International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:7, 2014

Design of a Dual Polarized Resonator Antenna for Mobile Communication System

N. Fhafhiem, P. Krachodnok, R. Wongsan

***Abstract*—**This paper proposes the development and design of double layer metamaterials based on electromagnetic band gap (EBG) rods as a superstrate of a resonator antenna to enhance required antenna characteristics for the mobile base station. The metallic rod type metamaterial can partially reflect wave of a primary radiator. The antenna was designed and analyzed by a simulation result from CST Microwave Studio and designed technique could be confirmed by a measurement results from prototype antenna that agree with simulation results. The results indicate that the antenna can also generate a dual polarization by using a 45˚ oriented curved strip dipole located at the center of the reflector plane with double layer superstrate. It can be used to simplify the feed system of an antenna. The proposed antenna has a bandwidth covering the frequency range of 1920 – 2200 MHz, the gain of the antenna increases up to 14.06 dBi. In addition, an interesting sectoral 60˚ pattern is presented in horizontal plane.

***Keywords*—**Metamaterial, electromagnetic band gap, dual polarization, resonator antenna.

I. Introduction

DUAL polarization antennas with sector-shaped radiation pattern are often required for the mobile communication systems. To radiate the dual polarized wave, two dipole antennas need to be used with dual feeding. They are placed on a reflector plane at ±45˚ angle and arrayed to improve the gain [1]-[4]; however, it is hard to fabricate the feed system. Even though the dipole antenna is still interesting in wireless communication systems, it has elementary structure, simple concept, and broadband characteristics [5]-[7]. One solution to enhance the gain of an antenna is using metallic reflector plane as shown in Fig. 1 (a). The metallic reflector is located at the back of a dipole antenna with gap as a quarter wavelength. Usually, the main disadvantage of an antenna on metallic plane is making the overall size of the antenna too big and bulky for the low frequency range of operations. Moreover, the reflector plane cannot suppress the surface wave, so an antenna gain and efficiency will then be greatly decreased [8]-[10]. Figs. 2 (a) and 3 (a) show radiation patterns of a curved strip dipole on reflector plane. Due to a 45˚ oriented primary radiator located over the reflector plane, its polarized waves values are equal in both x (horizontal) and y (vertical) axis with the maximum gain of 7.6 dBi at 2100 MHz. In this case, when a 45˚ oriented curved strip dipole on reflector plane has a positive effect on the pattern, it is leaving the beam at its centre.

In recent years, metamaterials based on electromagnetic band gap (EBG) structures have been widely investigated in the antennas domain to enhance gain and radiation efficiency. The metamaterials classified by a permittivity and permeability are primarily dependent on the geometrical properties of an inclusion shape and mutual distance between the lattices constant. EBG is not only used to a reflector plane [11]-[13], but also adapted for a superstrate of the primary radiator with reflector plane [14]-[17]. The main advantage of the EBG resonator is enhancing gain and efficiency. To confirm the advantage of the EBG resonator, we presented the radiating curved strip dipole antenna with cavity wall which is composed of single layer EBG as a superstrate and metallic reflector [18]. Unfortunately, few papers were proposing the EBG structures for polarization adjustment [19], [20].

In this paper, the metallic rods are used to a partially reflective surface (PRS) of a 45˚ oriented curved strip dipole located at the center of the reflector plane. The horizontal polarized partially reflective surface (PRS polar H) is placed above a primary radiator as shown in Fig. 1 (b). Not only it can improve the gain in horizontal polarization (as seen in Fig 2 (b)), but also the gain in vertical polarization is improved by using the vertical polarized partially reflective surface (PRS polar V) as shown in Figs. 1 (c) and 2 (c). A part from this, both of superstrate layers contribute to symmetrical radiation pattern of the antennas demonstrated in Figs. 2 (b), 2 (c), 3 (b) and 3 (c). Two layers of metallic rod type metamaterials, horizontal and vertical polarizations, are combined for dual polarization with high gain. However, the square antenna is not suitable and does not meet the requirements of the sector antenna element, in this paper; the antenna is reduced in size and added the vertical walls in yz plane for wide beamwith in horizontal plane.

II. Partially Reflective Surface Structure

In this paper, we firstly simulate the unit cell of metamaterial, a unit cell defined by parameters a_0, g_0, and t_0, shown in Fig. 4 (a). Aluminium rod is surrounded by four periodic boundaries. This model can be used to estimate the transmission and the reflection of the aluminium rods structure. The resonant frequency is determined by the parameter of the aluminium rod structure, especially by the width and thickness of rod structure. An aluminium rod structure is divided into polarized groups which are PRS horizontal polarization (PRS polar H) and PRS vertical polarization (PRS polar V). The PRS polar H and V structures resonating at 2100 MHz are designed and denoted in Figs. 4 (b) and 4 (c). The parameters

N. Fhafhiem, P. Krachodnok, and R. Wongsan are with the School of Telecommunication Engineering, Suranaree University of Technology, Nakhonratchasima 30000, Thailand (e-mail: m5140732@g.sut.ac.th, priam@sut.ac.th, rangsan@sut.ac.th, respectively).

are optimized by using CST microwave studio. The aluminium rods are 1 mm and 6 mm thick, respectively, and the parameters are as follows: A_1 = 13.26 mm, A_2 = 3.85 mm, g_1 = 29.83 mm, g_2 = 46.42 mm and t_1 = t_2 = 530 mm. The S-parameters of the unit cell are simulated and then the S_{11} and S_{21} can be plotted in Fig. 5 (a). These results indicate that PRS structure is partially reflective surface, as shown in Fig. 5 (b). Whenever the electromagnetic band gap becomes one of the several aluminium rods' functions, it works as a medium in the form of a superstrate. Figs. 5 (b) and 5 (c) demonstrate the propagation of electromagnetic fields which is passed through the medium. When the electromagnetic field propagates on the medium, the reflection and refraction wave occur.

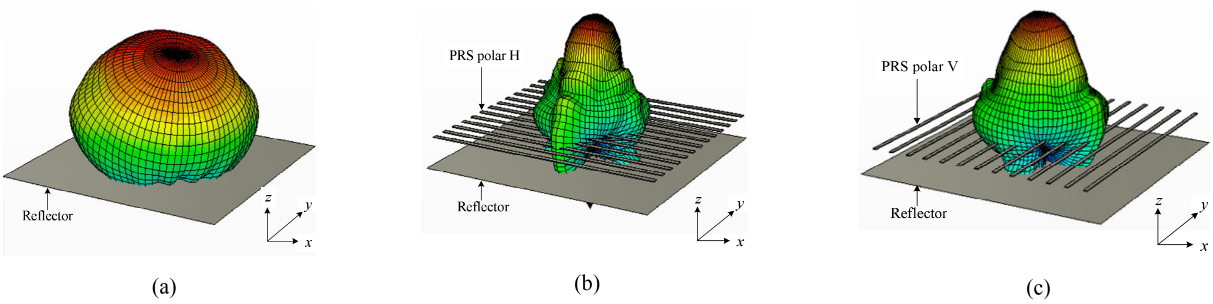


Fig. 1 3 D radiation patterns and structures of a 45˚ oriented curved strip dipole placed (a) over reflector plane with quarter wavelength, (b) between reflector and PRS polar H, and (c) between reflector and PRS polar V

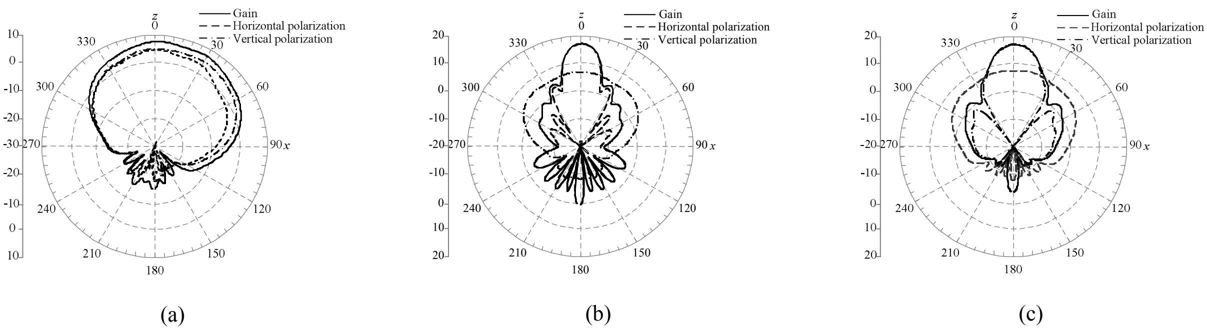


Fig. 2 The *xz* plane of a 45˚ oriented curved strip dipole placed (a) over reflector with quarter wavelength, (b) between reflector and PRS polar H, and (c) between reflector and PRS polar V

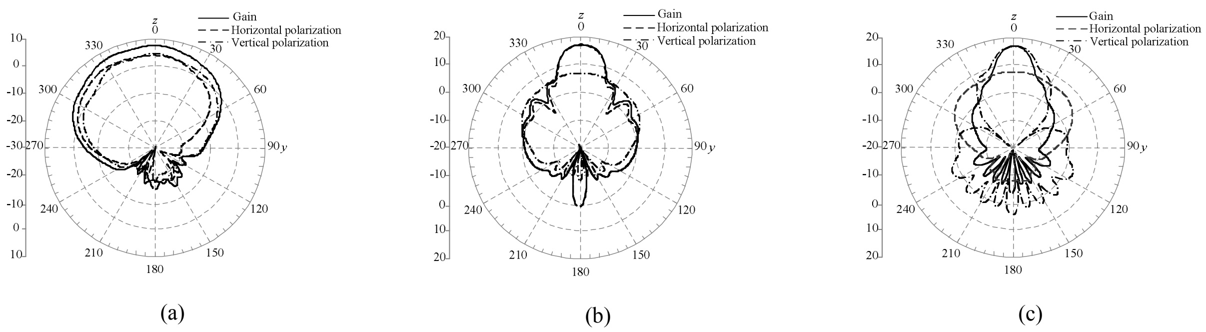


Fig. 3 The *yz* plane of a 45˚ oriented curved strip dipole placed (a) over reflector with quarter wavelength, (b) between reflector and PRS polar H, and (c) between reflector and PRS polar V

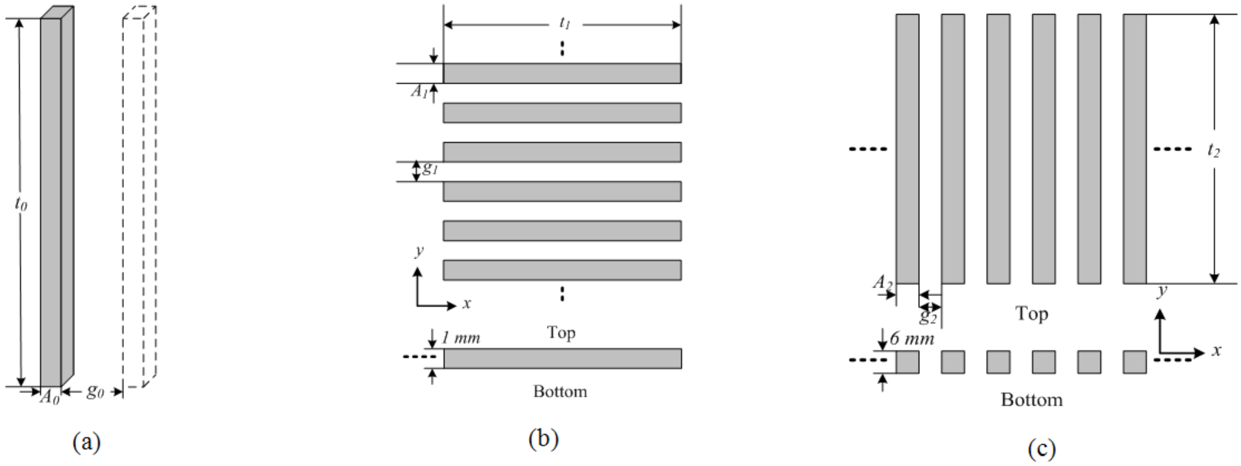


Fig. 4 (a) Unit cell of PRS rod structure, (b) PRS polar H, and (c) PRS polar V

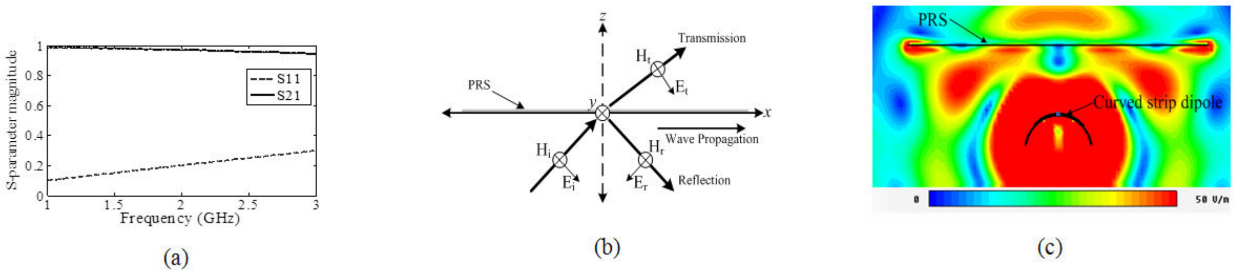


Fig. 5 (a) the *S*-parameters of PRS, (b) wave propagation of PRS, and (c) near-field distribution

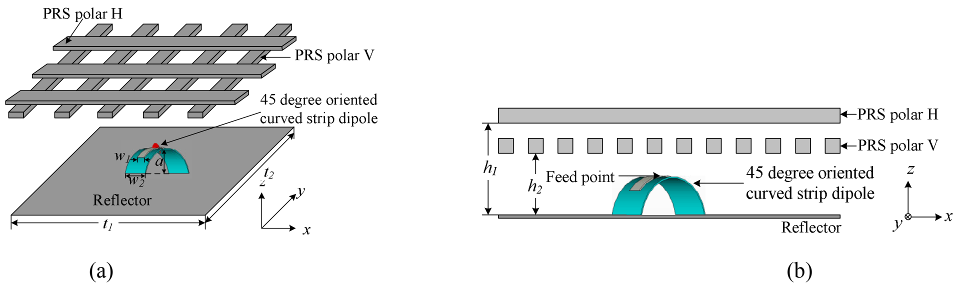


Fig. 6 Antenna configurations (a) 3D view and (b) side view of dual polarization square antenna. The center point of antenna is defined as the origin of coordinates

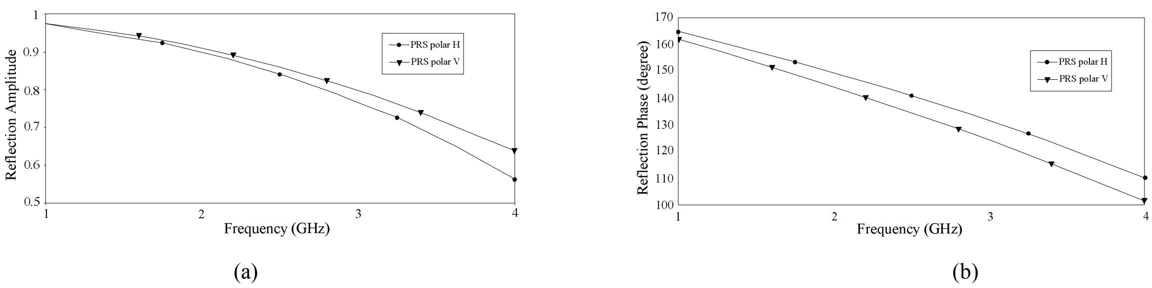


Fig. 7 The reflection (a) amplitude and (b) phase of PRS

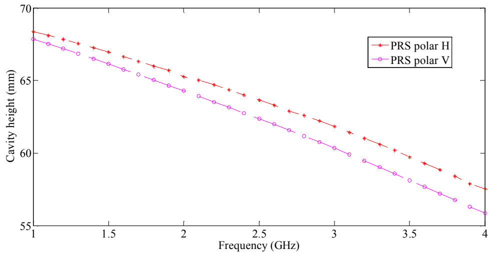


Fig. 8 Cavity height between the ground plane and superstrate

III. Design of Dual Polarized Resonator Antenna

Fig. 6 shows the dual polarized resonator antenna which is excited by a curved strip dipole. It is oriented along $\phi = 45°$ direction and placed over the reflector plane with the height (a) of 0.2λ. The antenna is designed to work at 2100 MHz which is the same resonant frequency of PRS design in the last section. The appropriate parameters are w_1 = 15 mm, w_2 = 30 mm, a = 34 mm, and L = 82.81 mm. Besides, the cavity wall consisting of the reflector plane and double PRS layers in polar V and H, is necessary for the two transmitted components to process the equally amplitude. The reflection coefficient amplitude and phase of the PRS polar H and V versus the frequency are shown in Fig. 7. The cavity height (h) depends on the frequency which can be obtained through following relations (1),

$$h = \frac{c}{2f}\left[\frac{\phi_{EBG} + \phi_{PEC}}{360^o}\right]. \tag{1}$$

where, the variables c, f, ϕ_{PEC}, and ϕ_{EBG} are the speed of light, resonant frequency, and the reflection coefficient phase of reflector and EBG, respectively. Due to the relationship between the reflection phase and (1), so the height h_1 is chosen to be 67 mm for the resonant frequency of 2100 MHz. According to our expectations of the dual polarized antenna, PRS polar V is added to the lower reflective wall with fix the cavity height (h_2) of 63 mm. If the cavity height (h parameter) is changed, Fig. 8 denotes that the resonant frequency is varied.

IV. Results and Discussion

This section presents that there is a relation between a curved strip dipole with double PRS layers and the electric field level in x- and y-axis is presented. The antenna therefore can radiate the dual polarization. Almost all the parameters are taken from the antenna constructed for the experiment. Only the reflector plate size is assumed to be infinite. The calculated current is weak enough on the peripheral area out of $3\lambda\times3\lambda$. As the simulated gain, it is around 18.52 dBi at the frequency of 2100MHz as shown in Fig. 9 (a). In addition, over the whole frequency band (2040 – 2180 MHz), the -3 dB directive gain could be obtained. The near-field distribution behavior on the PRS surface of the dual polarization square antenna is studied and indicated in Fig. 9 (b). Studying the electric field behavior between superstrate and primary radiator with reflector plane reveals that waves are refracted and reflected by PRS surface; therefore, the antenna can generate the high electric field level. The simulated radiation pattern of square resonator antenna is shown in Figs. 9 (c) and 9 (d), which has low side lobes. Because of the high requirements on base station antenna in cellular network, the most popular choices are the antennas with horizontal half power beamwidth of 60˚. The optimum horizontal and vertical beamwidth is decided by the network architecture and propagation environment.

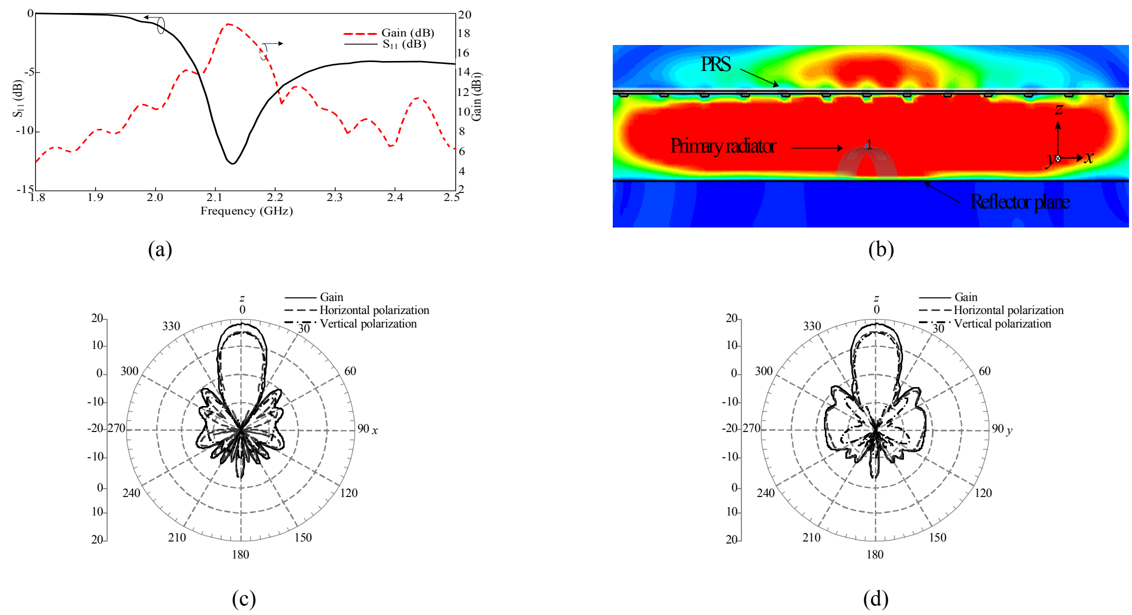


Fig. 9 Simulated results of square resonator antenna (a) gain and S_{11}, (b) near-field distribution, (c) radiation pattern in xz plane, and (d) radiation pattern in yz plane

TABLE I
SIMULATED RESULTS WHEN t_1 IS VARIED

t_1 (mm)	Gain (dBi)	HPBW (degree)
400	16.1	33.7
350	14.8	48.9
300	14.0	58.9
250	12.5	67.9

TABLE II
SIMULATED RESULTS WHEN t_2 IS VARIED

t_2 (mm)	Gain (dBi)	HPBW (degree)
530	13.3	58.9
650	14.2	56.2
750	14.3	57.5
850	14.1	60.1
950	15.0	59.0
1050	14.2	59.6

Consideration of Fig. 10 (a) concludes that if the square resonator antenna is reduced of t_1 = 400 mm, the pattern is rather symmetric and the beamwidth is wide. Therefore, t_1 parameter is reduced and has an effect on HPBW in horizontal plane, as shown in Fig. 10 (b). Because of the finite size of surface waves generated by the antenna on reflector plane, the maximum gain of the antenna is lower than square resonator antenna. Simulated gain and HPBW in *xz* plane are concluded in Table I. Although the pattern is symmetric at t_1 = 400 mm, the HPBW is not sufficient for the base station antenna. Therefore, the horizontal HPBW of 58.9° when t_1 = 300 mm is used. A side from this the *yz* radiation pattern is plotted in Fig. 10 (c); it has been already symmetric. To solve a problem in *xz* plane with *h* = 50 mm, vertical walls are installed in *yz* plane as shown in Fig. 11 (a). The parameters of PRS structure are described in section II. Five and nineteen metamaterial rods of PRS polar H and V structure, respectively, are used for a superstrate on reflector plane with vertical walls. To improve the directive gain, the length of antenna in *y* axis (t_2) is increased. Figs. 11 (b) and 11 (c) show the radiation pattern when t_2 is varied. It illustrates that the HPBW and the gain are suitable for the sector antenna, when t_2 is 950 mm, the simulated gain and HPBW in *xz* plane are concluded in Table II.

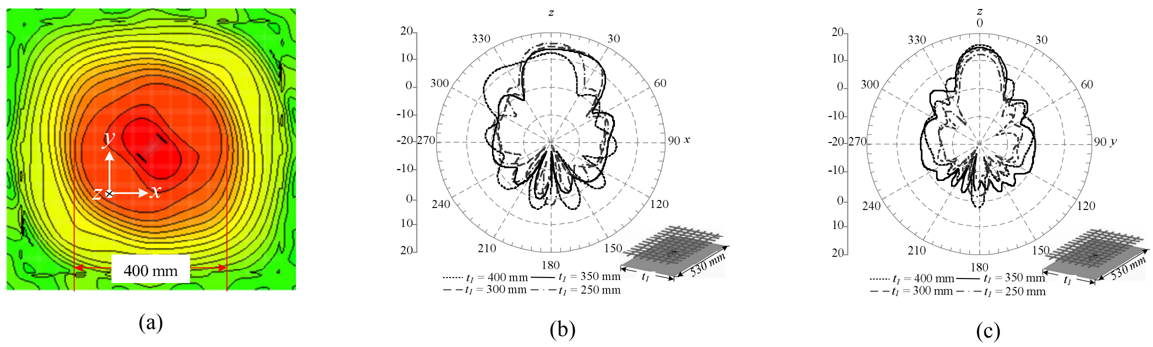


Fig. 10 Simulated results (a) current distribution on reflector plane at 2100 MHz, (b) radiation pattern in *xz* plane, and (c) *yz* plane when t_1 is varied

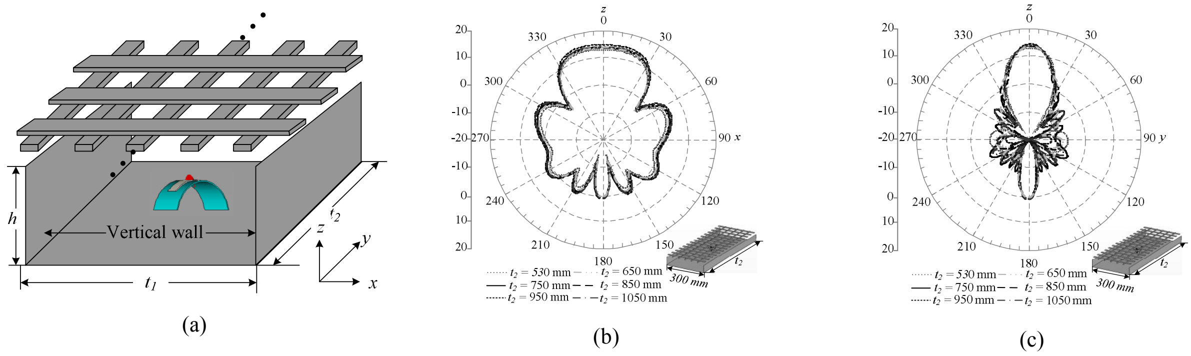
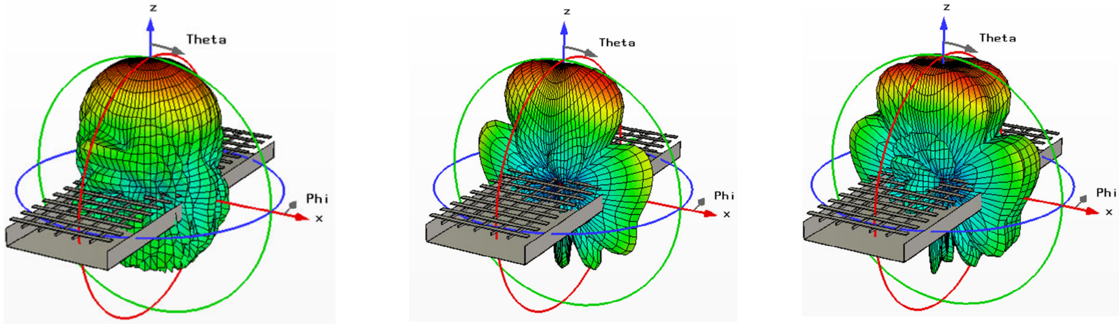
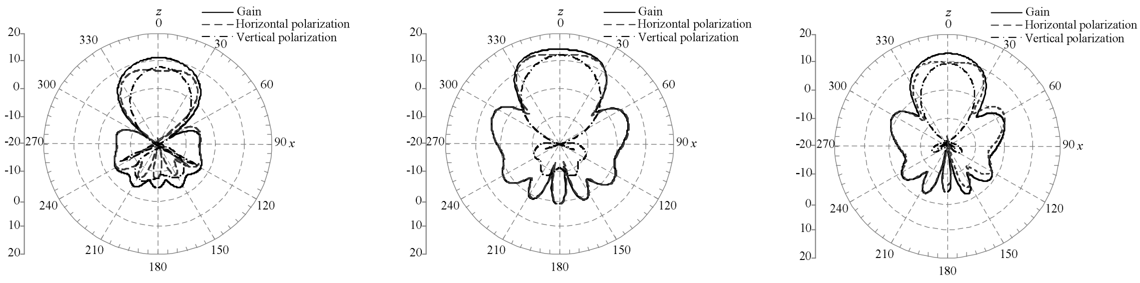


Fig. 11 (a) the geometry of sector antenna, (b) radiation pattern in *xz* plane, and (c) *yz* plane at 2100 MHz when t_2 is varied



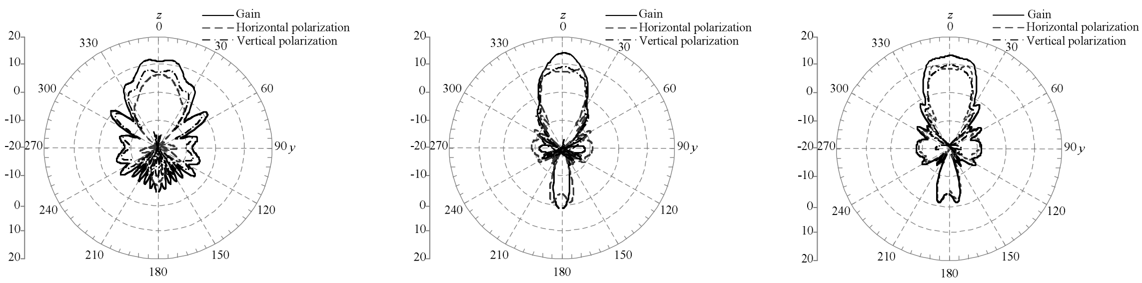
(a) (b) (c)

Fig. 12 3D simulated radiation patterns of dual polarization antenna with vertical walls at (a) 1920 MHz, (b) 2100 MHz, and (c) 2170 MHz



(a) (b) (c)

Fig. 13 The *xz* plane simulated radiation pattern of dual polarization antenna with vertical walls at (a) 1920 MHz, (b) 2100 MHz, and (c) 2170 MHz.



(a) (b) (c)

Fig. 14 The *yz* plane simulated radiation pattern of dual polarization antenna with vertical walls at (a) 1920 MHz, (b) 2100 MHz, and (c) 2170 MHz

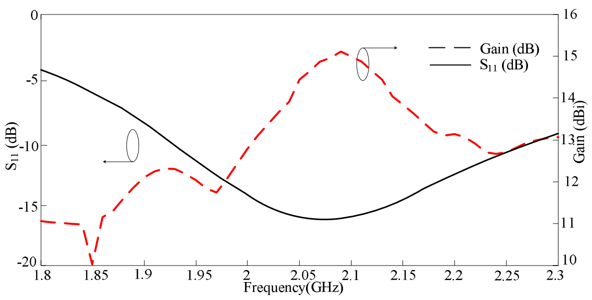


Fig. 15 Simulated gain and S_{11} of the antenna with vertical walls

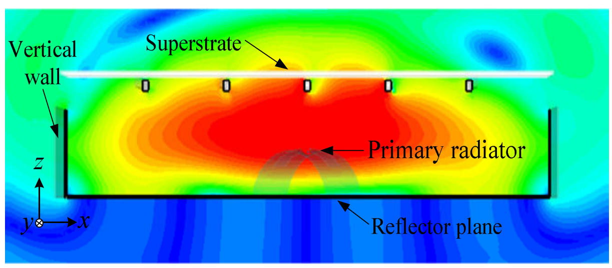


Fig. 16 Near-field distribution of the proposed antenna

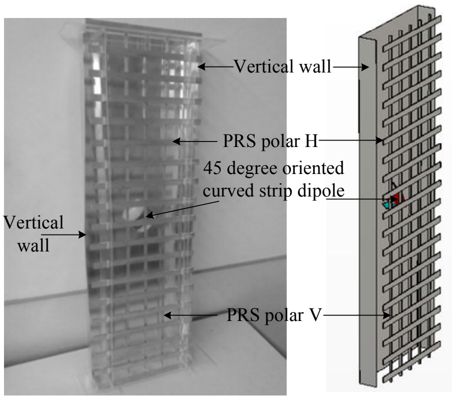


Fig. 17 Photographs of the fabricated antenna

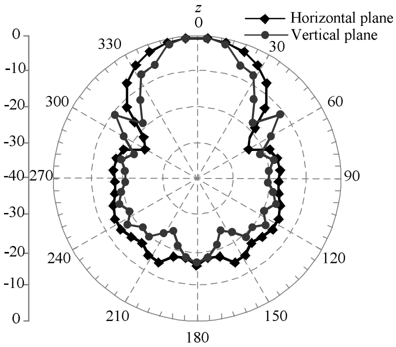
To reveal the radiation characteristic of dual polarization antenna in the whole operating bandwidth, the 3D radiation patterns of the proposed antenna at 1920 MHz, 2100 MHz, and 2170 MHz are also simulated and shown in Figs. 12-14. The antenna beam in horizontal plane (*xy* plane) is wide. These results illustrate the excellent sectoral properties of the antenna. In the vertical plane the radiation is directive with low side lobe, and in the horizontal plane these figures present an interesting sectoral pattern of 60˚. The simulated gain is around 15 dBi at the frequency of 2100 MHz as shown in Fig. 15. In addition, over the whole frequency band (1920–2170 MHz), the -3 dB directive gain could be obtained. Moreover, the vertical walls can control the surface wave at the edge and corner, therefore the wave is redirected to the *z* direction, as shown in Fig. 16.

To verify the performance of the antenna, an antenna prototype has been fabricated as shown in Fig. 17. Corresponding radiation patterns and realized gains of the proposed antenna were measured in the anechoic antenna chamber located at the Suranaree University of Technology (SUT). In this manner, the normalized output power would be resembled in Fig. 18. This plot shows the agreement between the measured and the simulated results in both horizontal and vertical plane patterns. The measured HPBWs in horizontal plane are 51.1˚, 60˚, and 50˚ at 1920 MHz, 2100 MHz, and 2170 MHz, respectively. Moreover the measured HPBWs in vertical plane are 30.8˚, 17.9˚, and 32.5˚ at 1920 MHz, 2100 MHz, and 2170 MHz, respectively. The half-power beamwith in horizontal plane is suitable for 3G mobile base station. Fig. 19 shows the measured gain of the proposed antenna. It can be seen that the gain of the antenna is around 14 dBi for either polar V or polar H at working range of frequency. The similar radiation and gain enhance the efficiency of mobile communication systems.

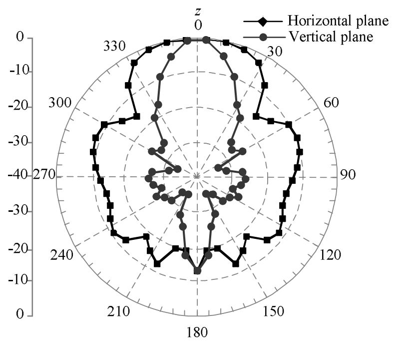
In addition, some specifications from experiment are compared with the ones from simulation as shown in Table III. As we can see, the experiment results have a good agreement with the ones from simulation results. Also, the proposed antenna obtained half-power beamwidth in horizontal and vertical planes and directive gain.

TABLE III
SPECIFICATION OF THE PROPOSED ANTENNA

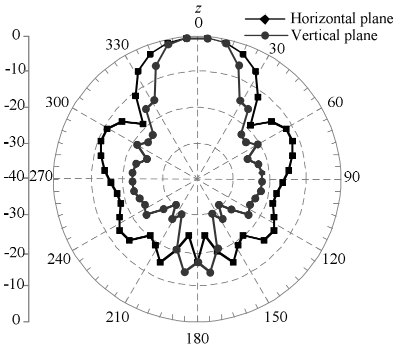
Electrical Data	Simulation	Measurement
Material	Aluminium	Aluminium
Frequency band (MHz)	2100 (1920-2170)	2100 (1920-2200)
Polarization	dual	dual
HPBW (degree)	H:60 V:17.9	H:60 V:20
Gain (dBi)	15	14.06
Antenna size (mm)	950×300×50	950×300×50
Antenna weight (kg)	-	2.7



(a)



(b)



(c)

Fig. 18 Measured radiation pattern of the proposed antenna with vertical walls at (a) 1920 MHZ, (b) 2100 MHz, and (c) 2170 MHz

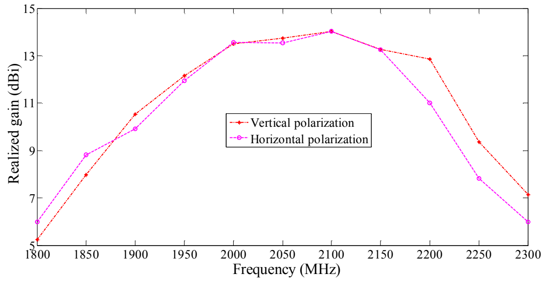


Fig. 19 Measured gain of the proposed antenna

V. CONCLUSIONS

Dual polarized resonator antenna using double polarizing metallic EBG layers with reflector plane and the vertical wall have been developed. It is found that using the double layer of metallic rod type metamaterials above a 45˚ oriented curved strip dipole provides a dual polarization antenna with the gain of 14.06 dBi. Attractively, if vertical walls are placed along *yz* plane, a symmetrical and sectoral radiation pattern (HPBW around 60˚) can be obtained. Moreover, the proposed antenna has a simple structure and low cost, it is generally required in mobile communication systems.

ACKNOWLEDGMENT

The authors gratefully acknowledge financial support for this research project from the Telecommunications Research and Industrial and Development Institute (TRIDI), National Telecommunications Commission (NTC) Fund, Thailand. Moreover, this work was supported by Suranaree University of Technology (SUT) and by the Office of the Higher Education under NRU project of Thailand.

REFERENCES

[1] Y. Liu, A.-T. Bu, E. S. Li, D. M Fu, L. Y. Xiao, “A new dual polarization dipole antenna.” *International Conference on Microwave and Millimeter Wave Technology*, pp. 5-7. 2004

[2] K. M. Mak, H. Wong, K. M. Luk, “A shorted bowtie patch antenna with a cross dipole for dual polarization.” *IEEE Antennas and Wireless Propag.* Lett. 6, pp. 126 – 129. 2007.

[3] A. Abas, A. Asrokin, R. H. Basri, N. Jamlus, “Dual-polarized dipole array antenna for CDMA 450 base station application.” *IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, pp. 1-4. 2010.

[4] Y. Liu, H. Yi, H. Liu, S. Gong, “A novel dual-polarized dipole antenna with compact size for wireless communication.” *Progress In Electromagnetics Research C*, 40, pp. 217-227. 2013.

[5] L. Han, R. Ma, X. Chen, W. Zhang, “Compact dual-band dipole antenna fed by a coplanar waveguide.” *International Conference on Microwave and Millimeter Wave Technology (ICMMT)* pp. 1-3. 2012.

[6] M.Z. Azad, M. Ali, “Novel Widebawd directional dipole antenna on a mushroom like EBG structure.” *IEEE Trans. on Antennas and Propag.* Vol. 5(56), pp. 1242 – 1250. 2008.

[7] Z. Zhang, M.F. Iskander, J.C. Langer, J. Mathews, “Wideband dipole antenna for WLAN.” *IEEE Antennas and Propagation Society International Symposium*, pp. 1963-1966. 2004.

[8] A. Thumvichit, T. Takano, “Ultra low profile dipole antenna with a simplified feeding structure and a parasitic element.” *IEICE Trans. Communications,* E89-B(2), pp. 576-580. 2006.

[9] L.Zhan, Y.Rahmat-Samii, “PBG, PMC and PEC ground plane: A case study of dipole antenna.” *IEICE Trans. Communications,* pp. 674–677. 2000.

[10] N. Fhafhiem, P. Krachodnok, R. Wongsan, “A shorted-end curved strip dipole on dielectric and conducting plane for wireless LANs,” *International Symposium on Antenna and Propagation (ISAP)* pp. 835-838. 2009.

[11] N. Fhafhiem, P. Krachodnok, R. Wongsan, “Curved strip dipole antenna on EBG reflector plane for RFID applications,” *WSEAS Transection on Communications,* 6(9), pp. 374-383. 2010.

[12] F.Yang, Y.Rahmat-Samii, “Electromagnetic band gap structures in antenna engneering.” *USA by Cambridge University Press,* New York 2009.

[13] M. Grelier, C. Djoma, M. Jousset, S. Mallegpl, A. C. Lepage, X. Begaud, “Axial ratio improvement of an archimedean spiral antenna over a radial AMC reflector.” *Appl. Phys. A* 109(3), pp. 1081-1086. 2012.

[14] S. Chaimool, C. Rakluea, P. Akkaraekthalin, “Mu-near-zero metasurface for microstrip-fed slot antennas.” *Appl. Phys. A* 112(3), pp. 669-675 2013.

[15] E. Rodes, M. Diblanc, E. Arnaud, T. Monediere, B. Jecko, “Dual-band EBG resonator antenna using a single-layer FSS.” *IEEE Antennas and Wireless Propag.* Lett. 6, pp. 368–371. 2007.

[16] M. Hajj, R. Chantalat, B. Jecko, “Design of a dual-band sectoral antenna for Hiperlan2 application using double layers of metallic electromagnetic band gap (M-EBG) materials as a superstrate.” *International Journal of Antennas and Propag.,* pp. 1 – 5 2009.

[17] G. V. Trentini, “Partially reflecting sheet array.” *IRE Trans. on Antennas and Propag.* 4(4), pp. 666 – 671. 1956.

[18] N. Fhafhiem, P. Krachodnok, R. Wongsan, “Gain improvement of curved strip dipole using EBG resonator.” *Progress In electromagnetics research symposium proceedings (PIERS)* pp. 1631 – 1634. 2012.

[19] L. Peng, C. L. Ruan, L. Z. Qiang, “A novel compact and polarization-dependent mushroom-type EBG using CSRR for dual/triple-band applications.” *IEEE Microwave and Wireless Components Letters*. 20(9), pp. 489 – 491. 2010.

[20] Q. Wu, C.P. Scarborough, B.G. Martin, R.K. Shaw, D.H. Werner, E. Lier, X. Wang, “A ku-band dual polarization hybrid-mode horn antenna enabled by printed-circuit-board metasurfaces.” *IEEE Trans. on Antennas and Propag.* 61(3), pp. 1089 – 1098. 2013.

Nuchanart Fhafhiem received the B.Eng. and M. Eng. degrees in telecommunication engineering from Suranaree University of Technology in 2007 and 2009, respectively. At present, He Studying doctoral’s degree in telecommunication engineering at Suranaree University of Technology, Thailand. Research interests include antenna design.

Piyaporn Krachodnok graduated with the Bachelor Degree of Engineering in Telecommunication Engineering in 1996 from Suranaree University of Technology (SUT), Thailand, M.Eng. (Electrical Engineering), Chulalongkorn University, Bangkok, Thailand in 2001, and D.Eng.(Telecommunication Engineering), Suranaree University of Technology (SUT), Thailand in 2008 and had worked at this University for a year. Experiences & Expert are Electromagnetic Theory, Microwave Engineering, and Antenna Engineering.

Rangsan Wongsan received B.E. degree in Electronic Engineering from Rajamongala Institute of technology, Theves, and M.E. degree in Electrical Engineering from King Mongkut’s Institue of Technology, North Bangkok, Thailand, in 1989, in 1994, respectively. He is currently working toward the Ph.D. degree in Electrical Engineering of King Mongkut’s Institute of Technology, Ladkrabang, Thailand. In October 1994 he joined the school of Telecommunication Engineering, Institute of Engineering at Suranaree University of Technology (SUT), Thailand. His research focus is on electromagnetic theory and antenna system for several applications.