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Planar Array-Antenna with Improved Radiation Characteristic Using Spiral Shaped DGS

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***Abstract*—In this paper, the improvement of radiation characteristic for planar array-antenna by incorporating spiral shaped defected-ground-structure (DGS) is presented. The proposed planar array-antenna which is designed to work at the frequency of 2.4GHz consists of 4×4 elements in which the inset feed method is employed to excite each antenna element. The planar array-antenna is implemented using a 1.6 mm thick FR4 epoxy dielectric substrate and analyzed through a simulation. The simulated result of radiation characteristics for the planar array-antenna is then validated by experimental characterization. It shows that the spiral shaped DGS incorporation yields measured radiation characteristics of the planar array-antenna to have the bandwidth response of 140 MHz and the gain achievement of 10.47 dB at its resonant frequency. This is comparable to the simulated result which is showing the potentiality of spiral shaped DGS usage in the improvement of radiation characteristics.**

***Index Terms*—Defected-ground-structure (DGS), inset feed, planar array-antenna, radiation characteristic, spiral shape.**

I. Introduction

During the last decade, many devices for wireless communications employ planar array-antennas as their front-end part including for application of multiple input multiple output (MIMO) system [1]. Usually a planar array-antenna is implemented by use of microstrip technology in consequence of its inheritance merits such as low profile, easy fabrication, and light weight [2]. Unfortunately, the use of microstrip technology particularly for MIMO antenna system is often unsatisfactorily due to the issue of surface wave that appears in the area of near field when the patch of microstrip antenna radiates. Hence, the radiation characteristics of antenna which is designed based on the technology of microstrip including directivity, efficiency and bandwidth can deteriorate.

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Another issue in the area of near field is the coupling which occurs between antenna elements when the elements of antenna are configured in an array [3]. Many researches emphasizing on the coupling suppression between adjacent elements in planar array-antenna, one of them is by incorporating defected ground structure (DGS) at the groundplane [4]–[8]. By suppressing the coupling between adjacent elements particularly for the planar array antenna, the radiation characteristics could be significantly improved. However, the issue of coupling in the area of near field is not more dominant compared to the surface wave issue if the antenna elements of planar array-antenna are configured to be close each other. Therefore, the configuration of element antennas should be considered in the design process.

In this paper, the spiral shape which is applied as DGS on 4×4 planar array-antenna is used for improving the radiation characteristics. A compact geometrical shape of spiral for DGS implementation incorporated into planar array-antenna will disturb current distributions flowing on its groundplane. Hence, this changes the transmission line characteristics of planar array-antenna such as slot resistance, slot inductance, and slot capacitance to the line resistance, line inductance, and line capacitance, respectively. The planar array-antenna is developed on a 1.6 mm thick FR4 epoxy dielectric substrate. Some overviews describe the DGS and the development of planar array-antenna will be presented briefly. The discussion of characterization results as well as its result comparison will be pointed out following by the conclusion.

II. Overview of DGS and Design of Planar Array-Antenna

A. DGS and Its Equivalent Circuit

Basically DGS is employed to intentionally defect the groundplane of planar transmission line based device in order to improve performances of the device. It is commonly constructed by cascading structures of periodic or non-periodic

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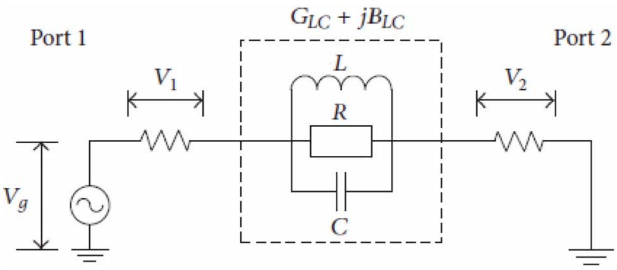


Fig. 1. RLC equivalent circuit of DGS [10].

configuration where these structures will affect the disturbance of current distribution flow on the groundplane [9]. Thence, in order to perform the analysis of DGS incorporation into the device, it is represented as an equivalent circuit consists of some lumped elements. For more efficient and accurate, the DGS is sometimes also analyzed by a parallel resonant circuit of R, L, and C as depicted in Fig. 1.

The present of resistance in the equivalent circuit is addressed to model the losses of radiation, conductor, and dielectric on DGS. This is useful for analyzing especially the loss characteristic of device affected by the DGS involvement. The values of capacitance, inductance, and resistance for the RLC equivalent circuit of DGS are expressed in (1), (2), and (3), respectively [10].

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

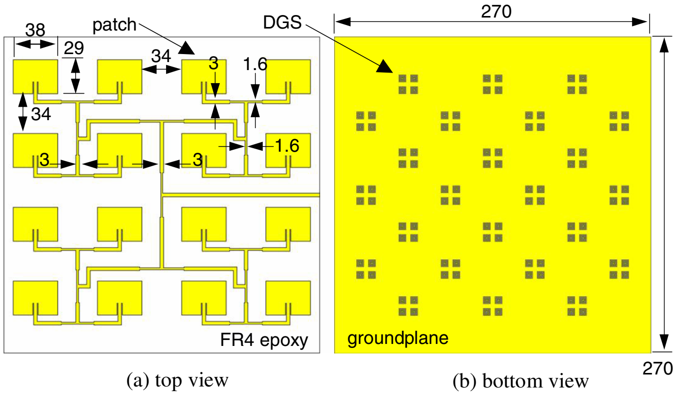
$$L = \frac{1}{4\pi^2 f_0^2 C} \tag{2}$$

$$R = \frac{2Z_0}{\sqrt{1/|S_{11}(\omega)|^2 - (2Z_0(\omega C - 1/\omega L))^2 - 1}} \tag{3}$$

Furthermore, in case of DGS incorporation into the antenna groundplane, values of capacitance, inductance, and resistance affect significantly to the characteristic impedance of antenna. As a consequence, the radiation characteristics including return loss, gain and voltage standing wave ratio (VSWR) will be influenced when the characteristic impedance of antenna is in a mismatch condition.

B. Planar Array-Antenna Design with Spiral Shaped DGS

Fig. 2 shows the configuration of proposed planar array-antenna which consists of 4×4 elements of patch antenna. The inset feed method is employed for each element antenna yielding a corporate feeding network to achieve the impedance match and to make the configuration of planar array antenna to be more compact. The proposed planar array-antenna intended to resonate at the frequency of 2.4 GHz is developed on a 1.6mm thick FR4 epoxy dielectric substrate with the dimension of 270 mm × 270 mm. Each patch has the dimension of 29 mm (length) × 38 mm (width) to resonate at the frequency of 2.4GHz, whilst the separation between patches is set to be 34 mm (around 0.6 λ_d).



(a) top view (b) bottom view

Fig. 2. Configuration of planar array-antenna design with spiral shaped DGS.

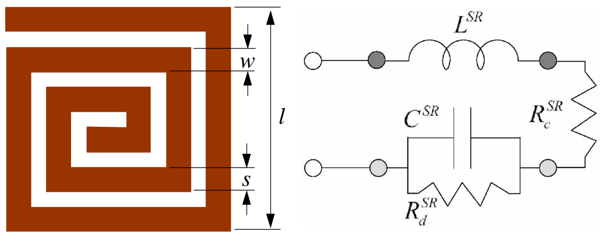


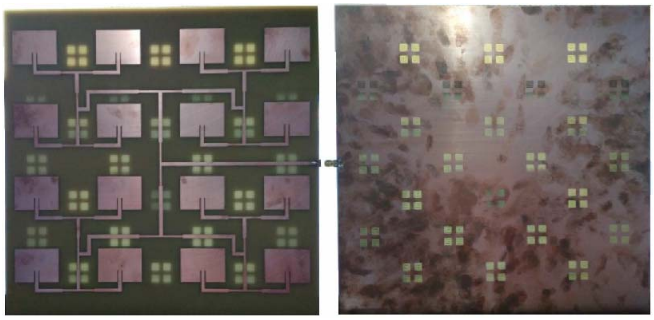
Fig. 3. Configuration of spiral shaped DGS and its equivalent circuit.

Several sets of DGS are incorporated into the planar array-antenna groundplane where each set consists of 4 pieces of DGS. Each DGS takes a planar structure with spiral resonator (SR) as shown in Fig. 3. The planar structure with SR has a loop number of N, a side length of l, a gap width between strips of s, and a strip width of w in which these parameters play important role in determining the characteristic of DGS. Meanwhile, to analyze the characteristic of spiral shaped DGS, the equivalent circuit of SR in [11] is applied as depicted in Fig. 3. The equivalent circuit of SR shape has an inductance of L^{SR}, a capacitance of C^{SR}, a loss resistance in metallic conductor of R_c^{SR}, and a shunt resistance of R_d^{SR} appears due to the dissipation in lossy dielectric substrate. It is noticeable that the values of R_c^{SR}, R_d^{SR}, L^{SR}, and C^{SR} in the equivalent circuit are obtained from the electric and magnetic properties and geometrical structure of SR shape [12].

Furthermore, to show the potentiality of DGS incorporation for improving the radiation characteristic, a planar array-antenna designed without DGS on its groundplane is also investigated. Here, the planar array-antenna without DGS is configured to be similar as another planar array-antenna with DGS incorporation. It has also 4×4 elements with the inset feed method for each antenna element which is developed on a 1.6 mm thick FR4 epoxy dielectric substrate with the dimension of 270 mm × 270 mm.

III. Realization, Result and Discussion

As shown in Fig. 4, a planar array-antenna designed with spiral shaped DGS is realized on a 1.6 mm thick FR4 epoxy



(a) top view (b) bottom view

Fig. 4. Realization of planar array-antenna designed with spiral shaped DGS.

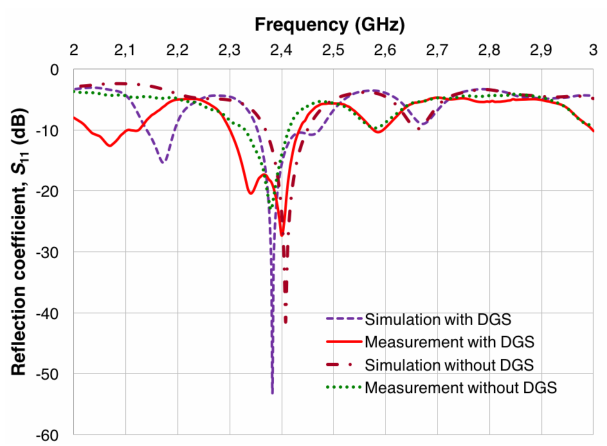


Fig. 5. Measurement and simulation results of reflection coefficient (S_{11}).

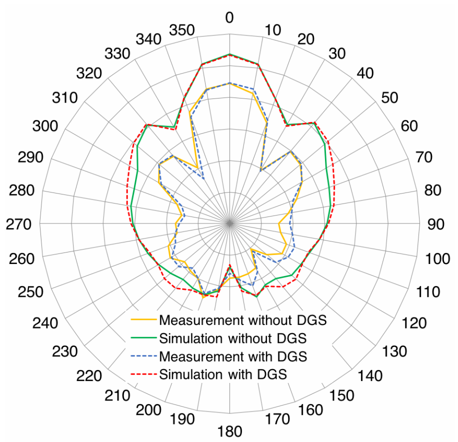


Fig. 6. Measurement and simulation results of radiation pattern.

dielectric substrate through wet etching method. At the end of microstrip feeding line, a 50Ω SMA connector is soldered for the characteristics measurement. The experimental characterization is measured using Network Analyzer emphasizing on how spiral shaped DGS incorporation into the planar array-antenna groundplane can improve radiation characteristics of proposed antenna.

Fig. 5 depicts the measurement results of reflection coefficient (S_{11}) for fabricated planar array antenna with the simulation result plotted together for result comparison. The simulation result shows that the proposed planar array-antennas without and with spiral shaped DGS incorporation resonate at the frequency of 2.4 GHz. The simulated S_{11} values reach up to –53 dB and –42 dB for the planar array antenna with spiral shaped DGS and without DGS, respectively. Meanwhile, the measured S_{11} values for the planar array-antenna with and without spiral shaped DGS incorporation are up to –28 dB and –22 dB, respectively. The result shows that the impedance matching has been accomplished for planar array antenna with spiral shaped DGS in which this is also indicated by the gain achievement of 10.74 dB.

Moreover, the simulated bandwidth responses for S_{11} value less than –10 dB are 118 MHz (2.354 GHz – 2.472 GHz) for the planar array-antenna with spiral shaped DGS and 80 MHz (2.37 GHz – 2.45 GHz) for the planar array-antenna without DGS. Whilst, the measured bandwidth response for S_{11} value less than –10 dB are 140 MHz (2.3 GHz – 2.44 GHz) and 90 MHz (2.33 GHz – 2.42 GHz) for the planar array-antenna with and without spiral shaped DGS, respectively. Therefore, there was a bandwidth improvement of planar array-antenna with spiral shaped DGS of 38 MHz for simulation and of 50 MHz for measurement. Furthermore, the comparison of measurement and simulation of planar array-antenna radiation pattern are plotted in Fig. 6. The results show some discrepancies occurred in the measured results which are possibly evoked by the dielectric substrate loss with the different value and the imperfectness in measurement.

IV. Conclusion

The design and implementation of planar array-antenna with improved radiation characteristics have been presented. Several sets of spiral shaped DGS which were incorporated into the planar array-antenna groundplane has affected in improving the radiation characteristics. The simulation result of radiation characteristics for the planar array-antenna with spiral shaped DGS has achieved the bandwidth response of 140 MHz and the gain of 10.47 dB. This achievement was much better than the simulation result of planar array-antenna without DGS. Meanwhile, the measurement result of fabricated planar array-antenna with spiral shaped DGS has some discrepancies compared to the simulated result due to the material issues and measurement process.

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