Coupling Reduction Between Two Elements of Array Antenna Using U-Shaped Defected Ground Structure

Halason Jefri Naibaho[1*], Mochamad Yunus[1‡], Edwar[2§], Achmad Munir[3†]
[1]Department of Electrical Engineering, Faculty of Engineering, University of Pakuan, Bogor, Indonesia
[2]School of Electrical Engineering, Telkom University, Bandung, Indonesia
[3]Radio Telecommunication and Microwave Laboratory, School of Electrical Engineering and Informatics
Institut Teknologi Bandung, Indonesia
*halasonnaibaho@gmail.com, ‡mochyunus@unpak.ac.id, §edwarm@telkomuniversity.ac.id, †munir@ieee.org

***Abstract*—This paper presents the U-shaped defected ground structure (DGS) which is incorporated into the groundplane of array antenna to reduce the coupling between antenna elements. The array antenna is constructed of two layers of flame resistant (FR) 4 epoxy dielectric substrate with the thickness of each layer of 1.6mm. The U-shaped DGS is placed at the bottom side of second layer between two elements of array antenna located on the top side of first layer. A proximity feeding technique of microstrip line applied to feed each antenna element is positioned on the top side of second layer. By reducing the coupling which is generated due to the input power at both feeding ports, the radiation characteristics of array antenna can be improved. To demonstrate the feasibility of U-shaped DGS in coupling reduction, an array antenna without DGS is also investigated. The characterization results have verified that the U-shaped DGS is applicable to reduced the coupling at the resonant frequency of 2.38GHz up to 2dB and 0.88dB for simulation and measurement, respectively.**

Keywords*—*Array antenna; coupling; defected ground structure (DGS); U-shaped.

I. Introduction

Recently, many wireless communication services use planar-array antennas especially for multiple input multiple output (MIMO) antenna application [1]–[2]. The microstrip technology frequently implemented as a planararray antenna is suitable to be applied in wireless communication due to its advantages such as low profile, thinness, light-weight, and easy fabrication [3]. However, a common issue of antenna developed based on microstrip technology is surface waves. It is well-known that the surface waves are undesired thing occurs when a patch of antenna radiates. This is due to a portion of 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 array antennas, the surface waves have a significant impact on the coupling between adjacent elements on an array [4]–[5].

In addition to surfaces waves, another issue is near field which can lead to coupling between microstrip antennas in array configuration [6]. The coupling caused by near field increases if the antenna is positioned in the near-field zone of the other one. Even on the antenna which is implemented using dielectric substrate with very low relative permittivity or thicker thickness, the near-field coupling can be stronger. This issue evokes in severe 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 the issue of surface waves, there are some methods to suppress that can be applied particularly on microstrip antenna, such as by implementing artificial materials [7]–[8], metamaterials [9]–[10], and defected ground structure (DGS) [11]– [13]. The latest one is usually realized by defecting the groundplane with a certain lattice shape which affects to disturb 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, in which each shape is representable as an equivalent circuit consisting of inductance and capacitance [14]–[16]. This leads to a certain frequency bandgap which is determinable by the shape, dimension, and position of DGS. Furthermore, DGS gives an extra degree of freedom in microwave circuit design and can be implemented for a wide range of applications [17]–[20]. For antenna applications including array antenna, DGS is mainly applied to the feeding technique.

Regarding to the ability of DGS in controlling the coupling between antenna elements in an array configuration, in this paper, the U-shaped DGS is proposed to be implemented for reducing the coupling between two elements of array antenna. Two layers of FR4 epoxy dielectric substrate is employed to deploy the array antenna. The U-shaped DGS is incorporated into the groundplane at the bottom side of second layer between two elements of array antenna located on the top side of first layer. To feed each antenna element, a proximity feeding technique is applied and made of microstrip line positioned on the top side of second layer.

The proposed array antenna uses the material that is more easily obtained and cheaper compared to other materials. It is also expected to provide the coupling reduction of array antenna. Simulation and measurement results are conducted to show that the DGS can improve the antenna performance. The influence of U-shaped DGS towards the improvement of undesired coupling is analyzed. The incorporation of U-shaped DGS, therefore, will suppress surface waves propagation in the dielectric layer indicated by reducing the coupling level. To observe the coupling behaviour of array antenna to the frequency response, the design of array antenna with U-shaped DGS will be implemented in the next section.

978-1-5386-1667-3/17/$31.00

II. DGS and Array Antenna

A. Brief Overview of DGS

Basically, DGS is a method of intentionally changes or 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 affects to disturb the shield current distribution in the groundplane [17]. Due to the ability to disturb the shield current distribution, hence it can be represented as an equivalent circuit consisting of inductance and capacitance.

There are several types of DGS, such as slotted groundplane, dumbbell, and interdigital. Fig. 1 shows some types of DGS 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. The equivalent circuit of DGS, e.g. dumbbell circuit, is usually represented as LC parallel circuit connected in series to the equivalent circuit of transmission line as illustrated in Fig. 2 [17].

B. Array Antenna Configuration

In attempting to reduce the coupling between antenna elements in an array configuration, the shape of DGS incorporated into the groundplane of array antenna takes the U-shaped DGS. The proposed array antenna with DGS is constructed of two layers of FR4 epoxy dielectric substrate with the relative permittivity of 4.3 and the thickness of each layer of 1.6mm. Fig. 3 illustrates the construction of array antenna with U-shaped DGS used for the investigation of coupling reduction. It is noted that the construction is taken from the array antenna design in [11] except the number of feeding ports and the shape of DGS. The array antenna construction with overall size of 100mm (length) × 140mm (width) has two antenna elements located on the top side of first layer and 3 U-shaped DGS incorporated into the groundplane placed at the bottom side of second layer.

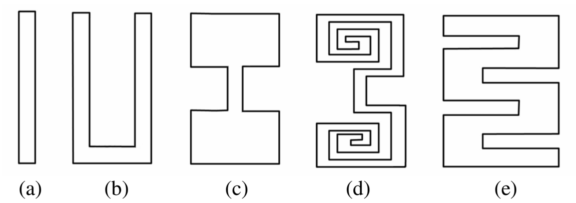

Fig. 1. Some types of DGS; (a) rectangular slot; (b) U-shaped slot; (c) square-slot dumbbell; (d) spiral-head dumbbell; (e) interdigital.

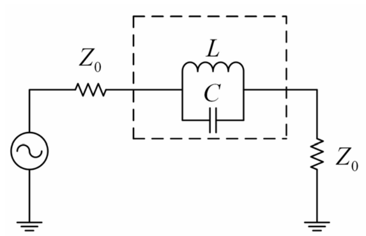

Fig. 2. LC parallel equivalent circuit for dumbbell DGS.

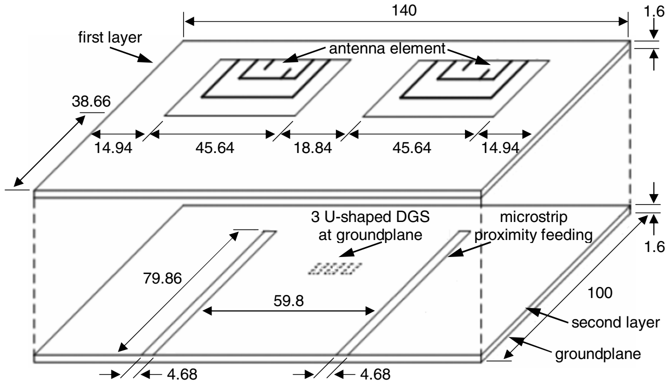

Fig. 3. Construction of array antenna with U-shaped DGS (unit in mm).

Furthermore, the feeding line for each antenna element is positioned at the top side of second layer. Hence each element of the antenna array gets the same power. The electromagnetic coupling method which is also known as proximity feeding technique is used to feed each antenna element. This feeding technique is chosen to improve the radiation characteristics of array antenna. Meanwhile, to demonstrate the feasibility of U-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 identical to the array antenna with U-shaped DGS.

III. Realization, Characterization and Discussion

A. Hardware Realization

Based on the design above, the array antennas with and without U-shaped DGS are characterized by using software simulation to obtain the radiation characteristics of antenna.

Fig. 4. Realized array antenna; two antenna elements on top side of first layer (top–left); microstrip feeding line on top side of second layer (top–right); groundplane with U-shaped DGS on bottom side of second layer (bottom–left); groundplane without U-shaped DGS on bottom side of second layer (bottom–right).

Whilst to verify the simulation results, both designed array antennas with and without U-shaped DGS are fabricated on 2 layers of 1.6mm thick on FR4 epoxy dielectric substrate. Both layers are then stacked each other and tight in such a way to avoid any gap between them.

Fig. 4 shows the pictures of realized array antenna with and without U-shaped DGS fabricated through wet etching technique. Two SMA connector types are soldered at the feeding ports of each realized array antenna for experimental characterization. It is noted that the characterization is focused on how the incorporation of U-shaped DGS into the groundplane of array antenna can reduce the coupling level between two antenna elements.

B. Characterization and Discussion

The measurement results of S_{11} for realized array antenna with and without U-shaped DGS are plotted in Fig. 5 with the simulation results depicted together as comparison. The results show that the array antenna without U-shaped DGS resonates at the frequency of 2.38GHz, while the array antenna with U-shaped DGS is 10MHz slightly higher, i.e. 2.39GHz, which is mostly affected by the presence of U-shaped DGS. Both simulated resonant frequencies are coincided with the measured ones. The value of S_{11} is up to 22dB for the array antenna with U-shaped DGS and 14dB for the antenna without U-shaped DGS. It is shown that the impedance matching improvement of array antenna with U-shaped DGS has been accomplished. The impedance bandwidth for $S_{11} \leq$ 10dB of the array antenna with and without U-shaped DGS are 80MHz (2.35–2.43GHz) and 60MHz (2.35–2.41GHz), respectively. It means that the presence of U-shaped DGS has contributed the improvement of impedance bandwidth up to 20MHz.

Furthermore, the measurement and simulation results of S_{21}, also known as coupling between two antenna elements, are plotted in Fig. 6. It can be observed that the coupling of array antenna with U-shaped DGS is lower than the array antenna without U-shape DGS. The simulated couplings for antenna array with and without U-shape DGS at the frequency of 2.38GHz are 23.34dB and 21.34dB, respectively, indicating the improvement of 2dB. Meanwhile, the measured couplings for realized antenna array with and without U-shaped DGS at the frequency of 2.38GHz are 22.89dB and 22.01dB, respectively, which also showing the improvement of 0.88dB. At the frequency of 2.35GHz, the simulated couplings of array antenna with and without U-shaped DGS are 23.87dB and 21.87dB, respectively. Whereas the measured couplings of realized antenna array with and without U-shaped DGS are 24.24dB and 21.79dB, respectively. Both simulated and measured couplings also provide the improvement of 2dB and 2.45dB, respectively.

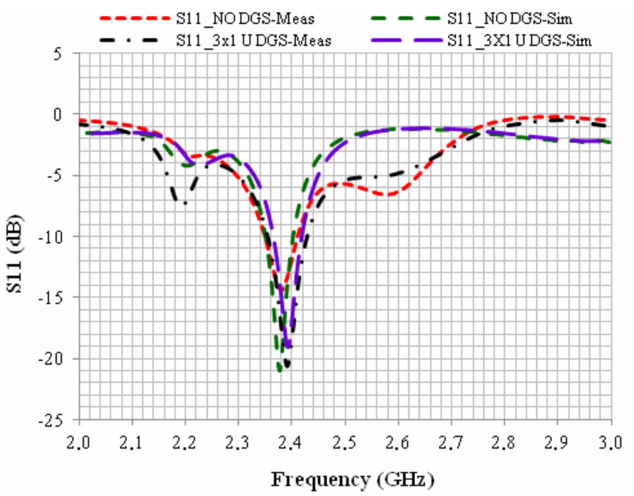

Fig. 5. Measurement and simulation results of S_{11} for array antenna with and without U-shaped DGS.

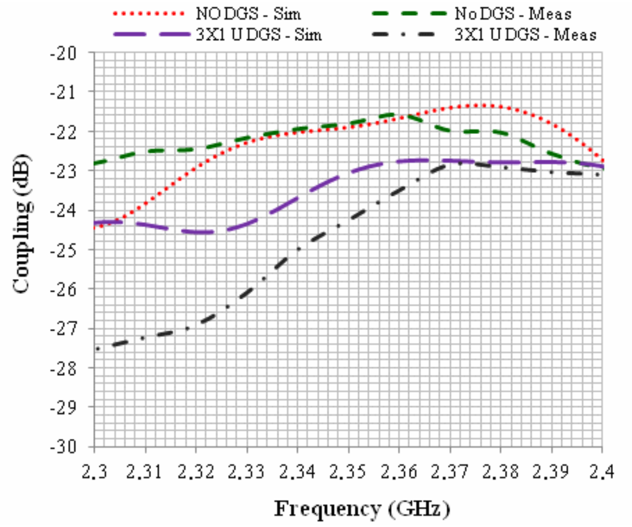

Fig. 6. Measurement and simulation results of S_{21} for array antenna with and without U-shaped DGS.

The interesting point from the characterization of array antenna with U-shaped DGS using different feeding port for each antenna element is that the coupling between two antenna elements is smaller compared to the coupling achieved in [11]. This is due to the power excitation which is fed at the port of feeding line. Since each antenna element obtains full power excitation at each port of the feeding line, it provides the impact of greater generated coupling. While in [11] each antenna element gets half power excitation which gives the impact of smaller generated coupling.

IV. Conclusion

The coupling reduction between two antenna elements of array antenna has been presented and implemented using U-shaped DGS incorporated into the groundplane of array antenna. The array antenna with U-shaped DGS has been simulated and realized to demonstrate the feasibility of U-shaped DGS in coupling reduction which was compared to the array antenna without DGS. It has been shown that the U-shaped DGS could reduce the coupling between two antenna elements. The measurement and simulation results have shown the achievement in coupling reduction up to 2dB and 0.88dB, respectively, at the resonance frequency of 2.38GHz. In addition, the investigation of other radiation characteristics relating to the coupling reduction between two antenna elements of array antenna is still in progress in which the result will be reported later.

ACKNOWLEDGMENT

The authors would like to thank Mr. Zenal Aripin from the Radio Telecommunication and Microwave Laboratory, School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia, for technical assistance and fruitful discussion in the experimentation.

REFERENCES

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

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

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

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

[5] N. Engheta and 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] 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.

[13] 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.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] 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.