Biconical–Shaped DGS To Reduce Coupling Between Two Elements Planar–Array Antenna

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Abstract – This paper presents the biconical–shaped defected ground structure (DGS). It is inserted into the groundplane of single layer planar–array antenna. Biconical–shaped DGS is designed to reduce the coupling between two elements planar–array antenna. Each element of planar–array antenna is excited by the same power input. Therefore, the coupling between two elements planar–array antenna is generated. Both simulation and measurement results verified that the biconical–shaped DGS reduced the coupling at the resonance frequency of 1.955 GHz. The simulated and measured couplings can be reduced by the biconical–shaped DGS upto 0.67 dB and 2.4 dB, respectively.

Keywords: *Coupling; Biconical Shaped; Planar Structure; Array Antenna*

I. Introduction

Recently, the development of wireless communication technology requires a thin and light–weight device by using the planar structure, which is easy fabrication [1]. The microstrip technology as a planar structure is frequently implemented in wireless–communcations applications. However, the surface wave is serious problem in the planar–antenna design. 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 and bandwidth could be reduced. For 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 the near field generate the coupling between microstrip antennas in array configuration [6]. The coupling that caused 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.

According to these issue, there are some methods can be applied to suppress surface waves particularly on microstrip antenna, such as by implementing artificial materials [7]–[8], metamaterials [9]–[10], and defected ground structure (DGS) [11]– [14]. The latest one is usually realized by defecting the groundplane with a certain lattice shape, which disturbs the shield current distribution of microstrip antenna and control the coupling between antenna elements in array antenna. Many shapes of DGS have been investigated including circle-shaped, spiral-shaped, and elliptical-shaped; and each shape is representable as an equivalent circuit that consisting of the inductance and capacitance [15]–[17]. This leads to a certain frequency bandgap, which can be determined by the shape, dimension, and position of DGS. Furthermore, DGS gives an extra degree of freedom in microwave circuit design. It can be implemented for a wide range of applications [18]–[21]. For antenna applications including array antenna, DGS is mainly applied for feeding technique.

Regarding to the ability of DGS in controlling the coupling between antenna elements in an array configuration, in this paper, the biconical-shaped DGS is proposed to be implemented for reducing the coupling between two elements of array antenna. Simulation and measurement results are conducted to show that the DGS can improve the antenna performance. The influence of biconical–shaped DGS towards the improvement of undesired coupling is analyzed. Therefeore, the incorporation of biconical–shaped DGS will suppress surface waves propagation in the dielectric layer that indicated by reducing the coupling level.

II. Array Antenna with Biconical–Shaped DGS

A. DGS as an overview

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 [17]. 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. Figure 1 shows some types of DGS that frequently implemented for enhancing circuit performance including rectangular slot, U-shaped slot, square-slot dumbbell, spiral-head dumbbell, and interdigital. Some of them have been more complex structure such as spiral-head dumbbell DGS and interdigital DGS for more unique characteristics contribution.

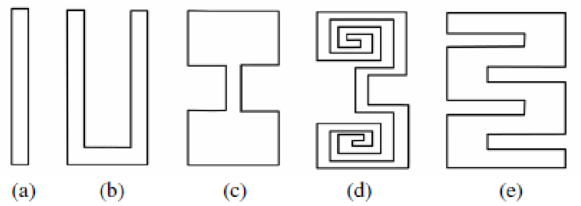
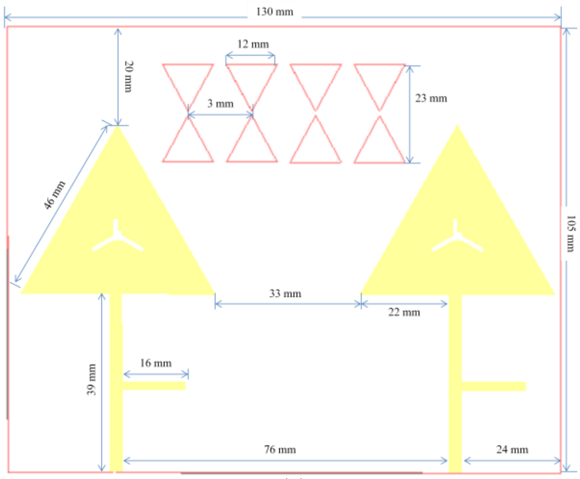


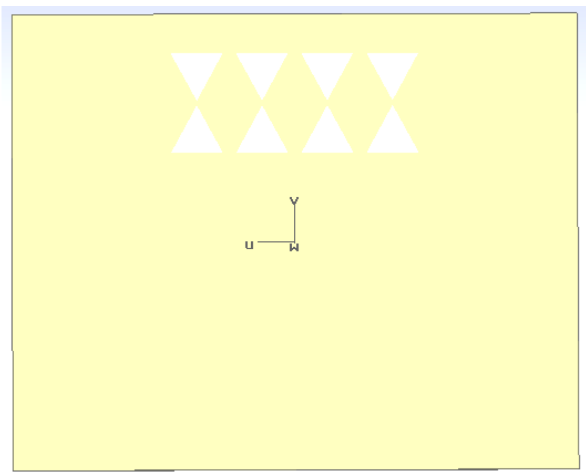
Fig. 1. Some types of DGS; (a) rectangular slot; (b) U-shaped slot; (c) square-slot dumbbell; (d) spiral-head dumbbell; (e) interdigital

B. *Design of Array Antenna with Biconical–Shaped DGS*

In this paper, the biconical–shaped DGS as new shape is introduced to reduce the coupling between two element of the planar–array antenna as shown in Fig. 2.



(a)



(b)

Fig. 2 Array Antenna with Biconical – Shape DGS: (a) Top view; (b) Bottom view

The proposed array antenna with biconical–shaped DGS is constructed on single layer of FR4 epoxy dielectric substrate with the relative permittivity of 4–4.3 and the thickness of 1.6mm. Figure 2 illustrates the construction of array antenna with biconical–shaped DGS, which is used for the investigation of coupling reduction. The construction is taken from the array antenna design in [12] except the number of feeding ports and the shape of DGS. The array antenna that constructed with overall size of 130 mm (length) × 105 mm (width) has two antenna elements located on the top view. Meanwhile, four units biconical–shaped DGS incorporated into the groundplane placed at the bottom view.

Furthermore, each element port of the array antenna gets the same power excitation. To demonstrate the feasibility of biconical–shaped DGS in coupling reduction, an array antenna without DGS is also investigated. The array antenna without DGS is also implemented on the same dielectric substrate with the geometry and design parameter are identic to the array antenna with biconical–shaped DGS.

III. Fabrication, Results And Discussion

A. *Hardware Fabrication*

The array antennas with and without biconical–shaped DGS are designed by using simulation software to obtain the radiation characteristics of antenna. To verify the simulation results, both designed array antennas with and without biconical–shaped DGS are fabricated on single layer of FR4 epoxy dielectric substrate with thickness of 1.6 mm as shown in Fig. 3.

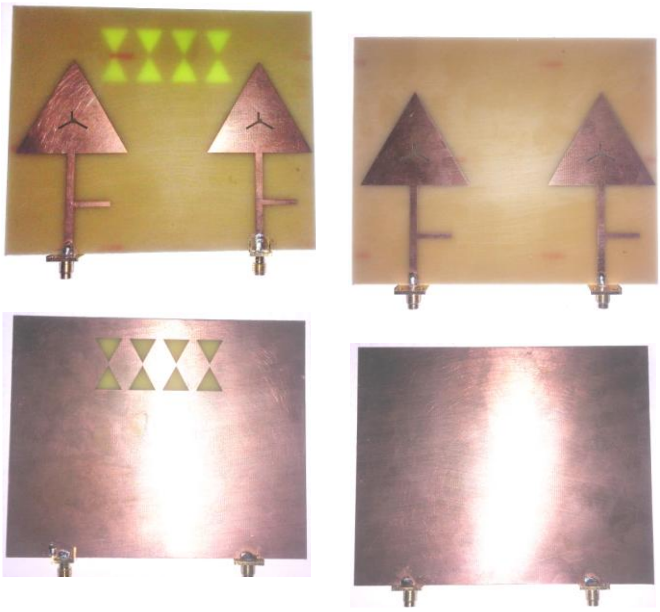


Fig. 3 Realized array antenna; two antenna elements (top); groundplane with biconical–shaped DGS (bottom–left); groundplane without biconical–shaped DGS (bottom–right).

Figure 3 shows the pictures of fabricated array antenna with and without biconical–shaped DGS that fabricated through wet etching technique. Two SMA connector types are soldered at the feeding ports of each fabricated array antenna for experimental characterization. The characterization is focused on how the incorporation of biconical–shaped DGS into the groundplane of array antenna can reduce the coupling level between two antenna elements.

B. *Results and Discussion*

The simulation and measurement results of S_{11} for array antenna with and without biconical–shaped DGS are shown in Fig. 4. The results show that the array antenna with and without biconical–shaped DGS resonates at the frequency of 1.955 GHz. The value of S_{11} is up to –24 dB for the array antenna with biconical–shaped DGS and –22 dB for the antenna without biconical–shaped through simulation. Meanwhile, the value of S_{11} is up to –17 dB for the array antenna with biconical–shaped DGS and –16 dB for the antenna without biconical–shaped through measurement. It is indicated that the impedance–matching improvement of array antenna with biconical–shaped DGS has been accomplished. The impedance bandwidth for $S_{11} \leq 10$dB of the array antenna with and without biconical–shaped DGS through simulation are 15 MHz (1.950–1.965 GHz) and 10 MHz (1.946–1.956 GHz), respectively. Meanwhile, the impedance bandwidth for $S_{11} \leq 10$dB of the array antenna with and without biconical–shaped DGS through measurement are 30 MHz (1.940–1.970 GHz) and 29 MHz (1.938–1.967 GHz), respectively.

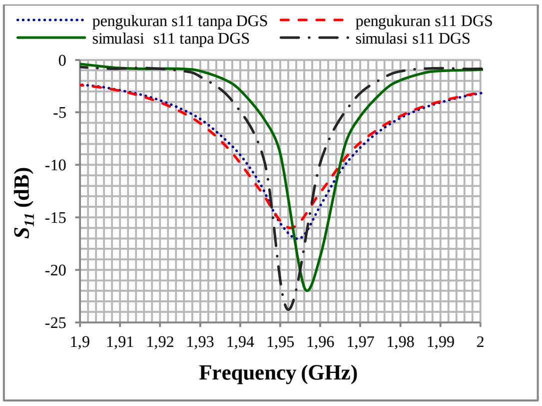


Fig. 4. Measurement and simulation results of S_{11} for array antenna with and without biconical–shaped DGS.

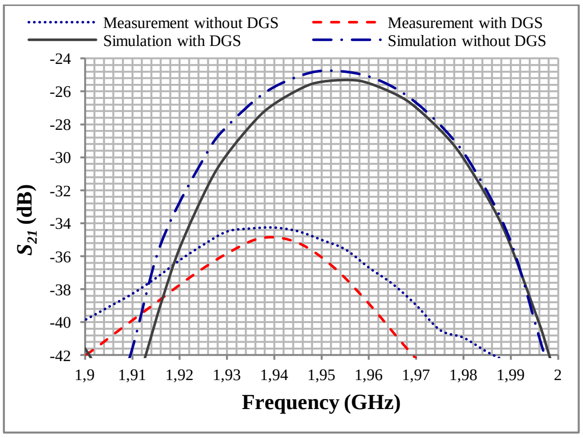


Fig. 5. Measurement and simulation results of S_{21} for array antenna with and without biconical–shaped DGS.

Furthermore, the measurement and simulation results of S_{21} that also known as coupling between two antenna elements are shown in Fig. 5. It can be observed that the coupling of array antenna with biconical–shaped DGS is lower than the array antenna without biconical–shaped DGS. The coupling of array antenna with and without biconical–shaped DGS at the frequency of 1.955 GHz through simulation are –25.42 dB and –24.75 dB, respectively. It indicates that there is the coupling improvement of 0.67 dB. Meanwhile, the coupling of array antenna with and without biconical–shaped DGS at the frequency of 1.955 GHz through measurement are –38 dB and 35.6 dB, respectively. It also indicates that there is 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.

The interesting point from the characterization of array antenna with biconical–shaped DGS using different feeding port for each antenna element is that the coupling between two antenna elements is slightly greater compared to the coupling achieved in [12]. This is due to the power excitation, which is fed at the port of feeding line. When each antenna element obtains full power excitation at each port of the feeding line, it provides the impact of greater generated coupling. While in [12] each antenna element obtains half power excitation, which gives the impact of smaller generated coupling.

IV. Conclusions

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

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References

[1] R. Garg, P. Bhartias, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Norwood: Artech House, 2000.

[2] Z. N. Chen and K-M. Luk, Antennas for Base Stations in Wireless Communications, 1st ed., McGraw-Hill, 2009.

[3] A. Kalis, A. G. Kanatas, and C. B. Papadias, Parasitic Antenna Arrays for Wireless MIMO Systems, 1st ed., Springer, 2014.

[4] J. L. Volakis, Antenna Engineering Handbook, 4th ed., Mc.Graw Hill, 2007.

[5] N. Engheta, R.W. Ziolkowski, "Metamaterial: "Physics and Engineering Explorations", *IEEE Press, John Wiley & Sons Inc.*, 2006.

[6] M. Nikolic, A. Djordjevic, and A. Nehorai, "Microstrip antennas with suppressed radiation in horizontal directions and reduced coupling," IEEE Trans. Antennas Propag., Vol. 53, No. 11, pp. 3469-3476, Nov 2005.

[7] M. N. Sujatha and K. J. Vinoy, "A stacked ring-patch artificial substrate for surface waves suppression and in phase reflection," in Proceeding of 5th International Conference on Industrial and Information Systems (ICIIS), Mangalore, India, Jul.–Aug. 2010, pp. 75–79.

[8] A. Ikhyari and A. Munir, "Dual-band microstrip patch antenna using capacitive artificial magnetic conductor," in Proceeding of 2nd International Conference on Wireless and Telematics (ICWT), Yogyakarta, Indonesia, Aug. 2016, pp. 36-39.

[9] L. Yang, M. Fan, and Z. Feng, "A spiral electromagnetic bandgap (EBG) structure and its application in microstrip antenna arrays," in Proceeding of Asia-Pacific Microwave Conference (APMC), Suzhou, China, Dec. 2005, pp. 1–4.

[10] K. Buell, H. Mosallaei, and K. Sarabandi, "Electromagnetic metamaterial insulator to eliminate substrate surface waves," in Proceeding of IEEE Antennas and Propagation Society International Symposium (AP-S), Washington, DC, USA, Jul. 2005, pp. 574–577.

[11] F. Y. Zulkifli, E. T. Rahardjo, and D. Hartanto, "Dumbbell defected ground structure for multiband microstrip antenna array," Progress In Electromagnetics Research Letters, Vol. 13, pp. 29-40, 2010.

[12] F. Y. Zulkifli, E. T. Rahardjo, and D. Hartanto, "Radiation properties enhancement of triangular patch microstrip antenna array using hexagonal defected ground structure," Progress In Electromagnetics Research M, Vol. 5, 101–109, 2008.

[13] H. Liu, Z. Li, X. Sun, and J. Mao, "Harmonic suppression with photonic bandgap and defected ground structure for a microstrip patch antenna," IEEE Microw. Compon. Lett., Vol. 15, No. 2, p. 55–56, Feb. 2005.

[14] M. Salehi, A. Motevasselian, A. Tavakoli, and T. Heidari, "Mutual coupling reduction of microstrip antennas using defected ground structure," in Proceeding of 10th IEEE Singapore International Conference on Communication Systems (ICCS), Singapore, Oct.–Nov. 2006, pp. 1–5.

[15] D. Guha, M. Biswas, and Y. M. M. Antar, "Microstrip patch antenna with defected ground structure for cross polarization suppression," IEEE Antennas Wireless Propag. Lett., Vol. 4, No. 1, pp. 455–458, Dec. 2005.

[16] Y. Chung, S. Jeon, D. Ahn, J. Choi, and T. Itoh, "High isolation dual polarized patch antenna using integrated defected ground structure," IEEE Microw. Compon. Lett., Vol. 14, No. 1, pp. 4–6, Feb. 2004.

[17] R. Dehdasht-Heydari and M. Naser-Moghadasi, "Introduction of a novel technique for the reduction of cross polarization of rectangular microstrip patch antenna with elliptical DGS," Journal of Electromagnetic Waves and Applications, Vol. 22, No. 8-9, pp. 1214–1222, 2008.

[18] L. H. Weng, Y. C. Guo, X. W. Shi, and X. Q. Chen, "An overview on defected ground structure," Progress In Electromagnetics Research B, Vol. 17, pp. 173-189, 2008.

[19] I. P. Sari and A. Munir, "Defected ground structure for bandwidth improvement of artificial magnetic conductor-based microwave absorber," in Proceedings of 7th International Conference on Telecommunication Systems, Services and Applications (TSSA), Bali, Indonesia, Oct. 2012, pp. 200–203.

[20] W. Aditomo and A. Munir, "Bandwidth enhancement of ultra-wideband microstrip bandpass filter using defected ground structure," in Proceedings of 13th International Conference on Quality in Research (QiR), Yogyakarta, Indonesia, Jun. 2013, pp. 150–154.

[21] A. Munir and R. Safitri, "Development of microstrip BPF using open split ring resonator with square groundplane window," in Proceedings of International Symposium on Antennas and Propagation (ISAP), Kaohsiung, Taiwan, Dec. 2014, pp. 49-50.

[22]