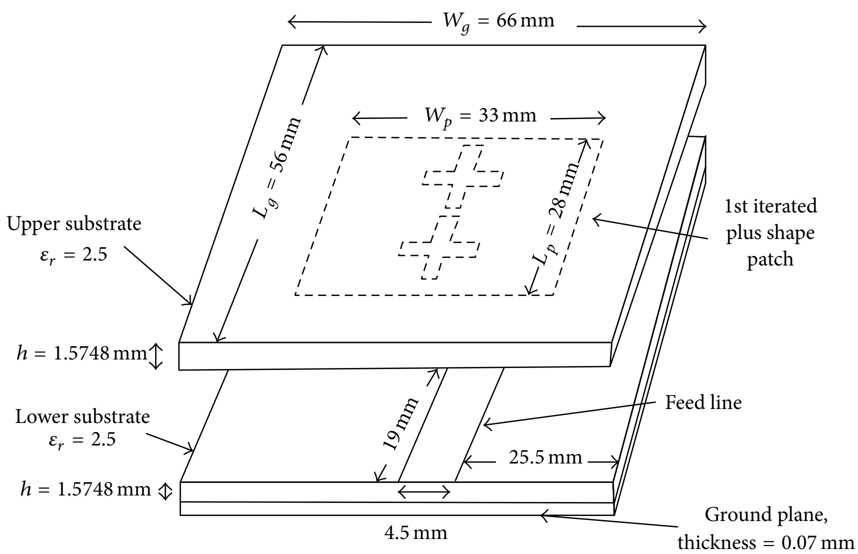

Figure 1: Geometry of proximity coupled plus shape fractal slot antenna.

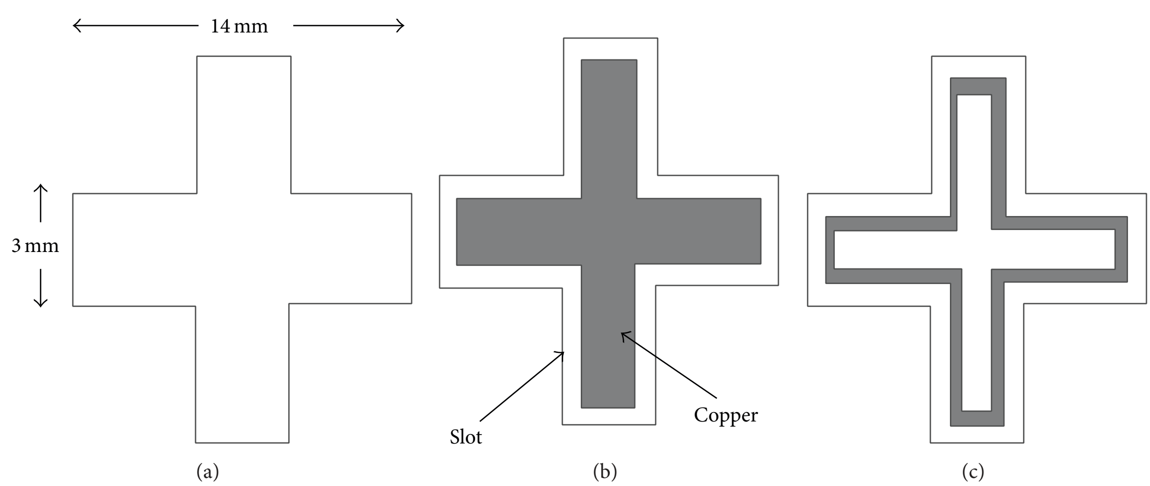

Figure 2: Geometry of plus shape fractal slot: (a) 1st iteration (b) 2nd iteration, (c) 3rd iteration.

permittivity $\varepsilon_r = 2.5$, thickness 1.5748 mm, and loss tangent 0.0025, is used for both substrates. Low dielectric constant material has been selected to get good radiation efficiency. The ground plane dimensions are $W_g \times L_g = 66 \times 56\,\text{mm}^2$. The microstrip line with 50 Ω impedance, width $W_f = 4.5\,\text{mm}$, and length $L_f = 19\,\text{mm}$ is fabricated on upper side of the lower substrate and H shape DGS is etched out from the lower side (ground plane) of lower substrate. The number of DGS shapes such as hook shape [19], arc shape [20], concentric ring shape [21], and spiral shape [22] was reported. The reason of selection of H shape DGS is that, as per parametric simulation, it was concluded that the effect of changing of length arm of H shape DGS (L_1), width of arm (L_2), distance between the two arms (C_1), and so forth on cut-off frequency of DGS is almost linear. So it is easy to get specific bandstop region by selecting appropriate dimensions of H shape. The rectangular patch with size $W_p \times L_p = 33 \times 26\,\text{mm}^2$ is fabricated on upper side of upper substrate. From that patch, plus shape slot is taken out. This procedure is repeated for next two iterations as shown in Figure 2. Figure 3 shows inner dimensions of the plus shape slot. H shape DGS is created in the ground plane of the antenna. The dimensions and location of H shaped DGS are mentioned in Figure 4.

3. Behavior of DGS as Band Stop Filter

Initially, H-DGS is considered below the 50 Ω microstrip line as shown in Figure 5. The microstrip line has a width of 4.5 mm considered from the calculation obtained by CST Microwave Studio, V. 12. The DGS cell is simulated by the same software and from S_{21} parameters, it was concluded that H-DGS has characteristics of a one-pole band stop filter. For getting the desired value of upper edge and lower edge of band stop frequencies, specific dimension of H-DGS was varied by keeping other dimensions constant. The effect of H-DGS dimensions on upper edge and lower edge band stop

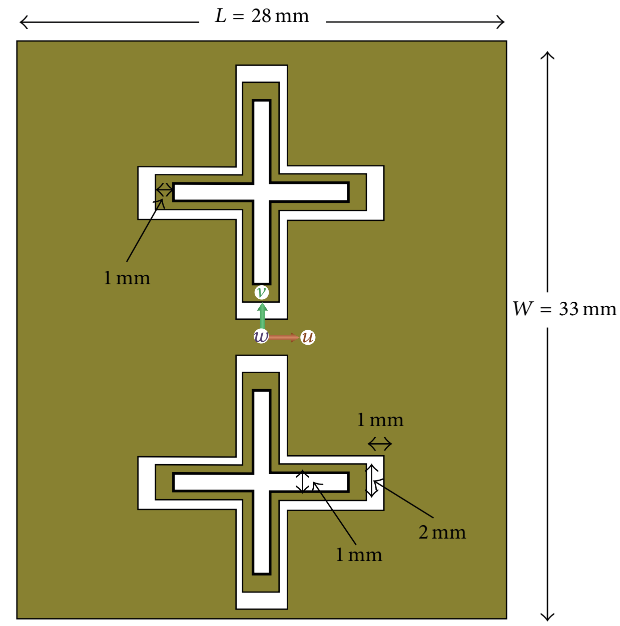

Figure 3: Design geometry of 3rd iterated plus shape patch.

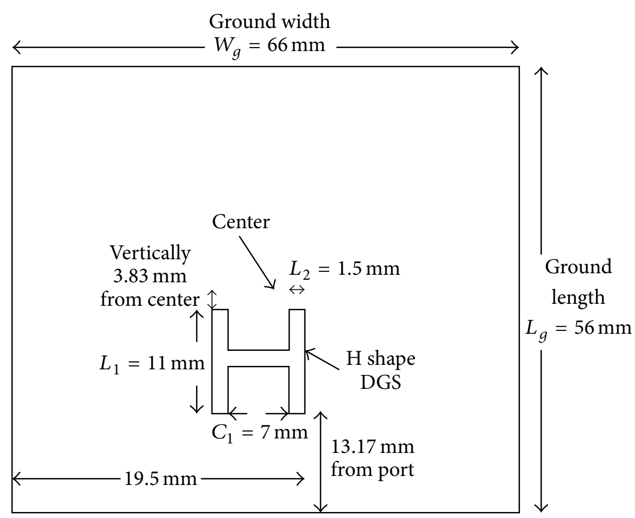

Figure 4: Design geometry of DGS on the ground plane of the proposed antenna.

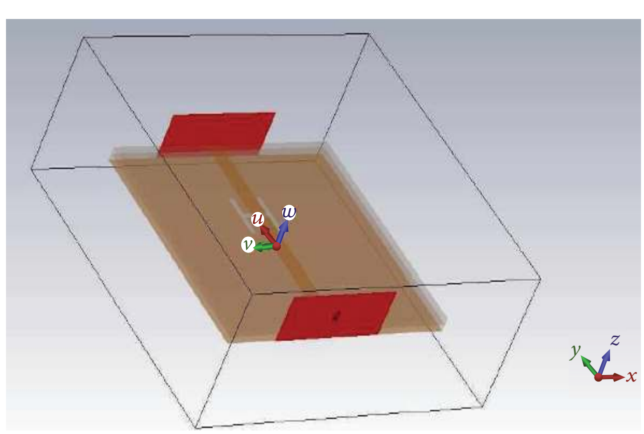

Figure 5: Setup of H-DGS under 50 Ω strip line in CST Microwave Studio to extract S_{21} parameters.

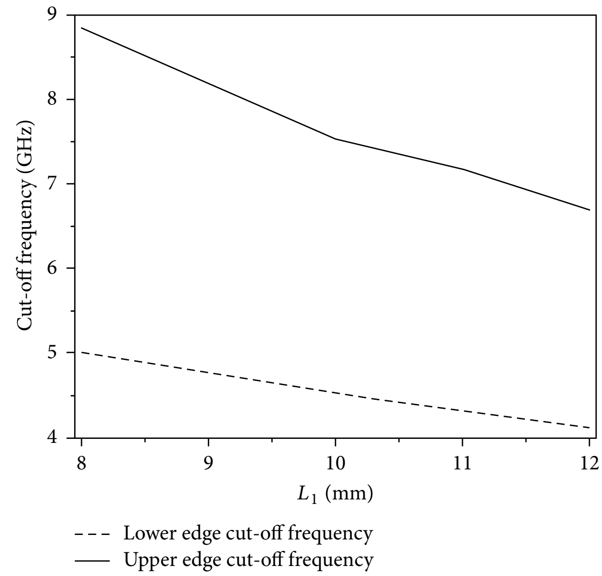

FIGURE 6: Effect of variation of L_1 on cut-off frequency of DGS as band stop filter.

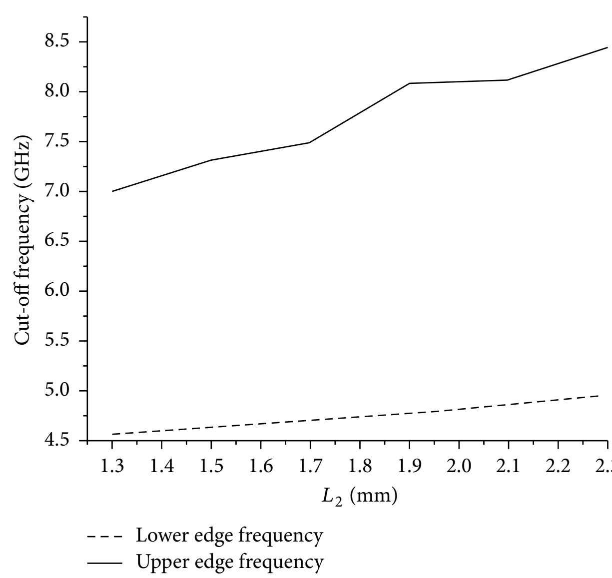

FIGURE 7: Effect of variation of L_2 on cut-off frequency of DGS as band stop filter.

frequencies is shown in Figures 6, 7, and 8. These figures show that as the arm length (L_1) of DGS and the gap (C_1) between two arms increase, frequency of upper edge and lower edge decreases and as thickness of both arms (L_2) increases, frequency of upper edge and lower edge increases. For getting the desired value of stop band frequencies, dimensions of H-DGS (L_1, L_2, and C_1) have been optimized by CST Microwave Studio software and $L_1 = 11$ mm, $L_2 = 1.5$ mm, and $C_1 = 5$ mm have been considered for upper edge 4.62 GHz and lower edge 7.19 GHz frequency. For desired band stop characteristics, the values of the LC equivalent model have been extracted by diplexer filter software.

The LC equivalent model of DGS has been shown in Figure 9. The equivalent LC model of DGS has been simulated by Advance Digital System (ADS) software and its S_{21} response has been compared with that of CST Microwave Studio, as shown in Figure 10. Even though there is a difference between the attenuation level at attenuation pole frequency, the 3 dB bandstop frequency is almost same for ADS and CST Microwave simulation. The reason of mismatch result of attenuation level is that ADS simulate with consideration of infinite ground plane, while in CST Microwave Studio finite ground plane has been considered.

4. Results and Discussion

The geometry of the proposed microstrip antenna has been optimized and simulated with CST Microwave Studio. Figure 11 shows the simulated return losses of the

Table 1: Comparison of conversional rectangular patch antenna with various fractal slot iterations of antenna.

Iteration	Resonating frequency (GHz)	Number of higher harmonics	Return loss (dB)	VSWR	Gain (dB)	Radiation efficiency (%)	Bandwidth of fundamental resonance frequency (%)	higher harmonics	Bandwidth of 2nd harmonics (%)	Patch size (mm^2)	Size reduction (%)
0	2.42	1	−12.53	1.61	6.3	67.6	2.46	2.90	—	1725	—
1st	2.43	2	−13.44	1.54	3.3	55.4	3.27	2.64	5.08	983.25	43
2nd	2.42	2	−22	1.17	3.8	51.2	3.30	9.19	4.34	983.25	43
3rd	2.42	2	−27	1.2	4.16	51.5	3.27	2.29	4.93	983.25	43
3rd with H-DGS	2.45	0	−23.26	1.14	4.46	63.8	3.68	—	—	932	46

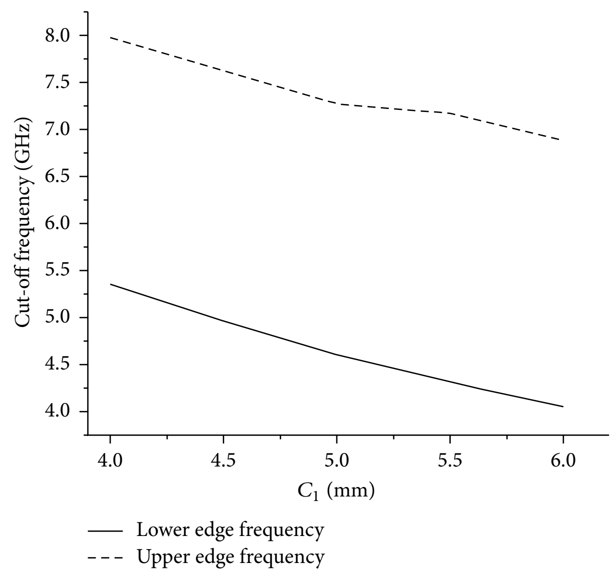

Figure 8: Effect of variation of C_1 on cut-off frequency of DGS as band stop filter.

conventional antenna and all iteration antennas. It can be observed that, besides fundamental mode, the conventional rectangular antenna gives higher harmonics, which are not useful. Here, to reduce the size of the radiating element, slot technique is used. In simulation, by taking different slots, we found that plus shape slot gives the maximum size reduction factor and also does not have any adverse effect on the desired characteristics of the patch antenna. To increase the gain of the antenna, the space of the plus shape slot used with an innovative method and copper layer is etched in the space of the slot. To further increment in the gain, again the same method is repeated (2nd iteration). Table 1 shows that 1st, 2nd, and 3rd iterations reduce the size of the conventional antenna by 43%. By etching H-DGS at the ground plane, the size of fractal slot antenna further reduced by 3% and the bandwidth is enhanced from 2.46% to 3.68%. Table 1 shows that as iterations increase from 1st to 3rd, the gain of the antenna at resonance frequency increases. This is according to babinet's principle [2], which states that each slot acts as a radiator and gives contribution in gain of the antenna.

Table 1 shows that, after 1st iteration, if one more iteration is introduced, that is, in 2nd iteration antenna, VSWR improves due to matching and thus radiation loss also improves. The gain of the 2nd iteration antenna also increases according to babinet's principle, but radiation efficiency decreases due to increment in the bandwidth of 1st harmonics. Similarly, 3rd iteration antenna gives more gain at a fundamental resonance frequency as compared to 2nd iteration antenna. The 3rd iteration antenna has two higher harmonics, by introducing H-DGS at the ground plane, the size of an antenna further reduced by 3% as compared to 3rd iterated antenna without DGS, and due to the reduction of the size of an antenna, the 2nd harmonics are suppressed by about 14.75 dB. The 1st harmonics generated in 3rd iterated antenna are suppressed by about 6.89 dB as shown in Figure 12. This suppression occurred due to band stop characteristics of H-DGS. Due to suppression of higher harmonics by H-DGS, the power wastage reduced and thus radiation efficiency increased as compared to 1st, 2nd, and 3rd iteration antennas without DGS, as shown in Table 1.

Figure 13 shows simulated current distribution on plus shaped slot, which shows that most of the current density concentrates on the joints and edges. Figure 14 plots measured and simulated H-plane and E-plane radiation patterns of the 3rd iteration plus the slot antenna witH-DGS at 2.42 GHz resonance frequency.

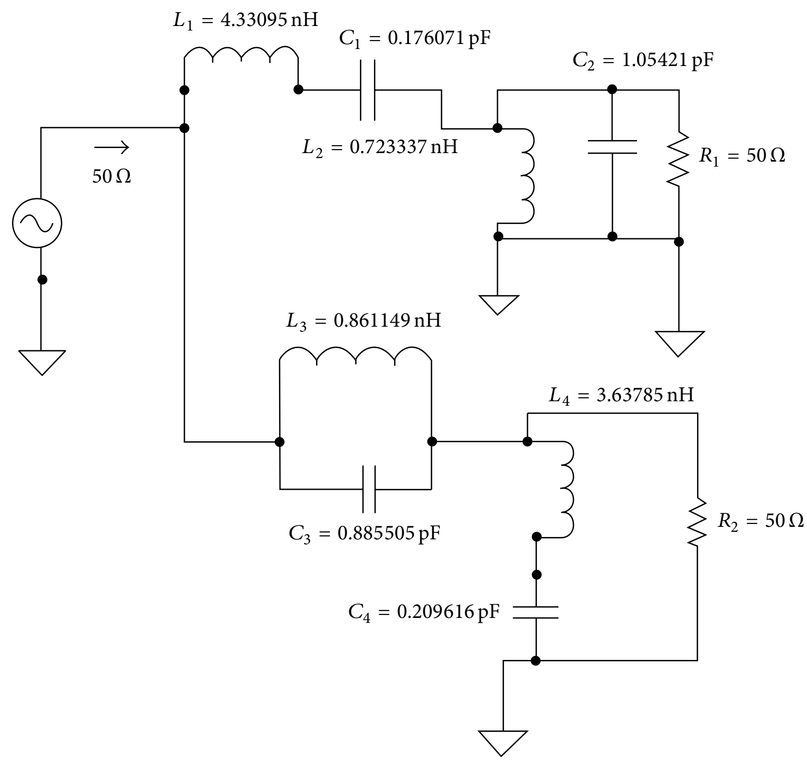

Figure 9: Equivalent *LC* model of H shape DGS.

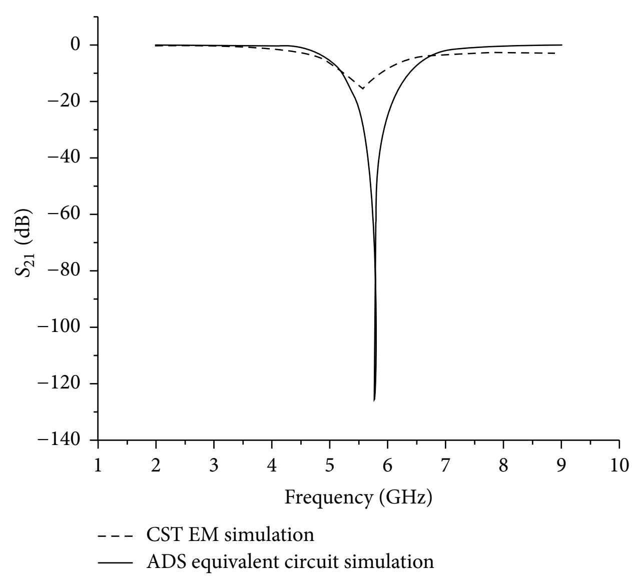

Figure 10: S_{21} parameter of *LC* equivalent model compared with that of H-DGS.

5. Conclusion

To obtain an impedance matching, high radiation efficiency, higher harmonic suppression, and the size reduction, a novel type of 3rd iteration plus shape fractal slot antenna has been proposed. By introducing fractal slots, VSWR improves and the size of an antenna reduces, but it also generates higher harmonics. To suppress higher harmonics, H shape DGS and its equivalent circuit have been proposed. The parameter extraction method for the proposed H-DGS has also been explained. Furthermore, by employing the extracted parameters, the band stop characteristics of H-DGS are explained, which suppressed higher harmonics. The radiated power of the proposed antenna in 1st and 2nd harmonic frequency is

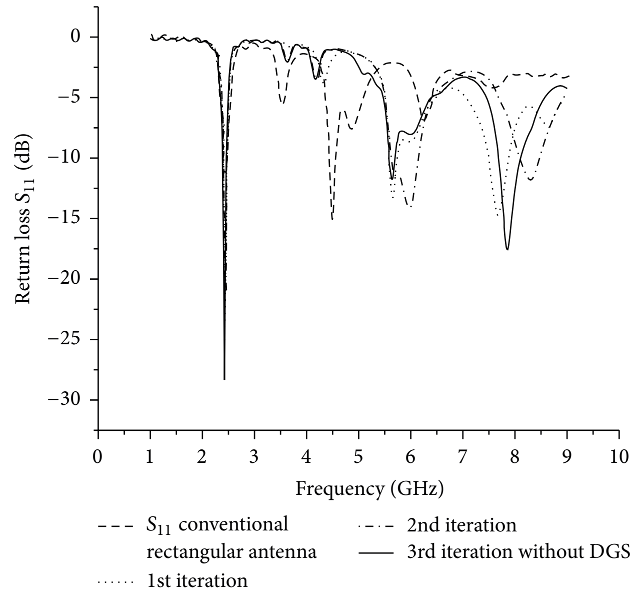

FIGURE 11: Simulated return losses S_{11} of conventional rectangular antenna and 1st to 3rd iterated plus fractal slot antennas.

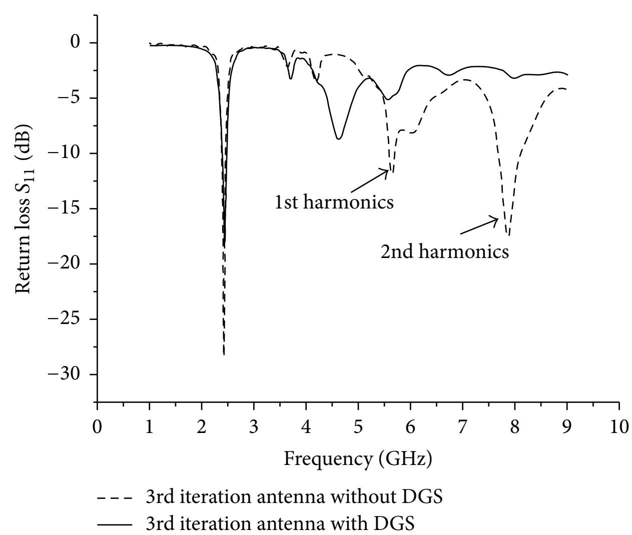

FIGURE 12: Comparison of return loss of 3rd iterated antenna with and without DGS.

FIGURE 13: Current distribution in 3rd iteration fractal slot antenna witH-DGS.

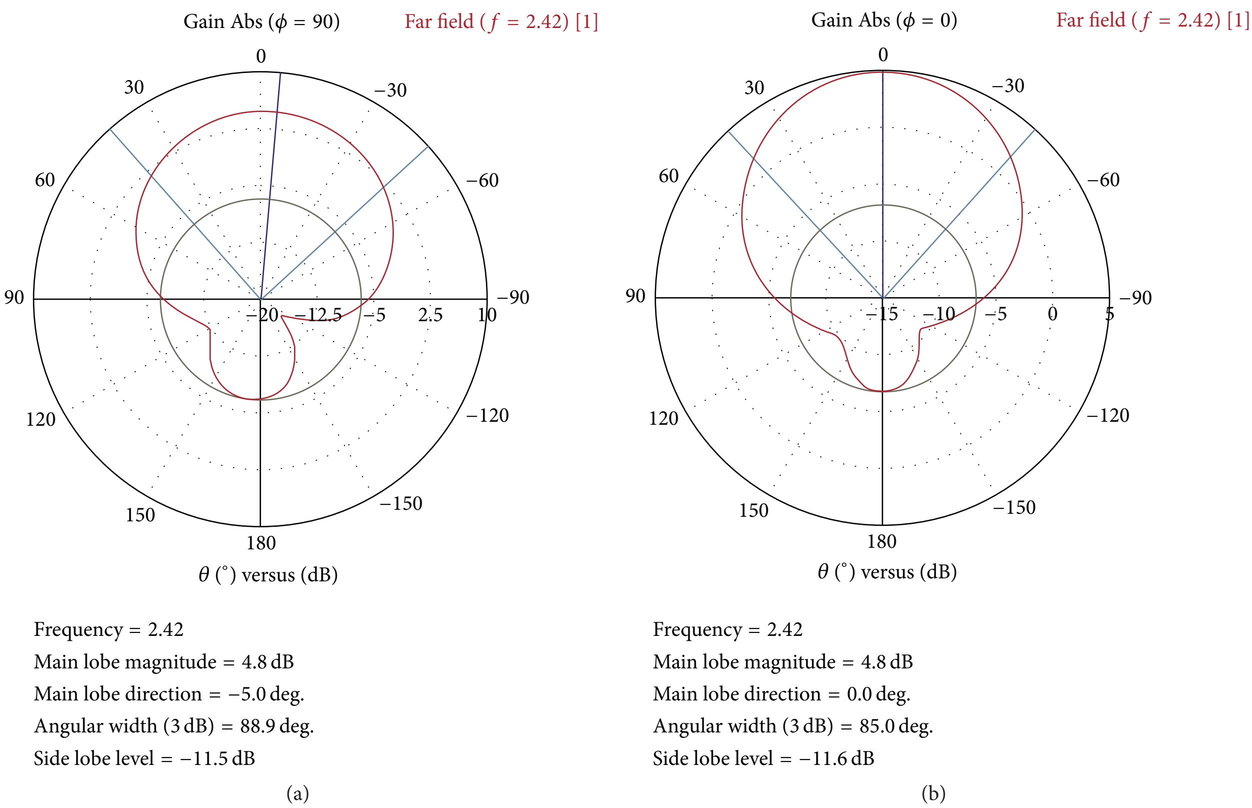

Figure 14: Simulated radiation pattern of 3rd iteration fractal slot antenna witH-DGS: (a) E-plane, (b) H-plane.

very low. The proposed DGS unit and its equivalent circuit could also find applications like microwave filter, coupler, power divider, and so forth.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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