Curved Strip Dipole Antenna on EBG Reflector Plane for RFID Applications

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Abstract: This paper presented the study and design the curved strip dipole on Electromagnetic Band Gap (EBG) reflector plane that can be affected the performance of the proposed antenna for RFID application. The proposed antenna consists of a strip dipole that constructed of a metallic sheet and it was bended to be a half of annular with feed point at the center for yielding wider beamwidth. Normally, a curved strip dipole antenna without the reflector provides low gain of 1.5 dB, due to its features of radiation patterns, both in azimuth and elevation planes. In our case, the resonant EBG technology has been used to be a reflector for directive gain increment by utilizing the good performances of EBG structure, which is capable of providing a constructive image current within a certain frequency band. Therefore, when this curved dipole is appropriated located horizontally on a resonant EBG reflector, the low profile antenna that provides good performance such as large beamwidth, wide bandwidth, and high directive gain can be obtained, consequently. The first curved strip dipole antenna with 3×3 elements and the second one with 5×5 elements of EBG reflectors, respectively, have been fabricated and their RF performances have been measured. For 3×3 elements of EBG reflector, the measured beamwidth in E- and H-planes are 100° and 110°, respectively, frequency bandwidth is 2.06-2.59 GHz and directive gain is 7.45 dBi at 2.45 GHz. In case of 5×5 elements of EBG reflector, the measured beamwidth in E- and H-planes are 65° and 120°, respectively, frequency bandwidth is 2.06-2.62 GHz and directive gain is 7.65 dBi at 2.45 GHz. From simulation and experimental results, it's obvious that many applications can be conceived for a curved strip dipole on EBG reflector plane due to its geometrical and electromagnetic features.

Key-Words: - Curved Strip Dipole Antenna, Electromagnetic Band Gap (EBG), RFID Technology

1 Introduction

With the advances of the wireless communication technology and the communication industry, the antenna becomes an important part of electrical devices in wireless communication after late 1888 [1-3]. Nowadays, the radio frequency identification (RFID) technology has been developed for an electronic toll collection on expressway. In addition, RFID technology can be used for any examples in identifying objects warehouse supply chain management, service logistics, control, and other automation process. The frequency bands of this technology divided into four bands are low frequency (100-200 KHz), high frequency (10-15 MHz), ultra high frequency (850-959 MHz) and microwave frequency (2.4-2.58 GHz). The compositions of RFID system are the communication between the reader and the tags, which is achieved by modulated back scattering of the reader's carrier wave signal, while the tag consists of microchip for gathering the data of objects that will be identified and antenna for communicating to the reader by radio wave. Therefore, the antenna is an important component, which has been developed to obtain the highest efficiency for the RFID system. In this paper, the antenna has been designed at 2.45 GHz for RFID applications in microwave frequency band. The desired features of the proposed antenna are sufficiently high gain, wide coverage area, and high power handing. In addition, economically, this antenna should be relatively simple in concept, easy structure, low cost, and so on. With some features of the microstrip patch antenna, which are attractive and popular due to their natural advantages such as light weight, conformability, inexpensive, and peak gain about 3.8 dBi [4], while the dipole antenna is easy to fabricate and variety [5-6].

From such advantages of two basic antennas, there are some authors presented the dipole antenna, which is mounted over on a perfect conductor plane to improve the directive gain [7]. In addition, some authors presented the related literatures, the dipole antenna is installed in the proximity of a conductor plane and cut in a quarter-wavelength each to form a half annular, and connected through a hole to a feeding network under the conductor, while its both ends of dipole are electrically shorted on the surface of square perfect electric conductor [8-9]. These antennas have a low profile configuration. However, the image current has the opposite direction and cancels the radiation from the original current. Thus, the EBG structure is capable of providing a constructive image current within a certain frequency band, resulting in good radiation efficiency [10]. Unfortunately, the curved strip dipole on reflector plane for wireless communication has a problem about bandwidth which is not enveloping the entire microwave frequency band. In this study, the EBG structure is obtained that able to operate covering the frequency range available. Moreover, when the radiator is mounted on EBG surface, its composition can eliminate the surface wave at the edge of reflector. Thus, the proposed antenna can be achieved the directive gain higher than dipole with the traditional PEC reflector. Our study, we have optimized the radius of curved strip dipole, the spacing distance between the feed point of radiating antenna and EBG surface, and finally, the total length of curved strip dipole, which can be affected for peak gain, large beamwidth, and covering resonant frequency of bandwidth.

In this paper, we have focused at the single curved strip dipole antenna with EBG ground plane/reflector. In section 2, the EBG configuration and design will be mentioned, while the parameters study of curved strip dipole locating on EBG reflector will be explained in section 3. Having confirmed the validity of this approach, the antenna prototype has been fabricated and tested in section 4. Finally, the conclusion will be discussed in section 5.

2 Curved Dipole Antenna and EBG Configurations

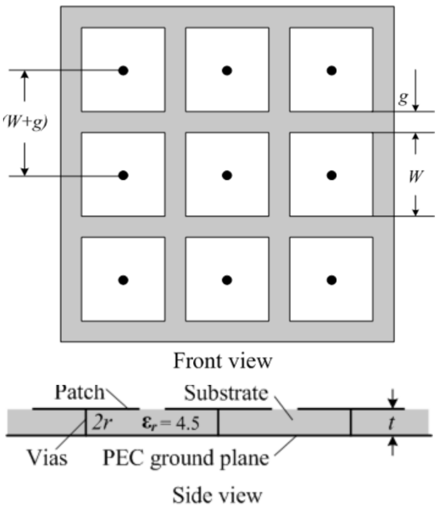


Fig.1 Front and side view of EBG structure.

Fig.1 shows the configuration of “mushroomlike" EBG that is used to be a reflector of curved strip dipole, which consists of three parts that are PEC ground plane, dielectric, and patches. The conducting patches are connected to PEC ground plane with small pins, which are called vias. For EBG structure, the patches array will be looked to be the unit cell by considering via by via, which is smaller than the resonant wavelength. However, the EBG structure could be described using lumped-circuit elements as illustrated in Fig.2.

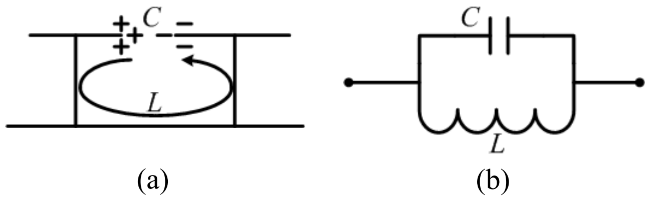


Fig.2 Equivalent parallel resonant *LC* circuit for EBG structure: (a) origin of the equivalent circuit elements and (b) a parallel *LC* circuit.

It introduces an inductor (*L*), which results from the current flowing through the vias, and a capacitor (*C*), which is due to the gap effect between adjacent patches. The calculation of the patch width (*W*), gap width (*g*), substrate thickness (*t*), and dielectric constant (ε_r), the values of inductor and capacitor can be approximated by the following formulas [11].

$$L = \mu_0 t \quad (1)$$

$$C = \frac{W\varepsilon_0(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2W+g}{g}\right) \quad (2)$$

where μ_0 and ε_0 are the permeability and permittivity of free-space, respectively. The local resonant frequency and the effective surface impedance can be obtained by

$$\omega_0 = \frac{1}{\sqrt{LC}}, \quad (3)$$

and

$$Z = \frac{j\omega L}{1-\omega^2 LC}, \quad (4)$$

respectively.

However, the formulas only yield an approximation of the resonant frequency since the effects from metallic vias in the EBG design are not considered. First, the curved strip dipole antenna constructed of a metal plate (a 1 mm thickness perfect conductor plate) and mounted on an inexpensive curved polyvinyl chloride (PVC) with the permittivity of 3.4 was designed to resonate around 2.45 GHz, which is in microwave band of RFID system as illustrated in Fig.3. The total length and strip's width of curved dipole are expressed by L_d and w_1, respectively, and the radius a aligned along ϕ -direction. The feed point of this antenna is connected at the center of dipole ($\phi = \pi/2$). The spacing between two arms of dipole is assumed that it has minimum width. The half-wavelength of curved strip dipole is $L_d = \pi a$, and the width of PVC (2 mm thickness PVC substrate) is expressed with w_2. For the EBG reflector, it must be designed to resonate with the same resonant frequency in microwave band. The physical dimensions of 3×3 elements EBG structure fabricated on a 1.6 mm thickness FR4-substrate with dielectric constant of 4.5 was previously illustrated in Fig.1.

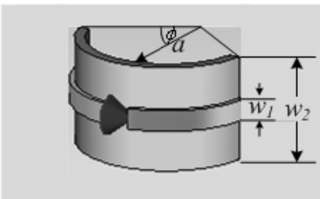


Fig.3 The structure of a curved strip dipole without reflector plane.

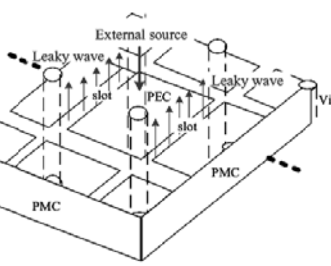


Fig.4 The unit cell model for the square EBG structure.

Finally of this section, Fig.4 shows the unit cell model of square EBG structure with 3x3 elements of patches. On the EBG surface, the leaky wave will be radiated through the slots in each unit cell. These regions are the proper positions where located the both ends of a curved dipole. However, the initial parameters of the proposed antenna are illustrated in Table 1.

3 The Parameters Study of Curved Strip Dipole on EBG Reflector Plane

In order to have got the good performance of the proposed antenna, in this section, the CST software will be utilized to study and analyze the important parameters, which impact the features of this antenna. In Fig.5, the proposed antenna has been designed to operate at center frequency of 2.45 GHz for RFID system. The model of antenna is fed with the external source by discrete port at the middle point of a strip dipole that is bended similarly to a half-circular shape and mounted on PVC strip. Next, this composition of curved dipole is placed over the EBG reflector plane in the proper position where was mentioned in the previous section. Since the one unit of EBG has the characteristic of the *LC* parallel resonant circuit, therefore, if it is resonated at the same resonant frequency of curved strip dipole, the active power will be coupled out of the slot that is equivalent to the leaky wave radiation by exciting from external source, which sent from the curved strip dipole to EBG surface.

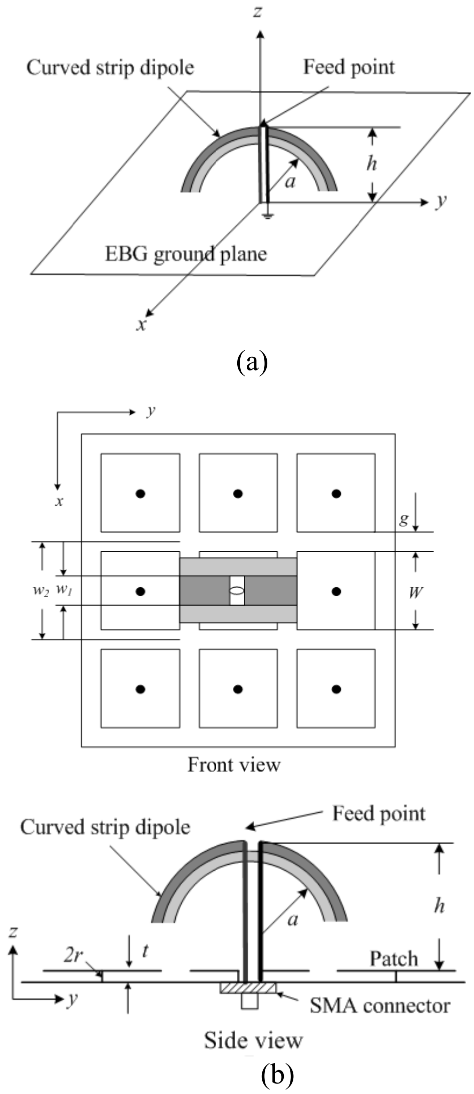


Fig.5 Geometry of curved strip dipole on EBG ground plane: (a) 3D view and (b) Front and side view.

To optimize the desired performance, the initial values of important parameters before adjustment as illustrated in Table 1. Furthermore, the dimensions of

EBG reflector as shown in this table were selected after a detailed parametric study for good performance.

Table 1 The initial parameters of curved strip dipole on EBG ground plane.

Antenna Parameters	Electrical Dimension ($\lambda_{2.45\ GHz}$)	Physical Dimension (mm)
L_d	0.5	61.22
a	0.15	18
h	0.24	30
w_1	0.03	4
g	0.044	5.39
w_2	0.16	20
W	0.2034	24.86
r	0.005	0.6
t	0.013	1.6

At first, the distance of spacing between the radiating element and the surface of EBG will be considered since the shape of proposed dipole is similar to a half annular. In case of a straight dipole is the radiating element and is placed over the EBG structure with distance of λ/2, then phase of coupling waves on the EBG surface will be not reversed. Consequently, the total round trip of phase shift from the radiating element to the surface and back to such element will be completely equal one wavelength of that resonant frequency. Otherwise, if such distance from the radiating element is not equal λ/2, the coupling waves on some elements will be out-of-phase, thus the surface waves occur at edge and corner of the ground plane. For our case, the radiating element is curved dipole, therefore, the proper height of the radiator has to consider between feed point and the top surface of EBG ground plane, which is different from the distance measured at the end of each arm. However, the proper height of curved dipole has been optimized, while the effects of radius of annular and the length of curved dipole have also been analyzed to meet the required performance.

At the desired frequency of 2.45 GHz, the initial dimension of a curved strip dipole antenna is calculated base on the total length (L_d) of λ/2, then radius (a) is found from (7):

$$L_d = \lambda_{2.45\ GHz}/2, \quad (5)$$

$$L_d = \pi a, \quad (6)$$

therefore,

$$a = (\lambda_{2.45\ GHz}/2)/\pi. \quad (7)$$

In the first step, a curved strip dipole has been separately computed without EBG reflector by varying L_d and w_1 to obtain the good matching with 50 ohms transmission line. From the resulting that illustrated in Fig.6, the best performance of single curved strip dipole antenna has a maximum gain of 1.7 dBi and return loss is -14 dB at 2.45 GHz. It is found that the omnidirectional pattern of this antenna in E-plane provides the half power beamwidth is around 92.4°, because of dipole is bended to be a half annular. With radiation features, it's not proper to utilize in RFID system, especially, reader antenna that need unidirectional pattern, high directive gain, wide beamwidth and large bandwidth. To meet requirement, the resonant EBG structure is applied to be a reflector plane of this curved strip dipole.

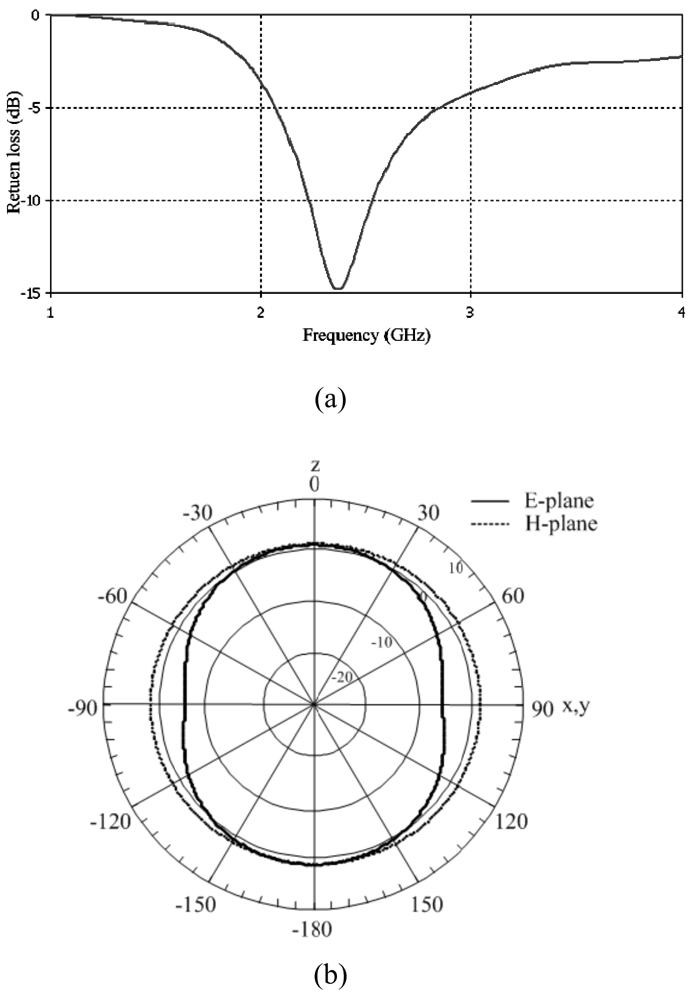


Fig.6 A curved strip dipole antenna: (a) return loss and (b) far field radiation pattern.

Fig.7 shows the reflection phase results of the EBG structure using dispersion diagram [12] calculated by CST simulation. As a result, the frequency region of EGB from 1.9 GHz to 2.7 GHz can be served for the ground plane/reflector in a certain frequency of the desired bandwidth of the proposed antenna. After this, we will study the impacts of the radius and total length of the curved strip dipole together with the spacing distance between feed point of curved dipole and EBG surface, which can affect the required performance.

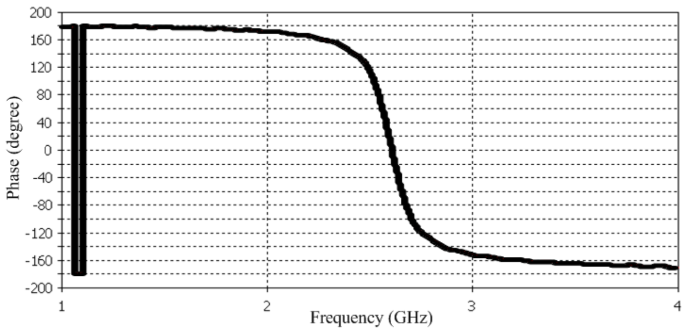


Fig.7 The EBG reflection phase results.

3.1 The Effective of an Annular Radius (*a*)

Initially, the length of a curved strip dipole is specified at 0.5λ and the height of the feed point over the EBG surface is 0.25λ, when λ is the free space wavelength of resonant frequency at 2.45 GHz. When the radius of a half annular of dipole is varied from 0.14λ to 0.17λ, this condition is similar to the both ends of curved dipole are trimming to obtain the proper dipole's length, good matching and sufficient bandwidth. In Fig.8, the simulated results of the return loss of curved strip dipole antenna, at the different radii, on the EBG reflector are illustrated comparatively. It's obvious that, although the specified radii of curved dipole on the resonant EBG reflector surface are different, but they could be matched well from 2.0 GHz to 2.63 GHz. Nevertheless, the best matching can be achieved with the radius 0.17λ. However, when the radius is decreased smaller than 0.17λ, the proposed antenna still covers the desired frequency band. But it has the minimum return loss at 2.45 GHz of the desired frequency.

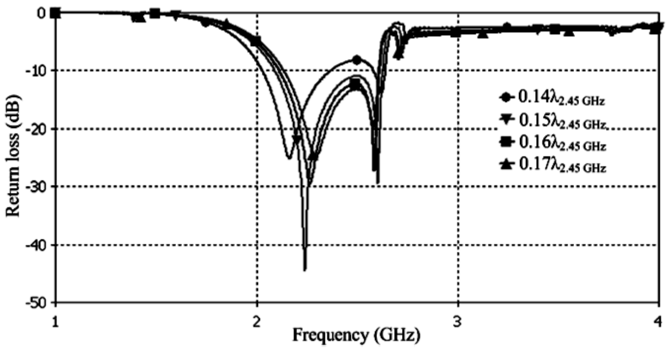


Fig.8 Return loss of curved strip dipole on EBG, the radius varying from 0.14λ to 0.17λ.

3.2 The Effective of Height (*h*) of the Feeder

From the previous subsection, now, the minimum return loss at 2.23 GHz has been occurred with 0.17λ of the annular radius and 0.5λ of the curved dipole length. In order to obtain the desired resonant frequency and operational bandwidth of the proposed antenna, the distance between radiating element and EBG surface will be adjusted as illustrated in Fig.9. It's obvious that at every distances of *h* provide the vicinal range of frequency, which can be covered all microwave band as requirement. Considering the curve of a specialty dipole, its cause of the reflection phase is not in almost elements that is why the *h* parameter is not satisfied to the theoretical EBG reflection phase as mentioned previously. However, we found that the height of 0.07λ is the appropriate distance between the both ends of curved strip dipole and EBG surface that yields the minimum return loss at -23.5 dB. In addition, such distance will affect to decrement or increment of the antenna gain if the reflection phase of overall dipole element is not suitable. The simulated result in Fig.11 shows the gain variation at different distances from feed point of curved dipole. This antenna provides the excellent gain of 7.5 dBi at *h* = 0.24λ, while the resonant frequency has been shifted to the desired position.

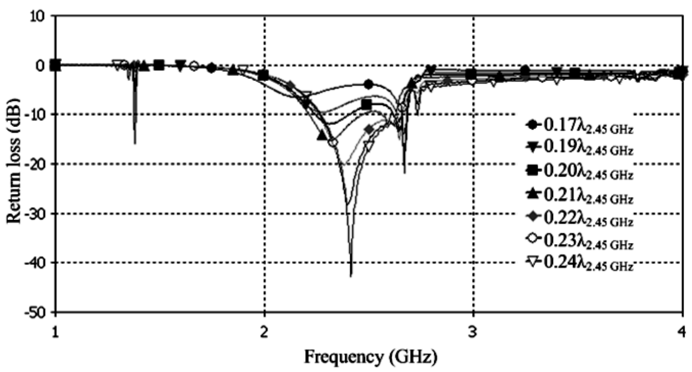


Fig.9 Return loss of curved strip dipole on EBG, the height *h* varying from 0.17λ to 0.24λ.

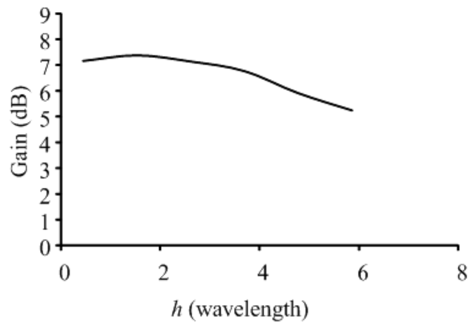


Fig.10 The effects of the antenna gain due to the height of feed point.

3.3 The Effective of a Length of dipole (L_d)

The last parameter, the total length of curved dipole will be finally adjusted for the best matching. This simulation is assumed that the both ends of curved dipole are trimmed equally. Similarly in previous section, the EBG surface and the optimized values are fixed when the length of curved dipole is not equal to a half wavelength.

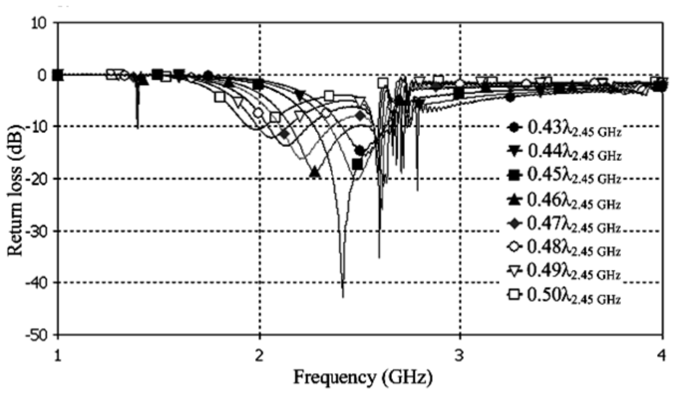


Fig.11 Return loss of curved strip dipole on EBG, the length varying from 0.43λ to 0.5λ.

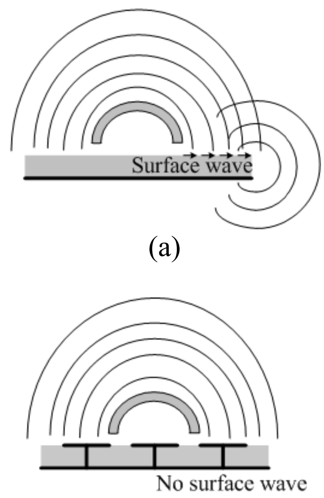
Fig.11 shows the effect of adjusting the length of curved dipole, which is varied from 0.5λ of the theoretical length decreasing to 0.43λ, while the frequencies are applied from 1 GHz to 4 GHz of each given length. With this radiator is not either a theoretical wire or straight dipole, but it is bended to be a half-annular curve and also be fabricated on PVC dielectric. Therefore, a half-wavelength will be change to be the exact electrical wavelength according to its composition. We found that when the total curved dipole length of 0.45λ is selected, the best matching at the desired resonant frequency of 2.45 GHz is obtained. Finally, the optimized dimensions of a curved strip dipole, as mentioned above, have been summarized in Table 2.

Table 2 The optimized parameters of curved strip dipole.

Antenna Parameters	**Electrical Dimension ($\lambda_{2.45\ GHz}$)**	**Physical Dimension (mm)**
L_d	0.45	61.22
a	0.17	18
h	0.24	30

3.4 The Curved Strip Dipole on EBG Reflector

The desired antenna is low profile that provides high gain, large area coverage, and required frequency band. Formerly, the curve strip dipole does not have all of qualifications but it can be modified easily and variably. To appreciate this point and suppress the surface waves at the edges and corners of reflector, the frequency band gap is designed to cover the band of 2.4 GHz -2.58 GHz. Generally, when a curved strip dipole antenna is horizontally placed close to PEC ground plane, the antenna will generate the surface waves onto the ground plane that its size is always finite as shown in Fig.12 (a). Otherwise, when the tradition ground plane is replaced and intead with EBG structure exciting with the external source from curved strip dipole into it, so, the surface waves are suppressed as shown in Fig.12 (b). It is seen that at the resonant frequency mode, each row of the metal patches has the opposite electric field and form the standing waves, which results to eliminate the surface waves in the designed band gap. But the active power will be coupled out from the slots, which is equivalent to the leaky wave radiation [13].

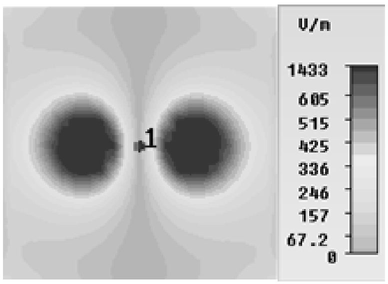


(b)

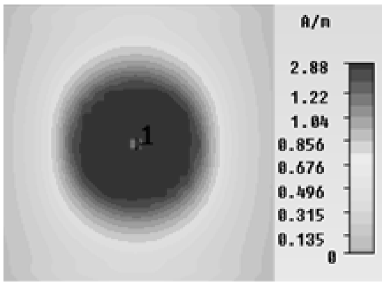
Fig.12 The radiator on reflector plane: (a) surface waves radiating at PEC surface edges and (b) surface wave suppression on an EBG surface.

In Fig.13, the comparison of near-fields that occurred on the different ground plane: PEC and 3×3 elements EBG surfaces, respectively, at the same resonant frequency of 2.45 GHz. The near-field levels both in E- and H-planes of EBG surface are around 1,444 V/m and 2.88 A/m, respectively, while the near-field levels of EBG surface is around 1,627 V/m and 10.8 A/m in E- and H-planes, respectively. The difference of field levels due to the surface wave, which is suppressed by the EBG surface. Fig.14 shows the return loss of resizing curve strip dipole when it operated with the EBG and PEC reflector respectively (with the same ground size of 0.74λ x 0.74λ and the same height of feed point), and without reflector. With the PEC reflector, its return loss is only -14 dB because the PEC surface redirect phase of

180°, so that the direction of image current is opposite to that of the original curve strip dipole. The reverse image current impedes the efficiency of the radiation of curved dipole, resulting poor return loss more than of curved strip dipole without reflector.

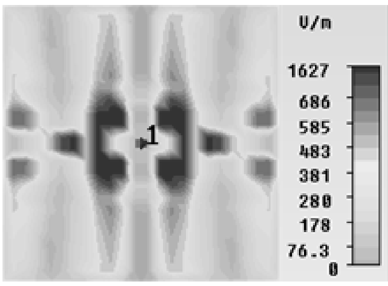


E field

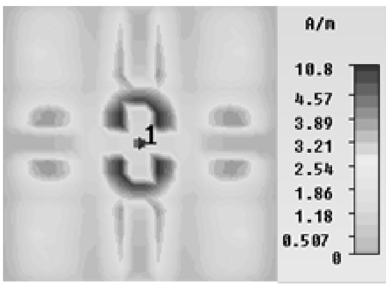


H field

(a)



E field



H field

(b)

Fig.13 Near-fields distribution on reflectors: (a) the PEC reflector and (b) the 3×3 elements EBG reflector.

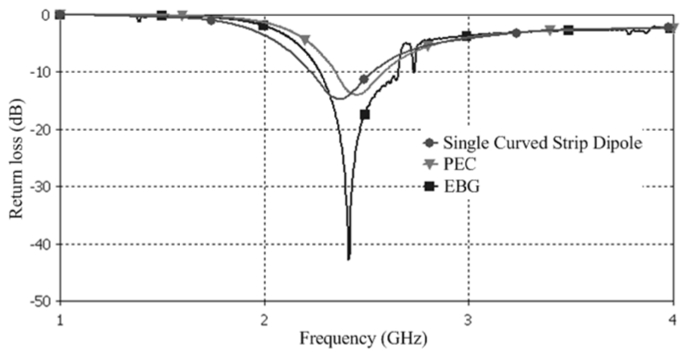


Fig.14 Return loss of the curved strip dipole, the antenna with the PEC and EBG reflector and without reflector.

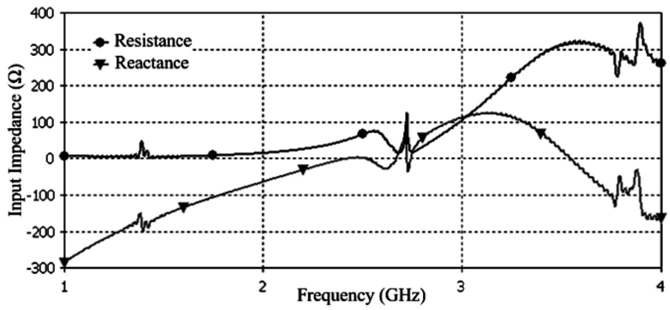
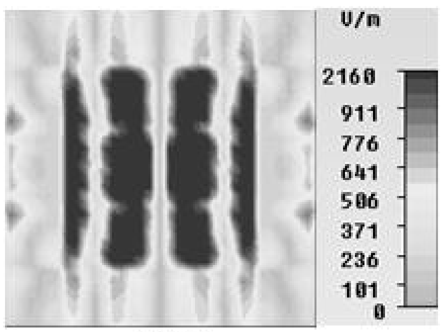


Fig.15 Input impedance of a curved strip dipole on EBG reflector with the height of 0.24λ.

From the results, it's obvious that the curved strip dipole mounting on the EBG ground plane with the optimized parameters can be achieved the return loss and the excellent gain of -23 dB and 7.5 dBi, respectively. According to the result in Fig.15 that yields impedance of the proposed antenna very close 50+*j*0 ohms at 2.45 GHz. The simulation results for HPBW in E- and H-planes are 75.3° and 84.5°, respectively, as shown in Fig.19. Furthermore, the near-field levels of the curved strip dipole on 5×5 elements EBG surface has also been calculated as shown in Fig16. The levels both in E- and H-fields are 2,160 V/m and 17.1 A/m, respectively.



E field

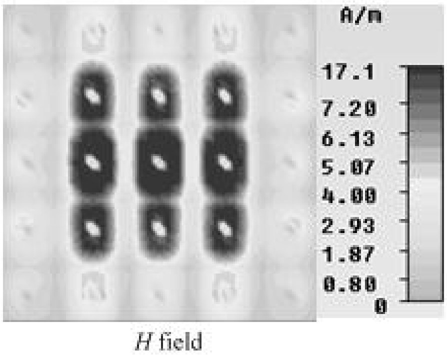


Fig.16 Near-fields distribution of the 5×5 EBG reflector.

4 Experimental Validation

To verify the simulation results, a prototype of the curved strip dipole antenna on EBG ground plane is fabricated as shown in Fig.17. After the good matching of curved strip dipole antenna without the reflector is qualified, next, it will be mounted above the center element of EBG reflector with h = 0.24λ from feed point. The feed mechanism is composed of the inner and outer of 50 ohms transmission line and connected to SMA connector. The return loss and impedance of the prototype antenna are measured by using an HP8722D Network Analyzer. Not only the proposed antenna with 3×3 elements EBG structure has been fabricated and tested for validation, but also we have been fabricated and measured this antenna with 5×5 elements EBG structure.

4.1 Case of 3×3 Elements EBG Reflector

The measured return loss of a curved strip dipole with 3×3 elements EBG reflector is shown in Fig.18, where frequency bandwidth for –10 dB return loss is around 530 MHz (2.06 – 2.59 GHz). It covers all of frequency band for the RFID microwave frequency band (2.4 – 2.58 GHz). At 2.45 GHz, the excellent return loss of -19.82 dB and the measured gain of 7.45 dBi are confirmed for the prototype antenna. The radiation patterns were measured in the E-plane and the H-plane of antenna which correspond to the y-z plane (ϕ = 90°) and x-z plane (ϕ = 0°) in Fig.19, respectively. The measured HPBW in E-plane is about 100° and in H-plane is about 110°, respectively. However, they are slightly larger than the simulated results.

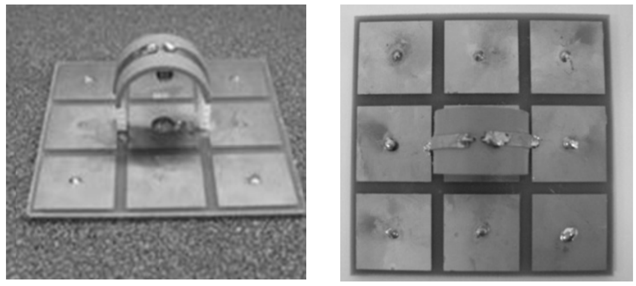


Fig.17 The prototype of the proposed antenna with 3×3 elements EBG reflector.

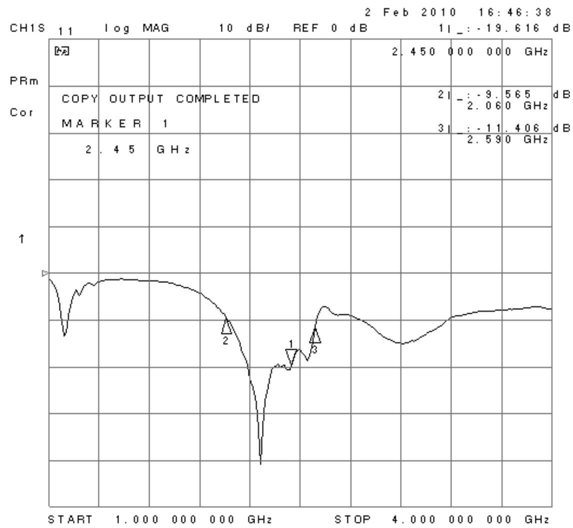
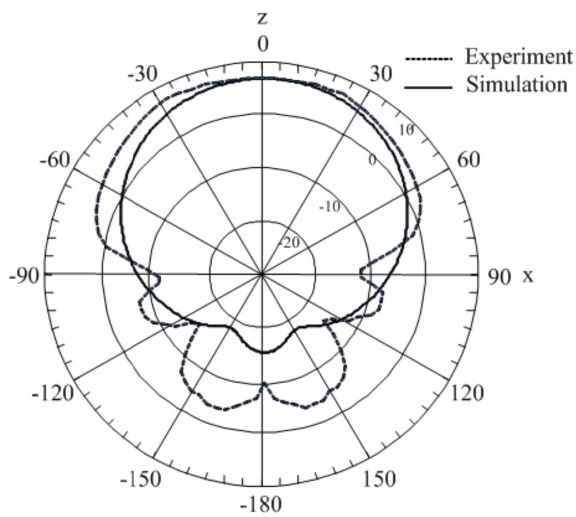
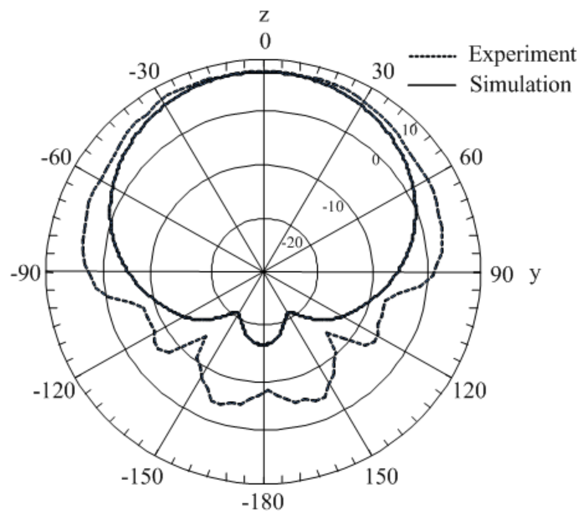


Fig.18 Measured return loss for a curved strip dipole with 3×3elements EBG reflector.



(a)



(b)

Fig.19 Comparison of the far-field radiation patterns of the proposed antenna with 3×3 elements EBG reflector in: (a) E-plane and (b) H-plane.

4.2 Case of 5×5 Elements EBG Reflector

In addition, the number of patches of EBG structure is increased to 5×5 elements for the additive study of antenna efficiency, the fabricated antenna as shown in Fig.20. In this case, when the total size of reflector is 1.24λ × 1.24λ, the frequency bandwidth for –10 dB return loss is around 560 MHz (2.06 – 2.62 GHz). It still covers all of frequency band for the RFID microwave frequency band. It is observed that, the band gap region is not shifted, when the size of reflector is changed. In Fig.20, at 2.45 GHz, the measured return loss of -25 dB and the measured gain of 7.65 dBi are confirmed for the impossibility to increase the antenna efficiency. The radiation patterns were measured in the E-plane and the H-plane of antenna in Fig.21, respectively. The measured HPBW in E-plane is about 65° and in H-plane is about 120°, respectively. However, the measured radiation pattern in the backward direction is higher than of the simulated results.

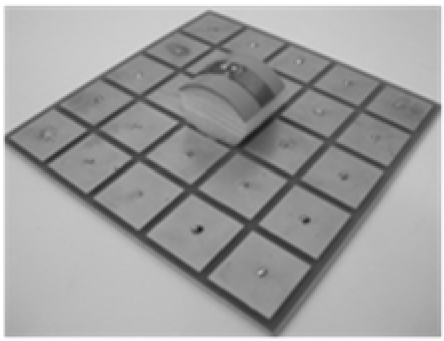


Fig.20 The prototype of the proposed antenna with 5×5 elements EBG reflector.

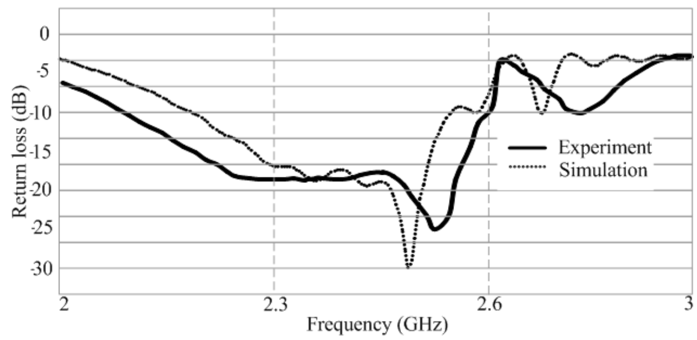
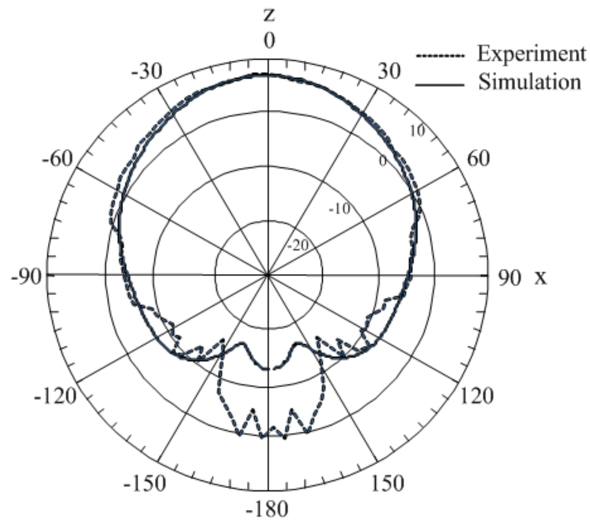
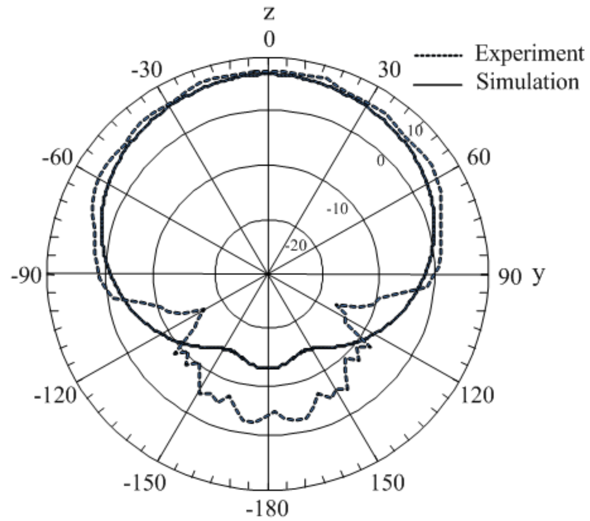


Fig.20 Return loss of the antenna with the 5×5 elements EBG reflector.



(a)



(b)

Fig.21 Comparison of the far-field radiation patterns of the proposed antenna with 5×5 elements EBG reflector in: (a) E-plane and (b) H-plane.

5 Conclusion

The curved strip dipole antenna with the resonant EBG ground plane/reflector has been studied theoretically and experimentally with CST software in laboratory. This antenna provides the wider beamwidth than straight wire dipole on the PEC reflector. The structure of antenna is not complicated and inexpensive that was demand on equipment for RFID system. The curved strip dipole on EBG reflector can be utilized to install at the RFID reader system. Since the curved strip dipole is mounted over the EBG structure, which redirects the half power of the radiation into the opposite direction improving the antenna gain to 7.45 dBi and 7.65 dBi for 3×3 elements and 5×5 elements EBG reflectors, respectively. The desired performance of this antenna could be achieved by adjusting the appropriate values of the distance between the feed point and reflector, the radius of annular curve of dipole, and the total length of curved dipole. Furthermore, the overall parameters of this antenna have been optimized appropriately with the frequency band of EBG. Whenever all values of parameters of antenna and reflector are satisfied, the antenna composition will provide the good performance as we required. However, the proposed antenna can be applied for another band by adjusting three important parameters of curved strip dipole and the reflection phase of EBG to the desired resonant frequency band.

References:

[1] P. Krachodnok and R. Wongsan, Design of Broad-Beam Microstrip Reflectarray, *WSEAS Transactions on Communications*, Vol.7, No.3, 2008, pp. 180-187.

[2] V. Thaivirot, P. Krachodnok and R. Wongsan, Radiation Pattern Synthesis from Various Shaped Reflectors Base on PO and PTD Methods for Point-to-Multipoint Application, *WSEAS Transactions on Communications*, Vol.7, 2008, pp. 531-540.

[3] S. Kumpeephat, P. Krachodnok, M. Uthansakul, and R. Wongsan, Gain and Pattern Improvements of Array Antenna using MSA with Asymmetric T-shaped Slit Loads, *WSEAS Transactions on Communications*, Vol.7, 2008, pp. 922-931.

[4] E. Wang, J. Zheng, and Y. Liu, A Novel Dual-Band Patch Antenna for WLAN Commuications, *Progress In Electromagnetics Research C*, Vol.6, 2009, pp. 93-102.

[5] Krishnan, L.-W. Li, and M.-S Leong, A V-Shaped Structure for Improving the Directional Properties of the Loop Antenna, *IEEE. Trans. Antenna Propag*, Vol.53, No.6, 2005, pp. 2114-2117.

[6] H. Elkamchouchi, and M. Abu Nasr, The S-Shaped Dipole Antenna, *2004 4th International Conference on Microwave and Millimeter Wave Technology Proceeding*, 2004, pp. 19-22.

[7] A. Thumvichit, T. Takano, and Y. Kamata, Ultra Low Profile Dipole Antenna with a Simplified Feeding Structure and a Parasitic Elelment , *IEICE Transactions. Communications*, vol. E89-B, 2006, pp. 576–580.

[8] N. Fhafhiem, P. Krachodnok, and R. Wongsan, A Shorted-End Curved Strip Dipole on Dielectric and Conducting Plane for Wireless LANs , *The 2009 International Symposium on Antenna and Propagation*, 2009, pp. 835-838.

[9] R. Wongsan, A wide-beam array antenna using shorted-end curved dipoles on a reflector plane, *WSEAS Transactions on Communications*, Vol.8, No.2, 2009, pp. 207-216.

[10] N. Fhafhiem and P. Krachodnok, The Study of A Curved Strip Dipole Antenna Parameters On EBG Reflector Plane for RFID Applications, *Proceedings of the 9th WSEAS International Conference on Applications of Electrical Engineering*, 2010, pp. 187-192.

[11] D.F. Sievenpiper, High-impedance electromagnetic surfaces, Ph.D. thesis, UCLA, 1999.

[12] F. Yang, Y. Rahmat-Samii, *Electromagnetic Band Gap Structures in Antenna Engineering*, USA by Cambridge University Press, New York, 2009

[13] L. Li, B. Li, H. Liu, and C. Liang, Locally resonant cavity cell model for electromagnetic band gap structure, *IEEE. Trans. Antenna Propag*, Vol.54, No.1, 2006, pp. 90-100.