Bowtie-Shaped DGS for Reducing Coupling Between Elements of Planar Array Antenna

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***Abstract*—In this paper, the utilization of bowtie-shaped defected ground structure (DGS) incorporated into the groundplane of planar array antenna is proposed to reduce the coupling between two elements of planar array antenna. A double side of FR4 epoxy dielectric substrate with the dimension of 105mm $\times$ 130mm and the thickness of 1.6mm is used to deploy the planar array antenna. Two elements of planar array antenna are placed on the top side of dielectric substrate, while the bowtie-shaped DGS is put in the groundplane at the bottom side. To reduce the amount of coupling between two elements of planar array antenna, the DGS which takes bowtie-shaped is introduced. From the results, both simulation and measurement verified that the bowtie-shaped DGS reduced the coupling at the resonance frequency of 1.955 GHz. The simulated and measured couplings could be reduced up to 0.67 dB and 2.4 dB, respectively.**

***Keywords*—bowtie-shaped; coupling; defected ground structure (DGS); planar array antenna.**

I. Introduction

In recent years, the development of wireless communication technology tends to use a thin and lightweight device implementable by using the planar structure which is ease of fabrication [1]. The microstrip technology as one of planar structures is frequently applied in wireless communication applications. However, the surface waves generated from the use of microstrip technology were being serious issues in the planarantenna design. As is well-known that the surface waves are undesired thing that occurs when a patch of antenna radiates, and it can degrade the antenna performance. The total available radiated power of the antenna becomes trapped along the surface of dielectric substrate. As a result, the radiation characteristics of antenna such as efficiency, gain, bandwidth, and radiation pattern could be reduced.

For multiple-input multiple-output (MIMO) applications that use planar-array antennas [2]–[3], the surface waves have a significant impact on the coupling between adjacent elements on an array [4]–[5]. Furthermore, another issue of the surface waves in near-field zone is able to produce the coupling between microstrip antennas in array configuration [6]. The coupling produced by near field increases if the antenna is positioned each other in the near-field zone. It evokes several degradation to the radiation characteristics of antenna, similar as the effect of surface waves. However, the effect of near-field coupling is less dominant than the surface wave, especially when the antennas are positioned close each other.

There are numerous attempts have been proposed and demonstrated by researchers to suppress the surface waves particularly on microstrip antenna, such as by implementing artificial materials [7]–[8], metamaterials [9]–[10], and defected ground structure (DGS) [11]–[15]. Among of them, DGS is usually realized by defecting the groundplane with a certain lattice shape. The use of DGS leads to a certain frequency bandgap, which can be determined by the shape, dimension, and position of DGS. In fact, there are many shapes of DGS that can be implemented in which each shape can be represented as an equivalent circuit consisting of inductance and capacitance [16]–[18]. Furthermore, DGS gives an extra degree of freedom in microwave circuit design which can be applied for a wide range of applications [19]–[22]. In case for antenna applications as well as array antenna, DGS is commonly used for feeding technique enhancement.

In this paper, the bowtie-shaped DGS is proposed to be utilized for reducing the coupling between two elements of planar array antenna. The use of DGS is based on its advantages especially in controlling the coupling between antenna elements in an array configuration, Here, simulation and measurement are performed to demonstrate the feasibility of DGS in improving the antenna performance. The influence of bowtie-shaped DGS incorporation towards the improvement of undesired coupling between antenna elements is analyzed showing the suppression of surface waves propagation in the dielectric layer indicated by reducing the coupling level.

II. Configuration of Planar Array Antenna with Bowtie-Shaped DGS

DGS is intentionally defects the groundplane on a planar transmission line including microstrip line in order to improve the electromagnetic device performance. It is configured by incorporating cascaded periodic or non-periodic structures into the groundplane, which disturbs the shield current distribution in the groundplane [19]. Due to the ability disturbs the shield current distribution, hence it can be represented as an equivalent circuit that consisting of the inductance and capacitance. Fig. 1 shows some types of DGS that frequently implemented for enhancing circuit performance including rectangular slot, U-shaped slot, bowtie-shaped slot, square-slot dumbbell, and spiral-head dumbbell. Some of them have been more complex structure such as spiral-head dumbbell DGS for more unique characteristics contribution.

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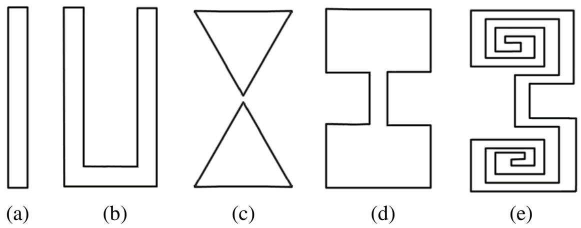

Fig. 1. Some types of DGS; (a) rectangular slot; (b) U-shaped slot; (c) bowtie-shaped slot; (d) square-slot dumbbell; (e) spiral-head dumbbell.

Among the types of DGS mentioned above, this work uses bowtie-shaped DGS for the investigation to reduce the coupling between two elements of planar-array antenna. A double side of FR4 epoxy dielectric substrate with the relative permittivity of 4.3 and the thickness of 1.6mm is employed to construct the planar array antenna with bowtie-shaped DGS. Fig. 2 illustrates the construction of proposed planar array antenna with bowtie-shaped DGS which is used for the investigation of coupling reduction. The construction of proposed planar array antenna is taken from the one in [11] except the number of feeding ports and the shape of DGS. Here, each element of feeding port for the planar array antenna obtains the same power excitation.

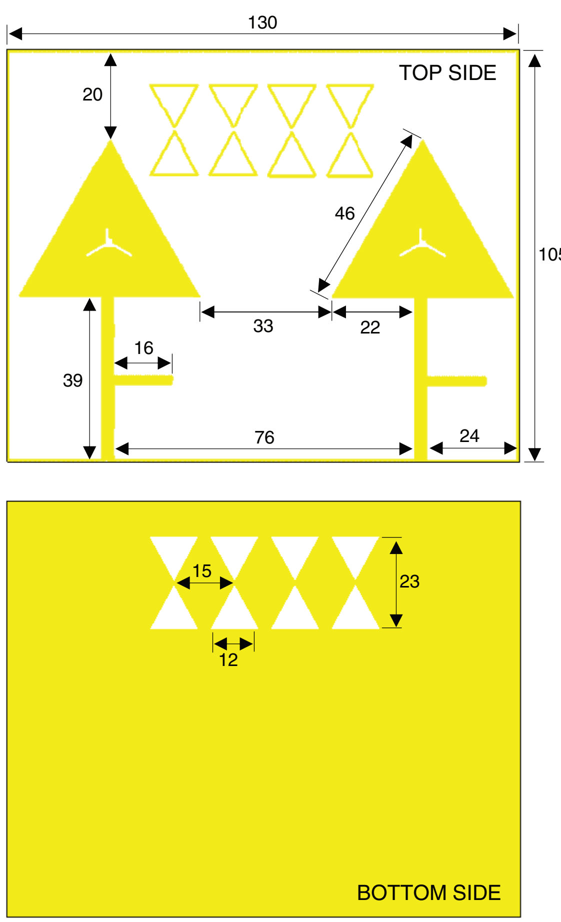

Fig. 2. Construction of proposed planar array antenna with bowtie-shaped DGS (unit in mm).

The planar array antenna which is constructed in the dimension of 130 mm $\times$ 105 mm has two antenna elements positioned on the top side of dielectric substrate. Whilst four bowtie-shaped DGS are incorporated into the groundplane of planar array antenna which is located at the bottom side of dielectric substrate. Furthermore, to shows the capability of bowtie-shaped DGS in coupling reduction, a planar array antenna without DGS is also investigated. The planar array antenna without DGS is also implemented on the same dielectric substrate with the geometry and design parameter are identical to the planar array antenna with bowtie-shaped DGS.

III. HARDWARE REALIZATION AND CHARACTERIZATION

The array antennas with and without bowtie-shaped DGS are designed by using simulation software to obtain the radiation characteristics of antenna. The coupling between two antenna elements is one of antenna parameters that should be paid more attention in the investigation. To verify the simulation results, both designed array antennas with and without bowtieshaped DGS are then fabricated on a double side of FR4 epoxy dielectric substrate with thickness of 1.6 mm. Fig. 3 shows the prototypes of planar array antenna with and without bowtie-shaped DGS which are fabricated through wet etching technique. For experimental characterization, two SMA connector types are connected at the feeding ports of each fabricated planar array antenna. It is noted that the experimental characterization is focused on how the incorporation of bowtie-shaped DGS into the groundplane of planar array antenna can contribute in the reduction of coupling level between two elements of planar array antenna.

The simulation and measurement results of S_{11} for planar array antenna with and without bowtie-shaped DGS are plotted in Fig. 4. The results show that the planar array antenna with and without bowtie-shaped DGS resonates at the frequency of 1.955 GHz. The value of S_{11} is up to -24 dB for the planar

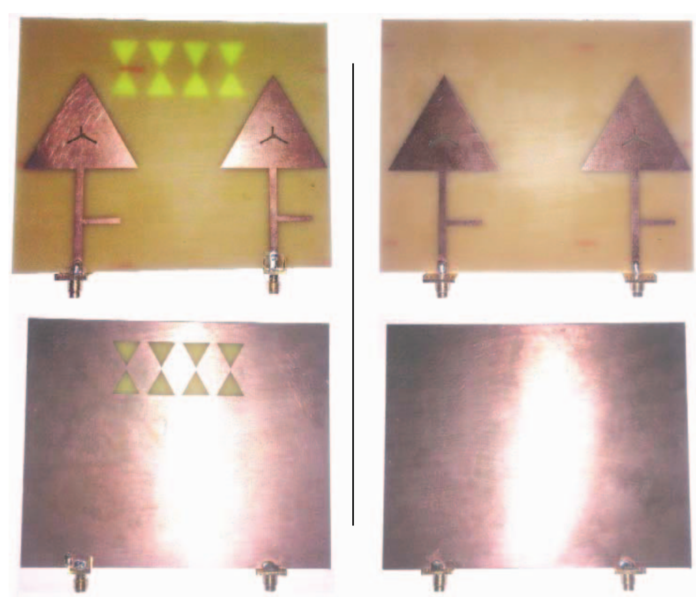

Fig. 3. Fabricated planar array antenna; left is with bowtie-shaped DGS (top–bottom); right is without DGS (top–bottom).

array antenna with bowtieshaped DGS and -22 dB for the planar array antenna without bowtie-shaped through simulation. Meanwhile, from experimental characterization, the value of S_{11} is up to -17 dB for the planar array antenna with bowtie-shaped DGS and 16 dB for the planar array antenna without DGS. The different achievement of S_{11} between simulation and measurement is probably evoked by the different value of dielectric loss. It seems that the dielectric loss of fabricated planar array antenna is worse than of the simulation.

It shows that the improvement of impedance matching for planar array antenna has been accomplished by implementing bowtie-shaped DGS. It can be observed from the result that the impedance bandwidth for $S_{11} \leq$ -10dB of the planar array antenna with and without bowtie-shaped DGS through simulation are 15 MHz (1.950–1.965 GHz) and 10 MHz (1.946–1.956 GHz), respectively. Whereas, the impedance bandwidth for $S_{11} \leq$ -10dB of the planar array antenna with and without bowtie-shaped DGS obtained from measurement are 30 MHz (1.940–1.970 GHz) and 29 MHz (1.938–1.967 GHz), respectively.

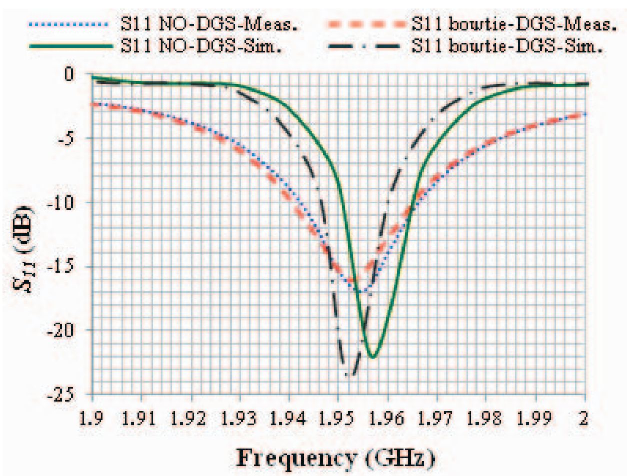

Fig. 4. Measurement and simulation results of S_{11} for array antenna with and without bowtie-shaped DGS.

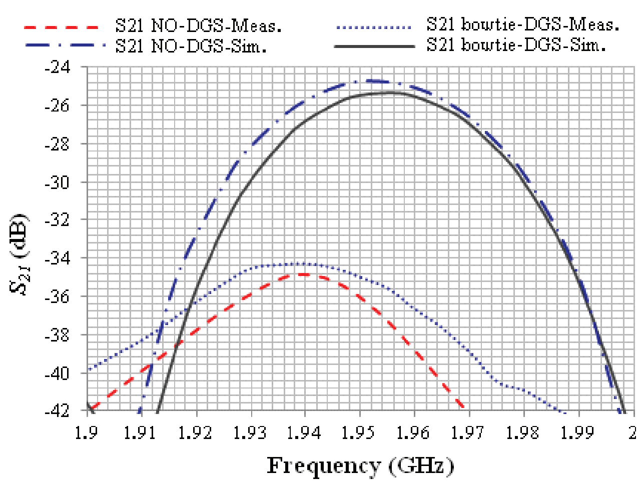

Fig. 5. Measurement and simulation results of S_{21} for array antenna with and without bowtie-shaped DGS.

Moreover, the measurement and simulation results of S_{21} which is also known as coupling between two elements of planar array antenna are depicted in Fig. 5. It is seen that the coupling of planar array antenna with bowtie-shaped DGS is lower than the planar array antenna without bowtie-shaped DGS. The simulated coupling of planar array antenna with and without bowtie-shaped DGS at the frequency of 1.955 GHz are -25.42 dB and -24.75 dB, respectively. This result is showing the coupling improvement of 0.67 dB. Meanwhile, the measured coupling of planar array antenna with and without bowtie-shaped DGS at the frequency of 1.955 GHz are -38 dB and -35.6 dB, respectively, which is also indicating the coupling improvement of 2.4 dB. Therefore, both simulated and measured couplings provide the improvement of 0.67 dB and 2.4 dB, respectively. Again, the discrepancy occurs between simulation and measurement results is possibly caused by the different loss value of dielectric substrate.

The interesting point from the characterization result of planar array antenna with bowtie-shaped DGS using different feeding port for each antenna element is that the coupling between two antenna elements is slightly stronger compared to the achieved coupling in [11]. This is due to the power excitation of planar array antenna which is fed at the port of feeding line. When each antenna element obtains full power excitation at each port of feeding line, it provides the impact in generating stronger coupling. Meanwhile in [11], each antenna element has obtained half power excitation which has given the impact of weaker generated coupling.

IV. Conclusion

The coupling reduction between two antenna elements of planar array antenna has been presented and implemented by using bowtie-shaped DGS incorporated into the antenna groundplane. The planar array antenna with bowtie-shaped DGS has been simulated and fabricated to demonstrate the feasibility of bowtie-shaped DGS in coupling reduction, which was compared to the planar array antenna without DGS. It has been demonstrated through simulation and measurement that the bowtie-shaped DGS could reduce the coupling between two antenna elements of planar array antenna. The simulation and measurement results have shown the achievement in coupling reduction up to 0.67 dB and 2.4 dB, respectively, at the resonant frequency of 1.955 GHz.

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