International Journal of Advanced Smart Convergence Vol.13 No.2 1-6 (2024)
http://dx.doi.org/10.7236/IJASC.2024.13.2.1

IJASC 24-2-1

A Unit-Cell Varying Pattern Reconfigurable Zeroth-order Resonance Antenna

Hyeon-Cheol Ki

Professor, Department of Electronic Engineering, Gachon University, Korea
E-mail: hcki@gachon.ac.kr

Abstract

Reconfiguration and miniaturization of antennas have become key attributes in modern wireless communication systems. Reconfiguration of radiation pattern can alleviate the problems encountered in modern wireless communication systems such as multi-path problems. Physical limitation of miniaturization also can be overcome by using a zeroth-order resonance (ZOR) antenna based on metamaterial. In order to achieve reconfiguration and miniaturization of antennas at the same time, we propose a new pattern reconfigurable zeroth-order resonance (ZOR) antenna that reconfigures the radiation patterns by varying the position and the number of unit cells comprising the antenna. The antenna is fabricated in an equilateral triangular shaped symmetrical structure to increase pattern variety. This structure can easily provide eight different radiation patterns (two omnidirectional and six monopole like patterns).

Keywords: *Pattern Reconfiguration, ZOR Antenna, ENG ZOR Antenna, Pattern Diversity*

1. Introduction

Metamaterials are artificial electromagnetic media that exhibit extraordinary electromagnetic properties not available in nature[1-3]. Since the early 2000s, metamaterials have spread into various fields, having found applications [4-6]. In this paper we are especially interested in miniaturized reconfiguration antenna based on metamaterials [7-9].

Reconfiguration and miniaturization have become key attributes strived by the researchers in designing the antennas. Especially, radiation pattern reconfiguration has attracted much interest among the researchers because it can alleviate the problems encountered in modern wireless communication systems such as multi-path problems [10]. For the miniaturization efforts, physical limitation is imposed when designing conventional electrically small resonant antennas. To overcome this limitation, a zeroth-order resonance (ZOR) antenna based on metamaterial may be used. The infinite wavelength nature of the ZOR antenna allows the resonance frequency of the antenna to be independent on the physical size [11]. In this paper, we propose a new pattern reconfigurable ZOR antenna that varies the position and the number of unit cells which comprise the ZOR antenna to reconfigure the radiation patterns.

Manuscript Received: April. 5. 2024 / Revised: May. 23. 2024 / Accepted: May. 29. 2024
Corresponding Author: hcki@gachon.ac.kr
Tel: *** - **** - **** Fax: +82-31-750-5322
Professor, Department of Electronic Engineering, Gachon University, Korea

2. Design of ZOR Antenna

The proposed antenna is composed of a triangular patch, six shortening pins, and three switches that switch the path link between the antenna patch and the three outer shortening pins at vertices (Fig. 1). Therefore, the antenna is composed of six unit-cells. Since the unit-cells are connected to each other without capacitors, it behaves as an ENG (epsilon negative) type of ZOR antenna [12]. By connecting or disconnecting the outer shorting pins, the number and the position of the unit-cells comprising the antenna can be manipulated. Using these three switches we can reconfigure the radiation pattern of the ZOR antenna (in this experiment we used small metal patches as switches)

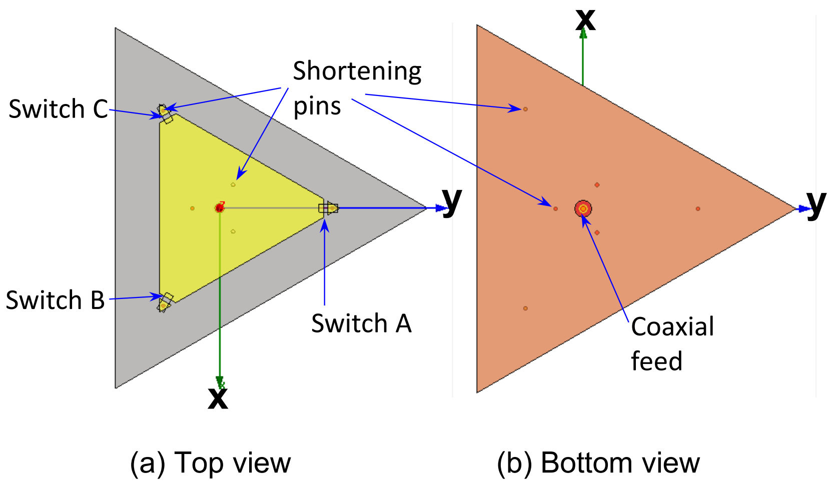
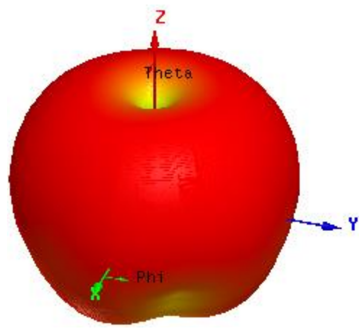


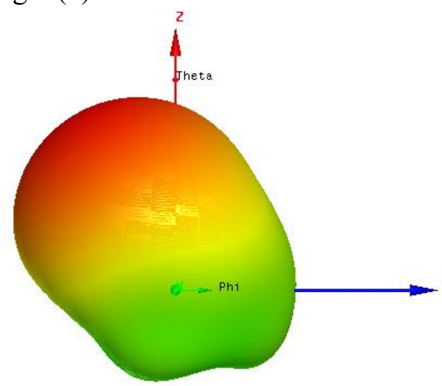
Figure 1. Designed ZOR antenna composed of 6 unit-cells

3. Principles of Reconfigurations

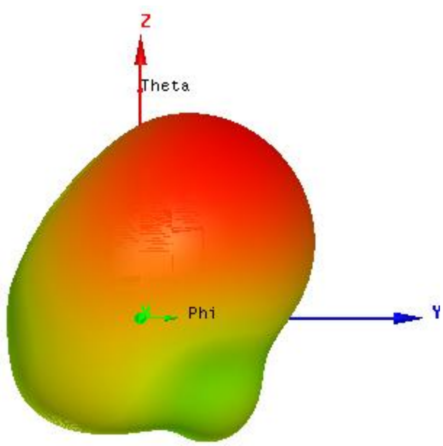
Fig. 2 shows antenna radiation patterns simulated by HFSS of Ansys Electronics Desktop (AEDT). When all the switches are turned ON, the antenna behaves as a ZOR antenna composed of six unit-cells. Because the lateral (xy-plane) net electric field is zero due to the symmetrical structure of the antenna, only the vertical (z-direction) net fields exist thereby omnidirectional radiation pattern is generated as shown in Fig. 2(a). When switch A is turned OFF and all other switches are turned ON, the antenna contains five unit cells and becomes asymmetrical. In this case, y-directional net lateral electric fields are generated especially in negative region of y-axis due to the asymmetry. In the latter case, the generated lateral fields are added to the omnidirectional pattern to fill the null of the omnidirectional pattern, which leads to a monopole like radiation pattern tilted to the negative y-direction as shown Fig. 2(b). If switch B is turned OFF instead of switch A, the tilted radiation pattern rotates clockwise by 120 degrees on z-axis without the change in the resonance frequency. In this manner, the tilted radiation pattern can be rotated by 360 degrees, which generates three different radiation patterns. When switch B and C are turned OFF and the switch A is turned ON, the antenna contains four unit cells and also becomes asymmetrical. In this case, y-directional net lateral electric fields are generated especially in positive region of y-axis due to the asymmetry. So the radiation pattern is tilted toward positive y-direction as shown in Fig. 2(c), which is opposite to Fig. 2(b) in direction. This tilted pattern can be rotated in the same manner as the previous case. Combining with previous results, the monopole like pattern can be controlled to point toward six different directions in the azimuth direction. When all the switches are turned OFF, the antenna contains three unit cells and becomes symmetrical. Due to the symmetrical structure, the radiation pattern becomes an omnidirectional as shown in Fig. 2(d).



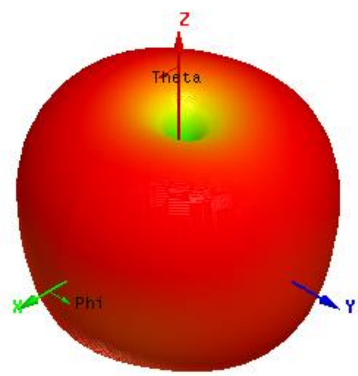
(a) All the switches are turned ON.



(b) Switch A is turned OFF and the rest are turned ON.



(c) Switch B and C are turned OFF and the rest is turned ON



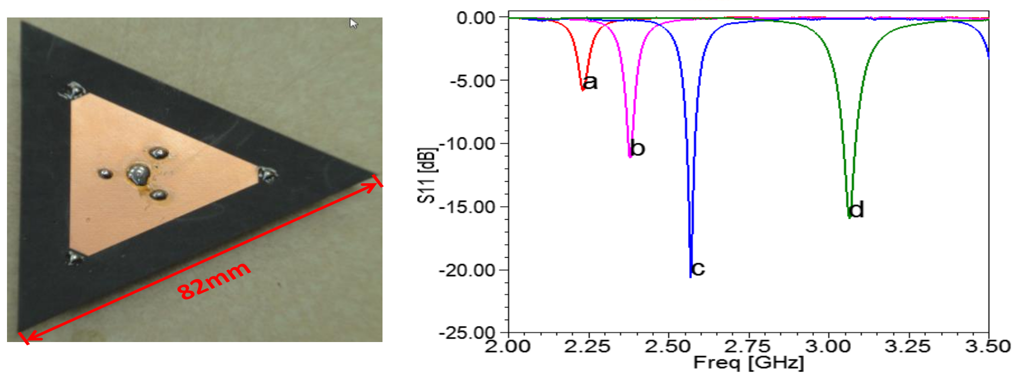
(d) All the switches are turned OFF

Figure 2. Antenna radiation patterns simulated by HFSS

4. Fabrication and Measurements

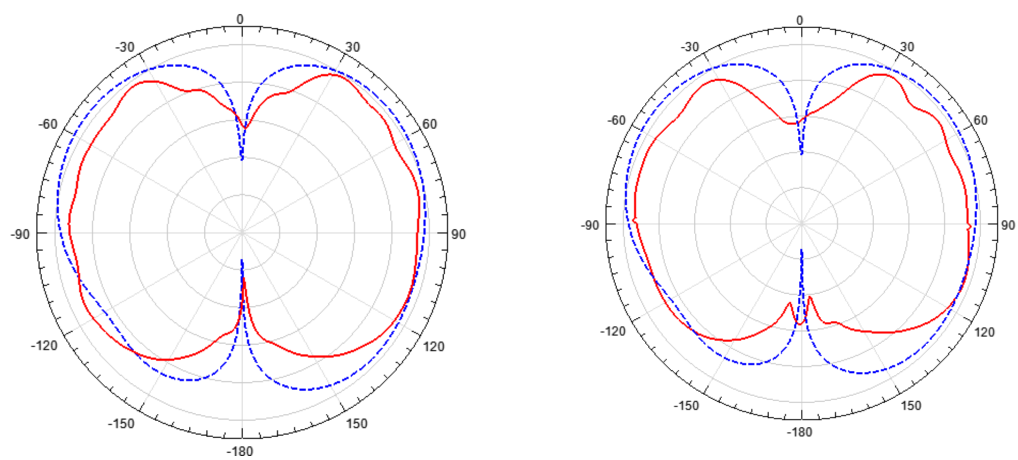
The fabricated pattern reconfigurable ZOR antenna is shaped in an equilateral triangle with a side length of 82mm as shown in Fig. 3(a). The return loss is measured for all possible ON/OFF combinations from all ON state to all OFF state (total of four states). The results are shown in Fig. 3(b) noted by a, b, c and d in sequence.

Fig. 4 shows the measured radiation patterns. Fig. 4(a) and (b) are the measured result of Fig. 2(a), and show cross sections of an omnidirectional pattern on z-axis as shown in Fig. 2(a). Fig. 4(C) and (d) are the measured results of Fig. 2(b) and (c) respectively. The patterns are tilted toward the opposite directions from each other as expected.

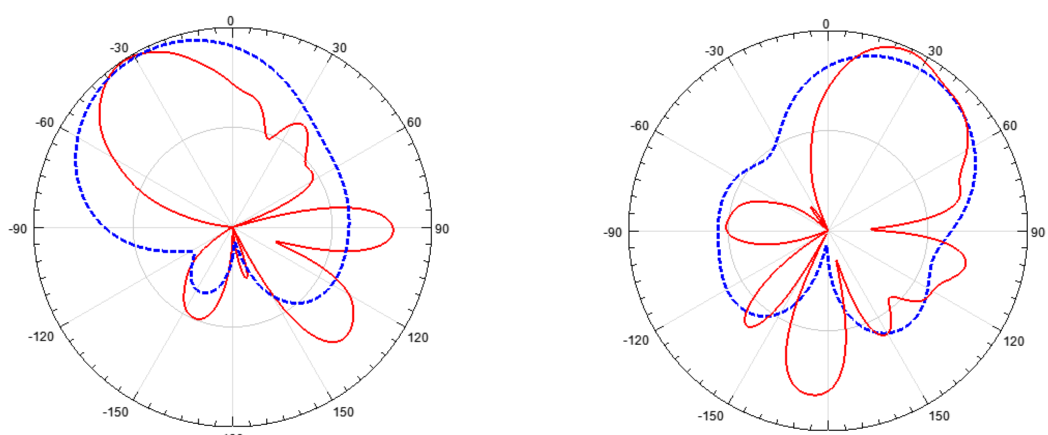


(a) Photograph (b) Measured S11

Figure 3. Fabricated pattern reconfigurable ZOR antenna.



(a) zy-plane (all the switches are turned ON) (b) zx-plane (all the switches are turned ON)



(c) zy-plane (switch A is turned OFF rest are turned ON) (d) zy-plane (switch B and C are turned and the OFF and the rest is turned ON).

Figure 4. Antenna radiation patterns (solid line: measured; dashed line: simulated)..

5. Conclusion

Reconfiguration and miniaturization of antennas have been issued in modern wireless communication systems. Reconfiguration of radiation pattern can alleviate the problems encountered in modern wireless communication systems such as multi-path problems. Physical limitation of miniaturization also can be overcome by using a zeroth-order resonance (ZOR) antenna based on metamaterial.

In order to achieve reconfiguration and miniaturization of antennas at the same time, we propose a new pattern reconfigurable zeroth-order resonance (ZOR) antenna which varies the position and the number of unit cells composing the ZOR antenna itself to reconfigure radiation patterns. The synergy is achieved by making the antenna structure symmetrical because it helps radiation pattern to be more variety by rotating the patterns. Using a triangular shaped symmetrical antenna, we can easily generate eight different radiation patterns, which shows its effectiveness and applicability for many fields.

References

[1] B.L. Prakash, B.T.P. Madhav, T. Lokesh, Y.R. Sri, N.V.D.S. Aditya and M.V. Rao, “Metamaterial Inspired Tri-Band Antenna with SRR and Shorting Stub,” ARPN Journal of Engineering and Applied Sciences, VOL. 12, NO. 21, pp. 6197- 6209, November 2017
DIO:https://doi.org/10.1007/s10470-022-02044-9

[2] Y. Kotsuka and S. Sugiyama, “ New methods of constructing computer controllable metamaterial and its microwave absorber application,” IEEE MTT-S International Microwave Symposium Digest, pp. 927–930, 2006
DIO:10.1109/MWSYM.2006.249868

[3] M. Moniruzzaman, M.T. Islam, M.T. Islam, M.E.H. Chowdhury, H. Rmili, and M. Samsuzzaman, “Cross coupled interlinked split ring resonator based epsilon negative metamaterial with high effective medium ratio for multiband satellite and radar communications,” Results in Physics, Vol.18, 2020
DIO:https://doi.org/10.1016/j.rinp.2020.103296

[4] M. Kärkkäinen and S. Maslovski, “Wave propagation, refraction, and focusing phenomena in Lorentzian double-negative materials:A theoretical and numerical study,” Microwave and Optical Technology Letters, Vol.37, No.1, pp.4–7, 2003.
DOI:10.1002/mop.10807

[5] D. Negi, R. Khanna and J. Kaur, “Design and performance analysis of a conformal CPW fed wideband antenna with Mu-Negative metamaterial for wearable applications,” International Journal of Microwave and Wireless Technologies, Vol.11, No.8, pp. 806–820, 2019.
DIO:https://doi.org/10.1017/S1759078719000497

[6] M.E.L. Ghzaoui, J. Belkadid, and A. Benbassou, “Near zero index Metamaterial-based SIW antenna for 6G Sub-Terahertz applications,” Results in Optics, Vol.12, pp.1-10, July 2023.
DIO:https://doi.org/10.1016/j.rio.2023.100468H. Nakano

[7] W. Yang, L. Gu, W. Che, Q. Meng, Q. Xue and C. Wan, "A novel steerable dual-beam metasurface antenna based on controllable feeding mechanism," IEEE Trans. Antennas Propag., vol. 67, no. 2, pp. 784-793, February 2019.
DIO:10.1109/TAP.2018.2880089

[8] H. C. Ki, "Effects of Tilting and Bending on Embroidered Dipole Array Antenna,” The Journal of The Institute of Internet, Broadcasting and Communication, Vol. 22, No. 2, pp.21-26, Apr. 30, 2022.
DIO:https://doi.org/10.7236/JIIBC.2022.22.2.21

[9] H. C. Ki, "An Investigation of human body influence on Embroidered Textile Dipole Antenna," The Journal of The Institute of Internet, Broadcasting and Communication, Vol. 21, No. 5, pp.155-160, Oct. 31, 2021.
DIO:https://doi.org/10.7236/JIIBC.2021.21.5.155

[10] J.D. Boerman, and J.T. Bernhard, "Performance Study of Pattern Reconfigurable Antennas in MIMO Communication Systems," IEEE Transactions on Antennas and Propagation, Vol. 56, No. 1, pp. 231-236, January 2008.
DOI: 10.1109/TAP.2007.913141

[11] A. Lai, C. Caloz, and T. Itoh, "Composite Right/Left-Handed Transmission Line Metamaterials," IEEE Microwave Magazine, pp.34-50, September 2004.
DOI: 10.1109/MMW.2004.1337766

[12] J. Park, Y. Ryu, J. Lee, and J. Lee, "Epsilon Negative Zeroth-Order Resonator Antenna," IEEE Transactions on Antennas and Propagation, Vol. 55, No. 12, pp. 3710-3712, December 2007.
DOI: 10.1109/TAP.2007.910505