

# A Circularly Polarized Sector Antenna for Mobile Base Station Using Single Feed with Metallic Rod EBG

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## Abstract

The propose of this paper is to design the circularly polarized antenna for mobile base station, using a curved strip dipole associated with U-shaped reflector and multi-layer metallic rod electromagnetic band gap (EBG). It can be used to simplify the single feed system of an antenna. The advantages of this proposed antenna are easy fabrication and installation, high gain and light weight. Moreover, it provides a sectoral radiation pattern, a main beam having a narrow beam width in the vertical direction and wider beamwidth in the horizontal direction, which are appropriate for mobile phone base station. The half-power beam in the H-plane and E-plane are 60 and 14.4 degrees, respectively. The antenna is designed and analyzed by using a computer simulation technology (CST). In addition,  $S_{11}$ , axial ratio, radiation pattern and gain are displayed. The designed technique could be confirmed by a measurement resulting from prototype antenna corresponding to simulation results. The proposed antenna has a bandwidth covering the frequency range of 1870 - 2170 MHz, and the gain of the antenna increases up to 15.11 dBi.

## Keywords

Sector Antenna, Curved Strip Dipole, Electromagnetic Band Gap, Resonator Antenna, Circular Polarization

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## 1. Introduction

Nowadays wireless communications have been developed for entertainment, education, economic, health and

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industry. Mobile technology is the most popular wireless communication and has progressed rapidly from 1 G to 4 G. The development of antennas with new performances becomes currently imperatively essential for the new services and network of telecommunication. Therefore, the purpose of this paper is to design a high gain antenna for a mobile base station; also, the antenna requirements are as follows [1]:

- Sector antenna gain: 13 - 16 dB;
- Sector antenna half power beamwidth: 60 - 65 degree or 90 degree;
- Impedance: 50 Ohm.

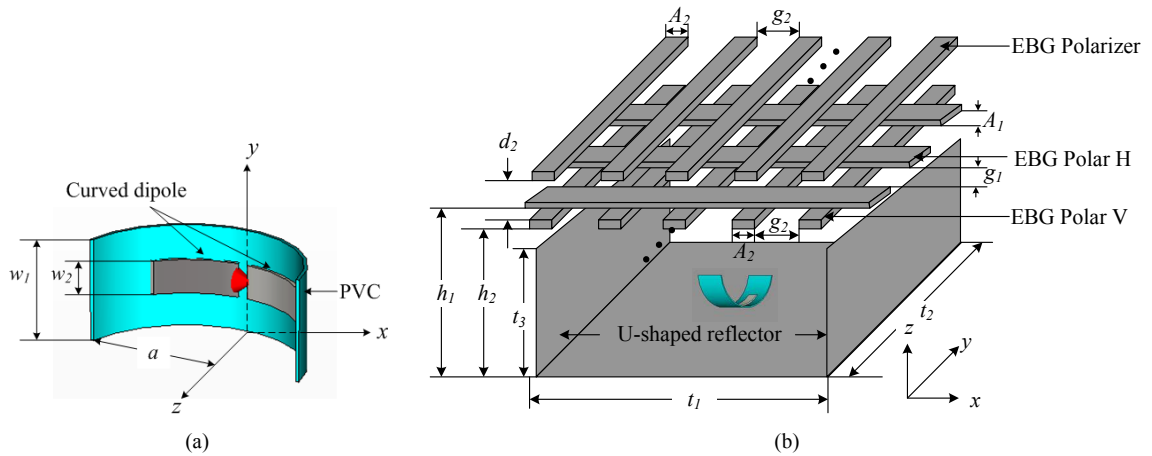
To achieve requirements, there is an interest in the dipole antenna in wireless communication systems because of its broadband characteristics, elementary structure and simple concept [2]-[4]. Presently, the dipole antenna extensively used in practical is S-shaped dipole antenna [5]. Moreover, the dipole is bent into a V-shape to achieve the maximum gain when it is properly aligned with the curvature of the earth [6]. Then, V-shape is compared with the upside bell dipole antenna, and it seems that the upside bell dipole can reduce the side lobe of the dipole [7] [8]. However, the dipole antenna has low gain and its radiation pattern is an omni-direction. This argues that, if we can design the antenna to increase a predefined directive gain, it will have more efficiency for field radiating.

Many new technologies have appeared in the current antenna design and one exciting discovery is the development of Electromagnetic Band Gap (EBG) structures [9]. The EBG structure applications in the antenna designs have become a thrilling topic for antenna engineering. It's a matter of the EBG structure technology, a new technology for the improvement of the antenna performances applicable for frequency spectrum of which extremely wide covered from the acoustic until the optical frequencies. Besides, EBG structures known as photonic crystals are also used to improve the performance of the antenna. The EBG can be applied to grating, frequency selective surface (FSS) and so on. Moreover, the EBG is not only used to a reflector plane [10]-[12], but also adapted for a superstrate of the primary radiator with reflector plane [13]-[16]. When EBG is used to superstrate on excitation feed with reflector plane, the advantage of EBG resonator antenna is the gain enhancement and can be increased the radiation efficiency [17] [18]. The other important feature of the primary radiator with EBG is its ability to generate linearly-polarized waves to radiate a circularly polarized (CP) wave required in many communication environments, such as the dipole antenna placed on EBG reflector plane at a 45° angle [19] [20] and the microstrip antenna with dual feed in the cavity wall [21] [22]. As mentioned above, when a dipole antenna is oriented along direction on EBG reflector plane, it seems that the directive gain is not suitable for a cellular system. In other words, if we use a microstrip antenna with dual feeding, it has more complexity. Therefore, this paper presents a curved strip dipole antenna placed on the U-shaped conductor plane at a 45° angle. In this proposed antenna, the directive gain is increased in  $x$  and  $y$  axes by using metallic rod EBG and the circular polarization is generated by using the EBG polarizer.

The rest of this paper is as follows. After brief introduction, the configuration geometry of a curved strip dipole and the proposed antenna is shown in Section 2. Then, the analysis of the resonator is presented in Section 3. Next, the simulated and measured results of the proposed antenna are discussed in Section 4. Finally, the conclusions are given in Section 5.

## 2. The Circular Polarized Resonator Antenna Configuration

The detailed geometry and parameters of resonator antenna using curved strip dipole antenna with metallic rod EBG are illustrated in **Figure 1** and **Table 1**, respectively. First, an upturned curved strip dipole antenna was designed to resonate around 2100 MHz and it is constructed of a copper plate (a 1 mm thickness). Next, it is mounted over an inexpensive curved polyvinyl chloride (PVC) with the dielectric constant of 3.4. The feed center of this antenna is connected at  $\varphi = \pi/2$ . The half-wavelength of curved strip dipole antenna is  $L_d = \pi a$ . Then, U-shaped reflector plane with the size of 300 mm × 950 mm is added behind the 45° oriented curved strip dipole to control the radiation pattern to be directional pattern and to reduce the side and back lobe. For the gain enhancement and the polarization development, the multi-layers metallic rod EBG structure is added in this design to perform as the superstrate. The configuration of three EBG layers consist of EBG polar H (in  $x$ -axis), EBG polar V (in  $y$ -axis), and EBG polarizer. For design studied here, the lower EBG polar V layer is made up of five aluminium rods of  $3.85 \times 950 \times 6 \text{ mm}^3$  periodicity. The upper EBG polar H layer is composed of nineteen aluminium rods of  $300 \times 13.26 \times 1 \text{ mm}^3$  periodicity. Furthermore, the polarizer layer is constituted of five aluminium rods of  $3.85 \times 950 \times 2.4 \text{ mm}^3$  periodicity; it has been located on the top layer. When, the superstrate is



**Figure 1.** The geometry of (a) an upturned curved strip dipole and (b) the proposed antenna.

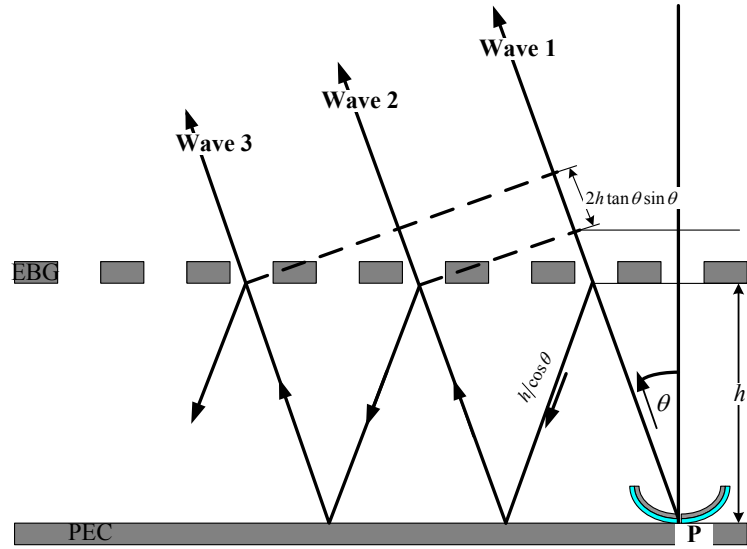
**Table 1.** Parameter of the proposed antenna.

Parameters	Size (mm)
$a$ : radius of a curved strip dipole	34
$L$ : length of a curved strip dipole	82.81
$w_1$ : width of a curved strip dipole	15
$w_2$ : width of a polyvinylchloride (PVC)	30
$A_1$ : width of EBG polar H	13.26
$g_1$ : the gap between the metallic rods of EBG polar H	29.83
$t_1$ : length of EBG polar H	300
$A_2$ : width of EBG polar V	3.85
$g_2$ : the gap between the metallic rods of EBG polar V and EBG polarizer	46.42
$t_2$ : length of EBG polar V and EBG polarizer	950
$t_3$ : the high of U-shaped reflector	50
$h_1$ : distance between EBG polar H and U-shaped reflector	67
$h_2$ : distance between EBG polar V and U-shaped reflector	60
$d_1$ : distance between EBG polar H and EBG polar V	4.5
$d_2$ : distance between EBG polar V and EBG polarizer	30

placed over a radiating element with the gap  $h_2$  of 63 mm, the circularly polarized resonator antenna is defined. It is possible to generate a 90 degree phase shift between the electric field in the  $x$  and  $y$  axis.

### 3. Analysis of the Resonator Antenna

This section shows the resonator antenna, which consists of three components. There are a superstrate, a reflector plane, and a curved strip dipole antenna for the excitation source. The superstrate forms a 1-D EBG structure where periodic conducting pattern are metallic rods. It behaves as the EBG array at the antenna operating frequencies. A curved strip dipole antenna is placed between PEC reflector plane and 1-D EBG as shown in **Figure 2**. The radiation of feeding antenna has a center point at P, whereas the radiation pattern of a curved strip dipole antenna is  $f(\theta)$ . In addition, the distance between the PEC reflector plane and EBG is  $h$ , and reflection coefficient of EBG is  $\gamma e^{j\phi_{\text{EBG}}}$ .



**Figure 2.** The reflection wave between PEC and EBG.

Assume that the transmission is lossless, the amplitude of the direct wave 1 is  $\sqrt{1-\gamma^2}$ , the amplitude of the once-reflected wave 2 is  $\gamma\sqrt{1-\gamma^2}$ , in the same way the amplitude of the twice-reflected wave 3 is  $\gamma^2\sqrt{1-\gamma^2}$ , etc. Therefore, summation of electric field is examined from

$$\bar{E} = \sum_{n=0}^{\infty} f(\theta) E_0 \gamma^n \sqrt{1-\gamma^2} e^{j\Delta\varphi_n}, \quad (1)$$

where,  $\Delta\varphi$  is the phase variations. When the phase difference between wave 2 and wave 1 is

$$\Delta\varphi_1 = \frac{2\pi}{\lambda} 2h \tan \theta \sin \theta - \frac{2\pi}{\lambda} \frac{2h}{\cos \theta} - \varphi_{\text{PEC}} + \varphi_{\text{EBG}}, \quad (2)$$

the phase difference between wave 3 and wave 1 is

$$\Delta\varphi_2 = \frac{2\pi}{\lambda} 4h \tan \theta \sin \theta - \frac{2\pi}{\lambda} \frac{4h}{\cos \theta} - 2\varphi_{\text{PEC}} + 2\varphi_{\text{EBG}}. \quad (3)$$

If the direct wave has  $n$  number, so the phase difference is

$$\Delta\varphi_n = n \left[ -\frac{4\pi}{\lambda} \cos \theta - \varphi_{\text{PEC}} + \varphi_{\text{EBG}} \right]. \quad (4)$$

When  $\gamma < 1$ , we obtain

$$\sum_{n=0}^{\infty} (\gamma e^{j\Delta\varphi})^n = \frac{1}{1 + \gamma e^{j\Delta\varphi}}. \quad (5)$$

Therefore, we can represent the electric field as follows:

$$|E| = |E_0| f(\theta) \sqrt{\frac{1-\gamma^2}{1+\gamma^2-2\gamma\cos\Delta\varphi}}, \quad (6)$$

and the power pattern is

$$\bar{S} = \frac{1-\gamma^2}{1+\gamma^2-2\gamma\cos\left(\varphi_{\text{EBG}}-\varphi_{\text{PEC}}-\frac{4\pi}{\lambda}h\cos\theta\right)} f^2(\theta). \quad (7)$$

However, the amplitude ( $\gamma$ ) and phase ( $\varphi_{\text{EBG}}$ ) of the EBG reflection coefficient are a function of the angle

$\theta$ . Maximum power in the normal direction is obtained, when

$$\varphi_{\text{EBG}} - \varphi_{\text{PEC}} - \frac{4\pi}{\lambda}h = 0. \quad (8)$$

So, the distance between PEC reflector plane and EBG is

$$h \cong \left( \frac{c}{2f} \right) \left( \frac{\varphi_{\text{EBG}} - \varphi_{\text{PEC}}}{2\pi} \right) + N \frac{\lambda}{2}, \quad (9)$$

where,  $N = 0, 1, 2, 3, \dots$ .

## 4. Results and Discussion

In a previous article, an antenna design of high directive gain using a curved strip dipole on electromagnetic band gap (EBG) was studied [10]. The resonant EBG technology has been used to be a reflector for directive gain increment by utilizing the good performance of the mushroom-like EBG structure, which is capable of providing a constructive image current within a certain frequency band. Therefore, when wide beam curved strip dipole is appropriated located horizontally on a resonant EBG reflector, high directive gain can be obtained of 7.6 dBi for RFID reader. The purpose of this paper is the antenna for mobile base station design, so the antenna performance is developed to perform the resonator antenna by using EBG structure as the superstrate. In this design, the EBG structure can partially reflect wave of a primary radiator. This section proposes the design and analysis of the proposed antenna.

### 4.1. The Feeding Antenna

In **Figure 3**, the exciting source of the proposed antenna is an upturned curved strip dipole antenna, which is placed on polyvinyl chloride (PVC). So, the radius of a curved strip dipole is specified at 18, 20, 24 and 34 mm. At the radius of 34 mm, it can be obtained the good matching with 50 ohms transmission line. It has the maximum gain of 2 dBi and  $S_{11}$  is  $-14$  dB at the resonant frequency of 2.1 GHz. The pattern of the curved strip dipole in E-plane provides the half power beamwidth (HPBW) around  $81.5^\circ$  because the dipole is bended to be a half annular and the omni-direction is displayed in H-plane.

### 4.2. Circular Polarized Resonator Antenna

The square circular polarized resonator antenna is excited by a curved strip dipole, oriented along  $\phi = 45^\circ$  direction and placed over the U-shaped reflector plane with the height of  $0.2\lambda$  [15]. Besides, the superstrate consisting of the three EBG layers in polar V, in polar H, and polarizer, is necessary for the two transmitted components to process the equally amplitude and  $90^\circ$  phase difference. The reflection and transmission phase of the versus frequency are shown in **Figure 4(a)** to estimate the gap between the reflector and EBG layer as the cavity height ( $h$ ). The cavity height depends on the frequency which can be obtained through following relations Equation (9) as plotted in **Figure 4(b)**. The parameters  $h_1$  and  $h_2$  are 67 mm and 60 mm, respectively, so, the dual polarized resonator antenna could be produced because of the E-field in horizontal and vertical polarization are equally amplitude.

Furthermore, this paper studies the circularly polarized antenna, so, two perpendicular electromagnetic plane waves not only are equal amplitude but also should have the  $90^\circ$  phase difference. Therefore, 1-D metallic EBG is designed for the third layer of superstrate, which is called polarizer. The transmission phase of polarizer  $\varphi_{s_{21}\text{polarizer}}$  is  $-6.24^\circ$  as denoted in **Figure 4(b)**. The requirement of phase difference is  $90^\circ$ , where it is given by

$$k_0 d_2 + \varphi_{s_{21}\text{EBGpolarH}} + \varphi_{s_{21}\text{EBGpolarV}} + \varphi_{s_{21}\text{polarizer}} = 90^\circ, \quad (10)$$

In Equation (10), if the superstrate is separated to find  $\varphi_{s_{21}}$ , therefore,  $d_2$  is 23.15 mm. In **Figure 5(a)**, when three layers of EBG structure are used for superstrate of a feeding antenna, the circularly polarized resonator antenna is achieved when the mutual coupling between EBG layers is considered. **Figure 5(b)** illustrates an axial ratio of square resonator antenna ( $t_1 = t_2 = 950$  mm), which  $d_2$  is varied. It seems that an axial ratio close to 0 dB at the resonant frequency bandwidth  $d_2$  of 30 mm. The maximum gain of 20 dB could be obtained and the HPBW in vertical and horizontal plane are  $18^\circ$  and  $18.1^\circ$ , respectively, as shown in **Figure 5(c)**.

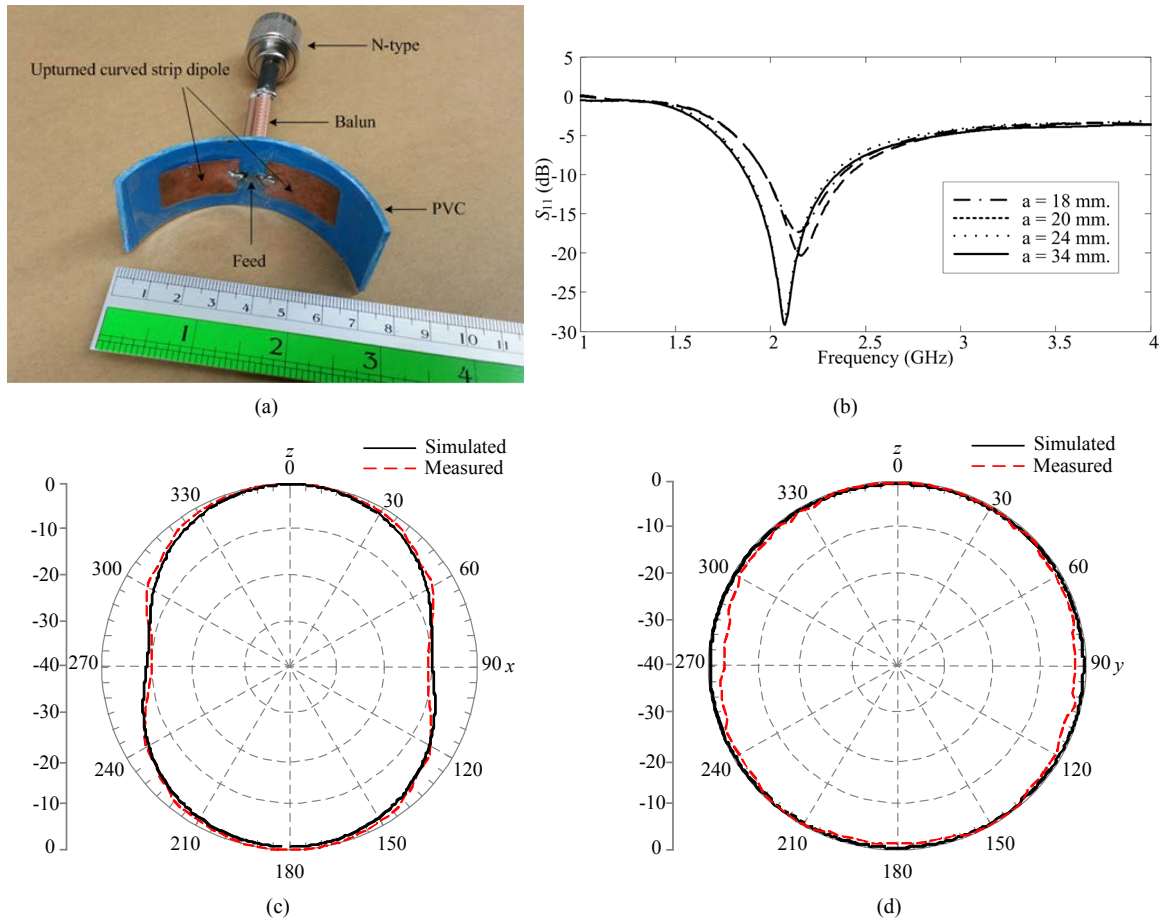


Figure 3. The results of upturn curved strip dipole antenna: (a) photographs; (b)  $S_{11}$ ; (c) E-plane; (d) H-plane.

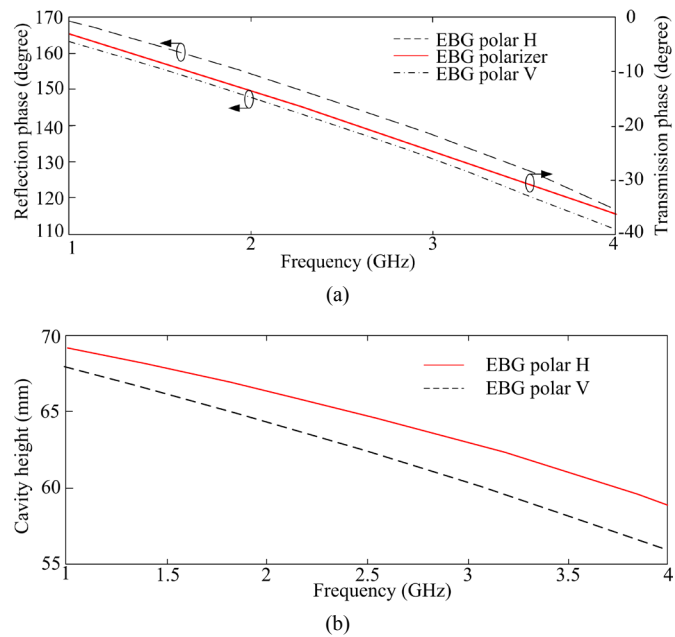
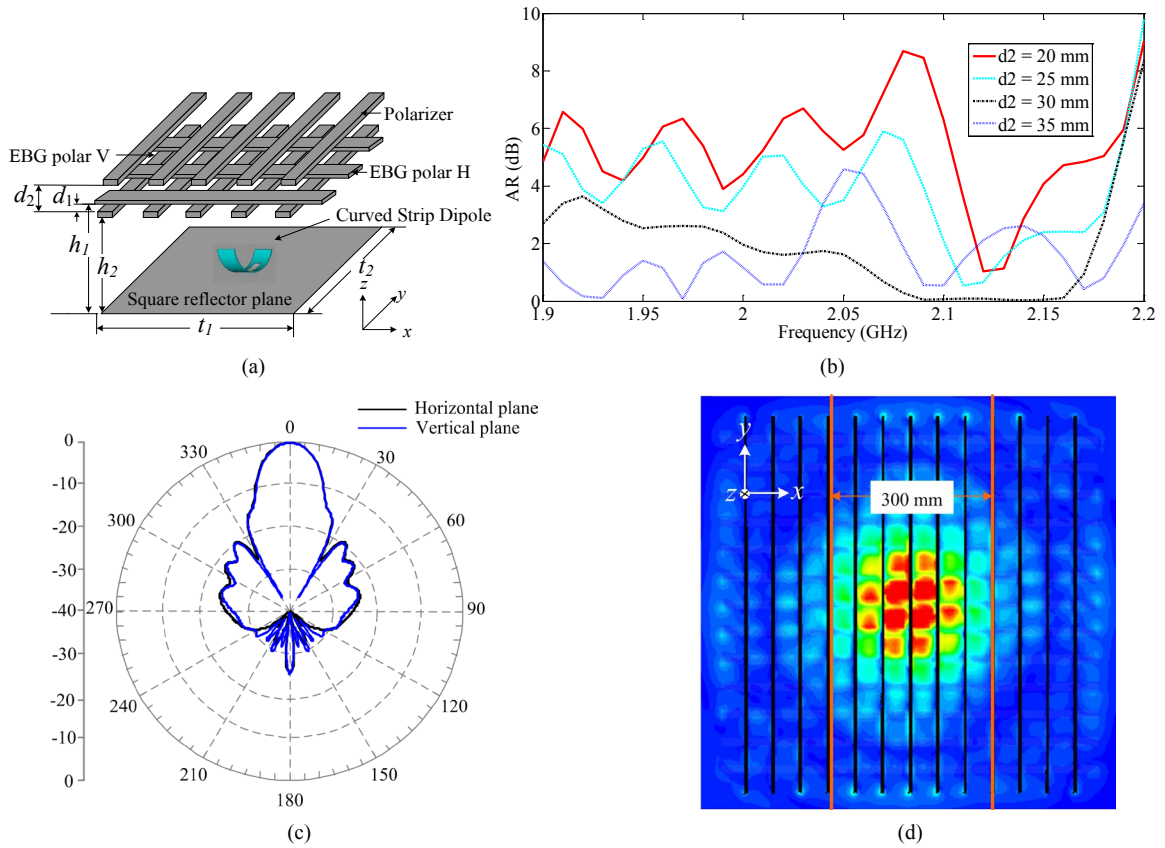


Figure 4. Simulated results of metallic rod EBG: (a) reflection and transmission phase; (b) calculated cavity height.



**Figure 5.** Simulated results of circularly polarized resonator antenna: (a) structure; (b) AR; (c) normalized radiation patterns; (d) near-field distribution on square reflector plane.

Even if the polarization was achieved in this section, an interesting sectoral 60° pattern in horizontal plane is the last target of this paper.

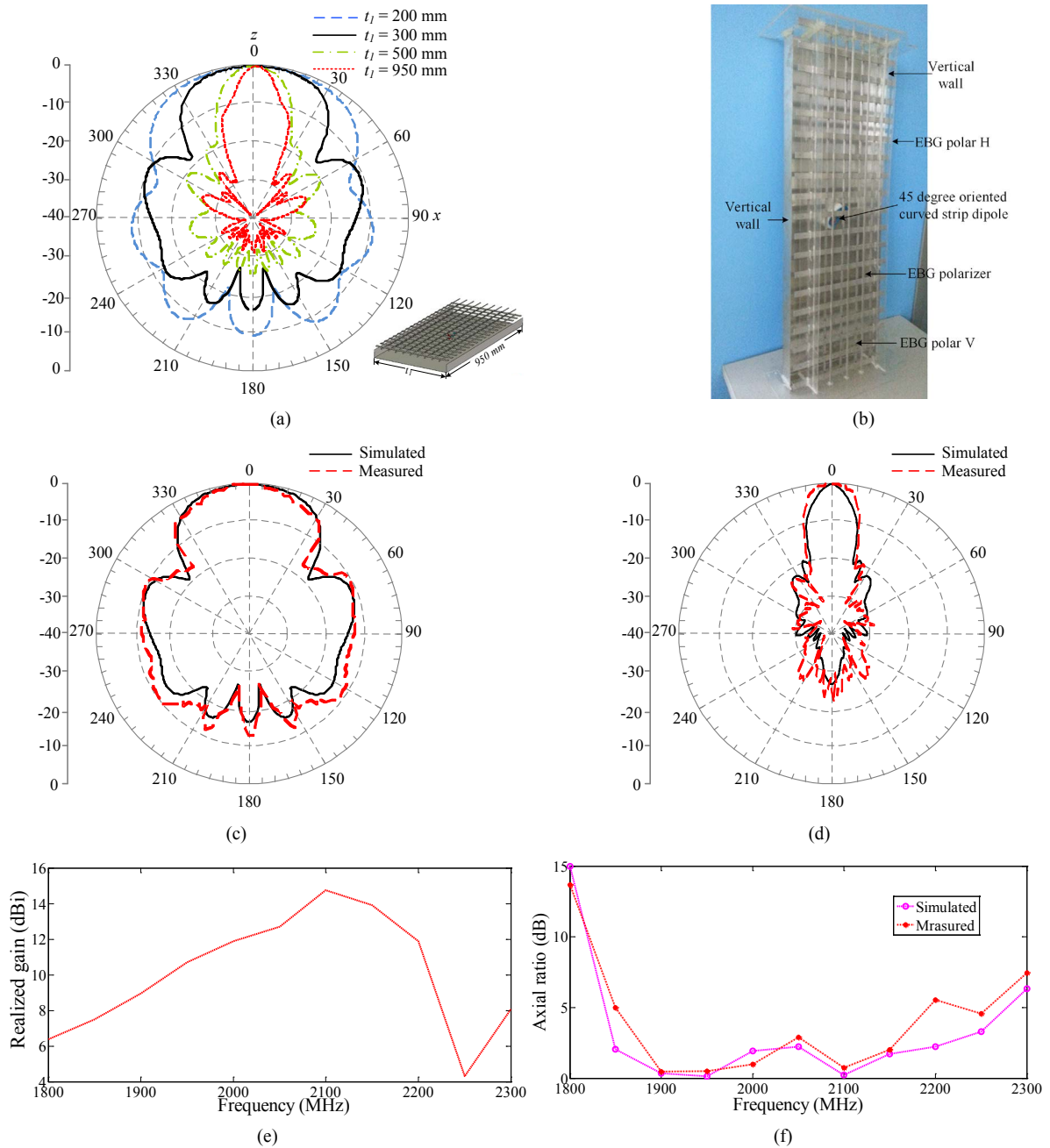
### 4.3. Sectoral Resonator Antenna with Circular Polarization

Consideration of **Figure 5(d)** and **Figure 6(a)** concludes that if the resonator antenna size ( $t_1$ ) is reduced to 300 mm because the near-field level is faded away at the width, the HPBW in horizontal plane of the resonator antenna is wider. While the pattern in horizontal plane is improved, the directive gain of resonator antenna is certainly down. To solve a problem in  $xz$  plane, the U-shaped reflector is installed as shown in **Figure 2**.

To verify the performance of the antenna, an antenna prototype has been fabricated on aluminium as shown in **Figure 6(b)**. The evaluation of the key antenna parameters such as radiation pattern, polarization, and gain were measured by using Network Analyzer. After that the proposed antenna is rotated and the measured radiation pattern of the antenna is plotted together with the simulated pattern as shown in **Figure 6(c)** and **Figure 6(d)**, respectively. This plot shows agreements between the measured and simulated results both in horizontal and vertical plane patterns. Furthermore, the measured realized gain and AR are continued measure to confirm the antenna performance. **Figure 6(e)** illustrates an axial ratio close to 0 dB at the resonant frequency band, covering the uplink and downlink band of 3 G base station. **Figure 6(f)** shows the measured gain of the proposed antenna. It can be seen that the gain of the antenna is around 15.11 dBi 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 2**. As we can see, the experiment results have a good agreement with the ones from simulation results.

## 5. Conclusion

The design of a circularly polarized resonator antenna using a curved strip dipole with electromagnetic band gap



**Figure 6.** The results of proposed antenna: (a) horizontal plane when  $t_1$  is varied; (b) photographs; (c) horizontal plane; (d) vertical plane; (e) realized gain; (f) AR.

material for mobile communications was presented. The antenna was analyzed by using the CST software. From the simulation results, we can conclude that a 45° oriented curved strip dipole is fed between the multilayers EBG and the reflector plane to produce the circularly polarization. Furthermore, the sectoral radiation pattern (HPBW around 60°) can be obtained by reducing the size of the antenna in  $xz$  plane. The antenna prototype was fabricated on aluminium to verify the antenna performance. The measured maximum gain is 15.11 dB. Good agreement between simulated and measured results is obtained.

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**Table 2.** Specification of the proposed antenna.

Parameters	Simulation			Measurement
Antenna type	Curved strip dipole	Square resonator antenna	Proposed antenna	Proposed antenna
Material	Copper plate and PVC	Aluminium	Aluminium	Aluminium
Frequency band (MHz)	2100 (1590 - 2059)	2100 (1999 - 2180)	2100 (1850 - 2230)	2100 (1870 - 2170)
Polarization	linear	circular	circular	circular
HPBW (degree)	E-plane: 81.5	H: 18.1 V: 18	H: 60.1 V: 12.3	H: 60 V: 14.4
Gain (dBi)	1.63	20.11	15.53	15.11
Antenna size (mm)	66.75 × 28	950 × 950 × 98	950 × 300 × 98	950 × 300 × 98
Antenna weight (kg)	-	-	-	3.3

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