Performance Improvement of a Wire Dipole using Novel Resonant EBG Reflector

C. Yotnuan, P. Krachodnok, and R. Wongsan

Abstract**—**Electromagnetic band-gap (EBG) structure exhibits unique electromagnetism properties that have led to a wide-range application of electromagnetic devices. This paper presented the high-directive gain antenna consisting of a wire dipole, which is horizontally lied above the novel EBG structure. The structure of EBG would be as resonator and dipole's reflector that eliminate the surface waves at edges of reflector and the back lobe of this antenna, respectively. In addition, the near-field distribution inside gap is studied to show the different distances of gap, which influence to the resonant frequency, bandwidth, and directive gain of this antenna. Consequently, we have achieved a maximum directive gain of 9.06 dBi, which is higher than a dipole with traditional ground plane. The bandwidth for -10 dB is about 15.86% at the center frequency of 5.8 GHz. Since the proposed structure remains simple but it can provide higher directive gain and larger bandwidth covering the IEEE standard (802.11a/g), the antenna, therefore, is expected to be the low cost innovation for WLAN applications.

Keywords**—**Electromagnetic Band Gap (EBG) ,directive gain antenna, novel resonant reflector, low profile antenna, large band.

I. Introduction

With the rapid development of the wireless communications and the communication industry, the antenna is an important to develop wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX), it is applied for high frequency at 5.8 GHz. In addition, the antenna should provide sufficient gain and it required either unidirectional or omnidirectional beam, coverage abroad area, and high power handing. Moreover, the antenna is relatively simple in concept, easy structure, and inexpensive. The dipole antenna has some prominent qualifications that its shape could be changed easily and variably. However, the dipole provides low gain antenna, which is not proper for installation when this type of antenna is placed on the wall of building. This argument, if we can design antenna to illuminate a predefined wide coverage area, then the efficiency of field radiation will be distinctly increased. The reflector plane is one method, which can be designed and applied to the behind of dipole for controlling the energy flows in the normal direction to the higher gain can be obtained consequently. The related literatures of dipole horizontally which is located above a reflector plane have been reported by several authors [1]-[5]. Generally, if the dipole is vertically laced to a PEC ground plane, it is not low profile dipole antenna. Fortunately, the image current has the same direction and reinforces the radiation from the original current, in consequence, the antenna will yields good efficiency. For a low profile antenna, when the dipole is placed horizontally on the same ground plane, the image current has not the same direction; thus, the antenna efficiency will be decreased, especially, if it is very close to the ground plane. To solve the solutions, the EBG structures were designed at resonant frequency and functioned as a reflector of the radiator element [6]-[9].

EBG structures have been widely applied in antenna engineering due to their interesting properties such as in-phase reflection, surface wave suppression, light weight, ease of fabrication, and low fabrication cost. As mentioned in [10], the EBG structures, when are employed as an artificial magnetic conductor (AMC), are innately narrow band. The antenna bandwidth is much wider than the AMC bandwidth, which in turn restricts the antenna bandwidth. On the other hand, the resonant frequency of the EBG structures cannot be changed after construction.

To eliminate the aforementioned problems, a wire dipole located horizontally above the novel EBG reflector for improving its directive gain and bandwidth has been proposed in this paper. The EBG structures have been developed in field of antenna, and it exhibits high impedance characteristic on a certain frequency range and in-phase reflection characteristics for the incident wave. Therefore, the EBG surface is capable of providing a constructive image current within a certain frequency band, resulting in good radiation efficiency. From this argument, we have chosen and modified the EBG structure to be the reflector or the ground plane of dipole antenna by studying various types of gap and the effects of gap variation, which can be optimized the required performances and all parameters of antenna. Finally, this antenna can be achieved the maximum directive gain higher than the antenna on the traditional conducting plane and provide the large bandwidth covering the IEEE standard (802.11a/g).

In Section II, we first describe the proposed antenna configuration. The simulation results are presented in Section III by conducting at center frequency of 5.8 GHz for a wire dipole and EBG resonator. The impedance characteristics, directive gain, bandwidth, and radiation patterns will be clarified, respectively. The experimental validation is presented in Section IV. Finally, the conclusion has been presented in Section V.

II. The Proposed Antenna Configuration

The configuration of the proposed antenna is shown in Fig 1. A wire dipole is mounted horizontally, in the *x*-direction, over the novel EBG reflector plane, which the front of structure directed to *z*-direction. The radius of conducting wire (r_l) is around 0.003369λ and assumed that it is the perfect electrical conductor (PEC). The total length of a wire dipole is expressed by *l*. The distance h_l between a wire dipole and surface of EBG structure is about 0.02λ, approximately. The analysis model of EBG reflector consists of several conducting patches on ground plane. The proposed model consists of 4×4 unit cell, while an overall dimension of reflector sheet is 59.02676 mm × 59.02676 mm by using a 1.6 mm thickness FR4-substrate with a permittivity of 4.5. The widths of patch width (W_l) and gap (*g*) are 14.75669 mm and 1.2 mm, respectively. The radius (*r*) of vias, which is connected between conducting patches and ground plane, is 1.22449 mm. However, all parameters of the antenna geometry can be shown by referring to free-space wavelength (*λ*) of 5.8 GHz, which is the resonance frequency of dipole and conducting patches, as shown in Table 1.

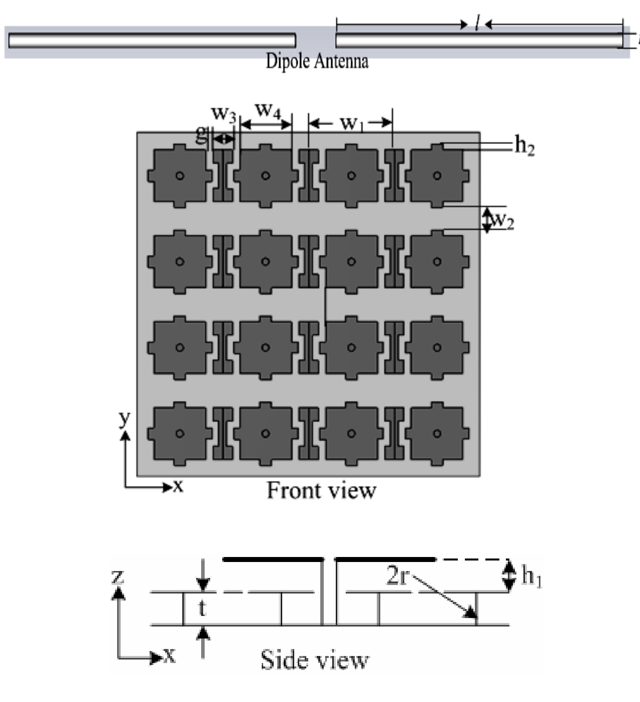


Fig. 1 configuration of wire dipole with novel EBG reflector

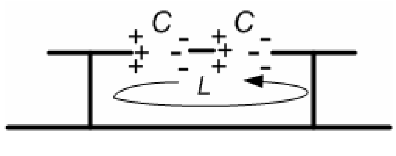


Fig.2 equivalent resonant *LC* circuit for EBG structure

Table. I The parameters of antenna geometry

Parameter	size
W_1	0.29λ
W_2	0.07λ
W_3	0.03λ
W_4	0.17λ
g	0.02λ
h_1	0.02λ
h_2	0.019 λ
r	0.01λ
t	0.03λ

The novel EBG structure is shown in Fig.1, which consists of three parts that are PEC ground plane, dielectric, and patches. Afterwards, the patch and PEC ground plane are shorted circuit by pins, they is called vias. Considering with the patches that is an array of metal patches which is the unit cell is small compared to the resonance wavelength. The structure of EBG could be described using lumped-circuit elements. For illustrated in Fig.2, this structure 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. For the EBG structure with patch width ($W = W_3 + W_4$), gap width (*g*), substrate thickness (*t*), and dielectric constant (ε_r), the values of inductor (*L*) and capacitor (*C*) can be approximated by the following formulas [11].

$$L = \mu_0 t \tag{1}$$

$$C = \frac{W\varepsilon_0\left(1+\varepsilon_r\right)}{\pi}\cosh^{-1}\left(\frac{2W_1}{g}\right) \tag{2}$$

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

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{3}$$

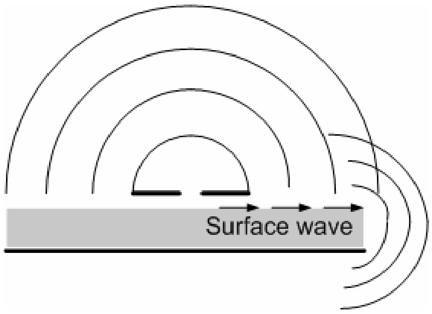
$$Z = \frac{j\omega L}{1-\omega^2 LC}\,. \tag{4}$$

III. Simulation Results

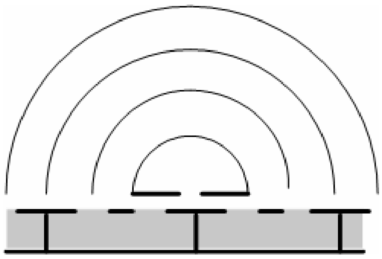
After configuration study, appropriate parameters have been chosen as indicated in Table 1. We used Computer Simulation Technology (CST) software version 2009 in order to optimize the required performances such as return loss, near-field distribution inside gap, and directive gain at the center frequency of 5.8 GHz. In this section, we separated the simulation results into two subsections consisting of the novel EBG structure and the dipole above novel EBG.

A. The Novel EBG Structure

Generally, when a wire dipole antenna is horizontally close to PEC ground plane, the antenna generates surface waves in the ground plane that size is always finite. Therefore, surface waves radiate from edges and corners that it can be seen in Fig. 3 (a). In Fig. 3 (b) is cased of EBG surface, the one unit of EBG is characteristic of the *LC* parallel resonant circuit. At the mode resonant frequency, each row of metal patches has opposite electric field, and form the standing waves which results in the surface waves suppression band gap.



(a)



(b)

Fig. 3 the radiator on reflector plane: (a) surface waves radiating at PEC surface edges and (b) surface wave suppression on an EBG surface

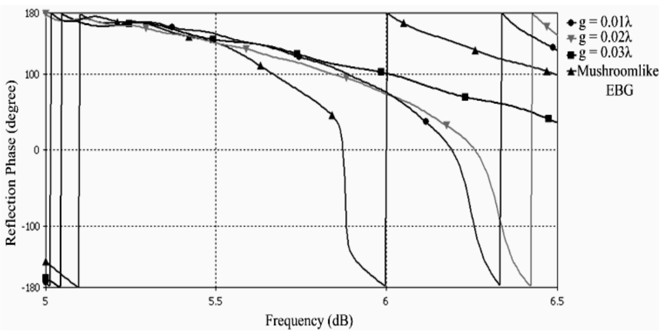


Fig. 4 the results of reflection phases of the EBG structure

Fig. 4 shows the results of reflection phases of the novel EBG structure using dispersion diagram [8] that are calculated by CST simulation. The gap widths are varied at g = 0.01 $\lambda_{5.8\ GHz}$, 0.02 $\lambda_{5.8\ GHz}$, and 0.03 $\lambda_{5.8\ GHz}$ to optimize the proper size of g for the largest bandwidth, while the "mushrooms like" EBG has also been compared to our novel structure. As a result, when the gap width is 0.02 $\lambda_{5.8\ GHz}$, the frequency region is varied from 5.7 GHz to 6.65 GHz (largest), which appropriate for serving as the ground plane or reflector in a certain frequency of this study.

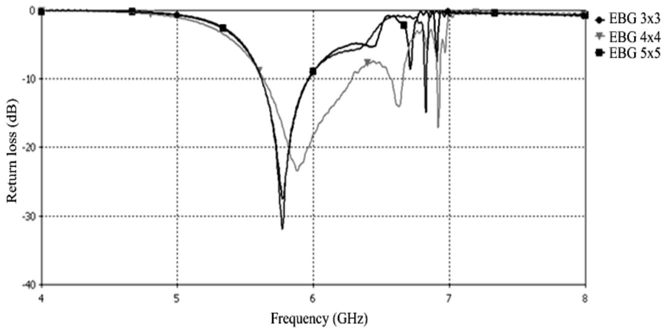
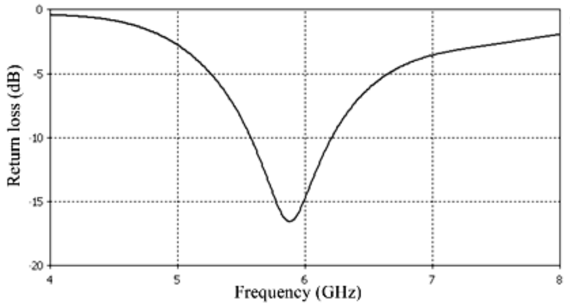
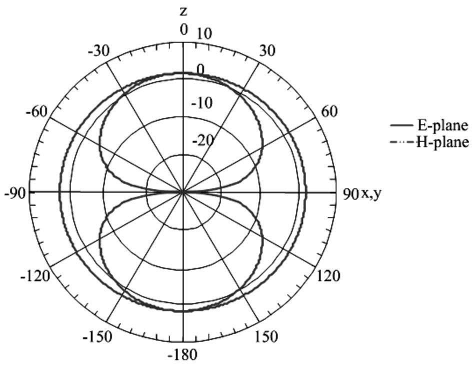


Fig. 5 the return loss of wire dipole above novel EBG reflector versus variation of a number of elements



(a)



(b)

Fig. 6 the dipole without novel EBG at 5.8 GHz: (a) return loss and (b) radiation pattern

The simulated return loss dependency of the dimension of the EBG ground plane is shown in Fig. 5. We found that the dimension of the EBG ground plane consisting of 3×3 elements yields lower the return loss but narrower the bandwidth as same as the EBG ground plane consisting of 5×5 elements. But in case of the EBG ground plane consisting of 4×4 elements will yield the largest bandwidth (950 MHz), while its return loss remains lower than -20 dB at the desired frequency of 5.8 GHz. Therefore, the EBG ground plane consisting of 4×4 elements will be selected to be the ground plane or reflector of wire dipole [12].

B. The Dipole above Novel EBG

From the resulting that illustrated in Fig.6(a) and (b), the dipole antenna without EBG ground plane has a low gain of 2.09 dB and return loss at 5.8 GHz is -16 dB. It has omnidirectional beam in H-plane and the half power beamwidth in E-plane is 79.1°. To improve the gain of the antenna, the EBG is applied for reflector plane of the dipole.

For optimization to obtain the appropriate parameters of the antenna, we have selected three different distances of h1 for studying its influences such as 0.01 $\lambda_{5.8\ GHz}$, 0.02 $\lambda_{5.8\ GHz}$, and 0.03 $\lambda_{5.8\ GHz}$, respectively, while the length of dipole will be varied from 0.34 $\lambda_{5.8\ GHz,}$ to 0.44 $\lambda_{5.8\ GHz}$.

In the first case, the dipole is placed above novel EBG at the distance of h_1 fixed at 0.01λ and the length of wire dipole is varied from 0.34 $\lambda_{5.8\ GHz,}$ to 0.44 $\lambda_{5.8\ GHz,}$, as shown in Fig. 7.

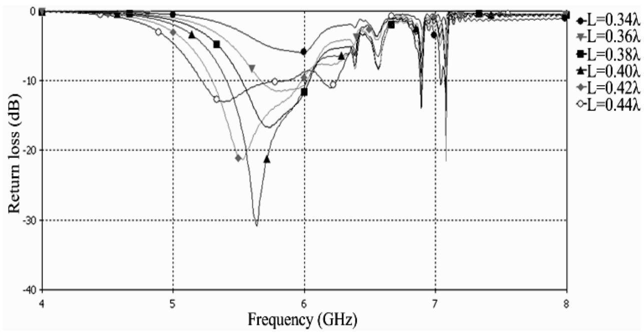


Fig. 7 return loss of the dipole above novel EBG with distance of h_1 is $0.01\lambda_{5.8\ GHz}$

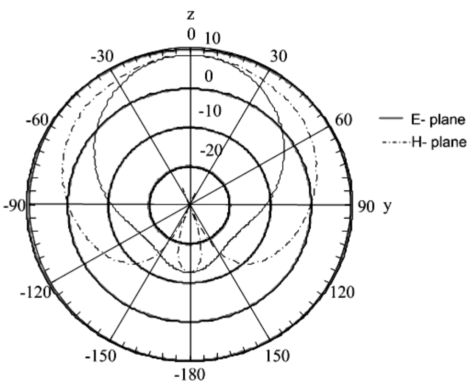
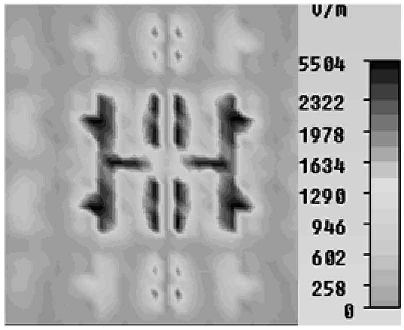


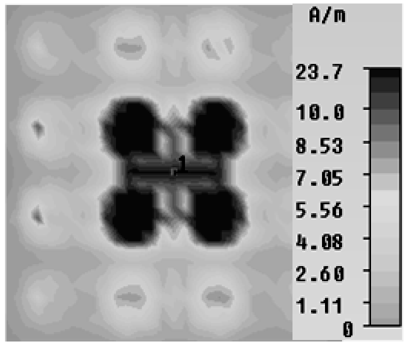
Fig. 8 directive gain of the dipole above novel EBG with distance of h_1 is $0.01\lambda_{5.8\ GHz}$

Fig. 7 is obvious that the wire dipole on the resonant EBG reflector can be matched well from 5.22 GHz to 6.06 GHz (at return loss lower than -10 dB). However, the good matching is achieved with the length of the dipole 0.40 $\lambda_{5.8\ GHz,}$ at frequency 5.64 GHz and the covering bandwidth is at 850 MHz, approximately.

Fig. 8 shows the directive gain of antenna about 9.01 dBi. Fig. 9 shows the near-fields distribution occurring on EBG reflector, which is calculated by using CST software. The E- and H-field levels of EBG structure are around 5,504 V/m and 23.7 A/m, respectively



(a)



(b)

Fig. 9 near-fields distribution inside the gap with distance of h_1 is $0.01\lambda_{5.8\ GHz}$: (a) E-fields and (b) H-fields

The next case, the distance h1 of dipole is fixed at 0.02 $\lambda_{5.8\ GHz,}$ and the length of wire dipole still be varied from 0.34 $\lambda_{5.8\ GHz,}$ to 0.44 $\lambda_{5.8\ GHz,}$. In Fig. 10, it is found that the wire dipole on the resonant EBG reflector can be matched well from 5.42 GHz to 6.34 GHz. Also, the best matching is achieved with the length of the dipole 0.38 $\lambda_{5.8\ GHz,}$, the proposed antenna will cover the desired frequency band (about 920 MHz). The resonant frequency is 5.8 GHz, which according to our requirement. Fig. 11 shows the directive gain of antenna about 9.06 dBi. The near-fields distribution inside EBG reflector are calculated by CST and shown in Fig. 12. The levels of E- and H-fields are 4,576 V/m and 24.4 A/m, respectively.

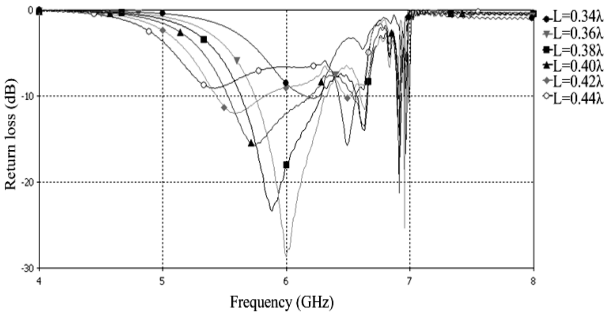


Fig. 10 return loss of the dipole above novel EBG with distance of h_1 is $0.02\lambda_{5.8\ \mathrm{GHz}}$

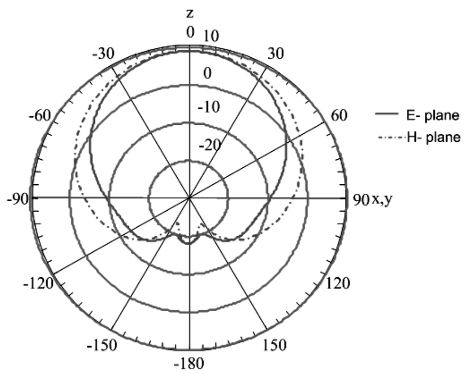
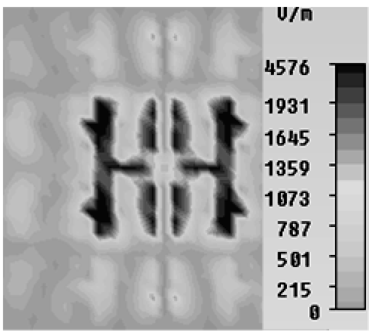
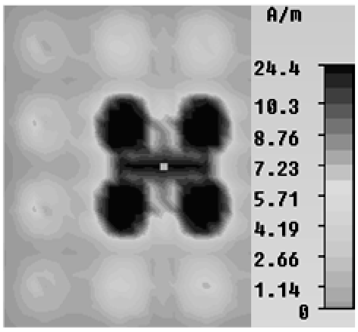


Fig. 11 directive gain of the dipole above novel EBG with distance of h_1 is $0.02\lambda_{5.8\ \mathrm{GHz}}$



(a)



(b)

Fig. 12 near-fields distribution inside the gap with distance of h_1 is $0.02\lambda_{5.8\ \mathrm{GHz}}$: (a) E-fields and (b) H-fields

The last case, the distance h_1 of dipole is specified at $0.03\lambda_{5.8\ \mathrm{GHz}}$ and the length of wire dipole still be varied as well. The simulated results of return loss of antenna are shown in Fig. 13. It is obvious that the dipole element on the same EBG reflector can be matched well from 5.58 GHz to 6.72 GHz. In addition, the good matching is achieved with the length of the dipole $0.36\lambda_{5.8\ \mathrm{GHz}}$, but the resonant frequency is shifted up to 6.05 MHz. However, it will yield the bandwidth about 1,140 MHz, which is larger than previous two cases.

Fig. 14 shows the directive gain of antenna about 8.9 dBi. The near-fields distribution inside EBG reflector are calculated by CST and shown in Fig. 15. The levels of E- and H-fields are 4,023 V/m and 25.09 A/m, respectively.

From three study cases of wire dipole above the resonant EGB reflector in previous section, therefore, the second case has been selected reasonably because it provides the highest directive gain (9.06 dBi) at the desired frequency (5.8 GHz) using the length of dipole equals to 0.38 $\lambda_{5.8\ \mathrm{GHz},}$ (l = 9.82760 mm). Although it provides the bandwidth narrower than the bandwidth of antenna in the third case, however, it still is large enough for IEEE standard (802.11a/g).

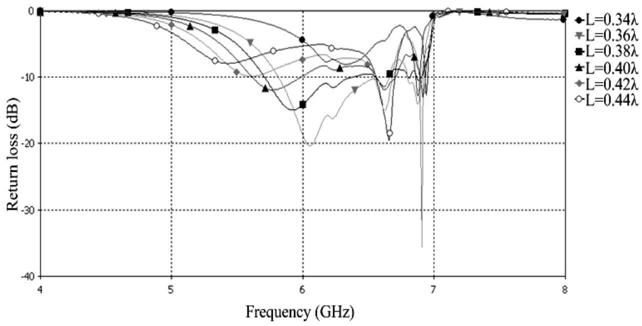


Fig. 13 return loss of the dipole above novel EBG with distance of h_1 is $0.03\lambda_{5.8\ \mathrm{GHz}}$

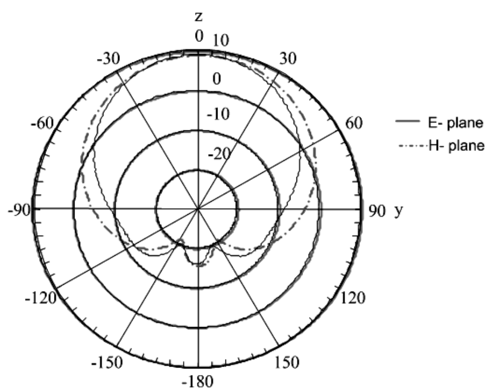
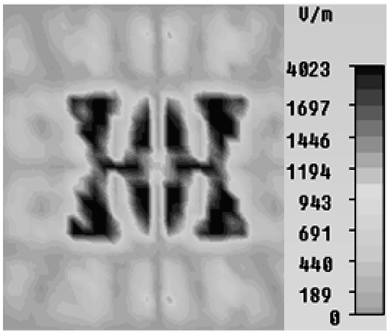
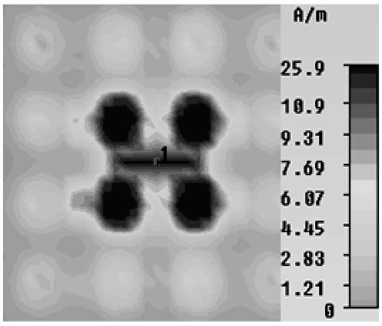


Fig. 14 directive gain of the dipole above novel EBG with distance of h_1 is $0.02\lambda_{5.8\ \mathrm{GHz}}$



(a)



(b)

Fig. 15 near-fields distribution inside the gap with distance of h_1 is $0.03\lambda_{5.8\ GHz}$: (a) E-fields and (b) H-fields

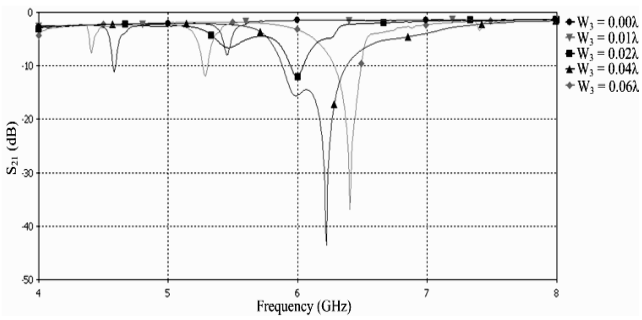


Fig.16 insertion loss of patch width (W_3) with difference sizes

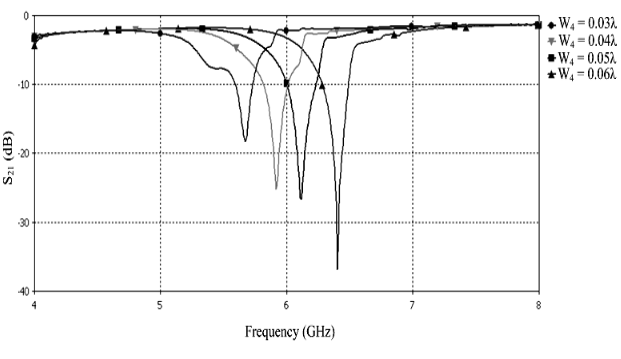


Fig.17 insertion loss of patch width (W_3) with difference sizes.

We continue to study about the impacts of W_3 , W_4 and h_2. The parameter W3 and W4 play an important role in determining the frequency band. Patch width is changed up to 0.06 λ. Figs. 16 and 17 show the insertion loss of EBG surface with different patch width. It is observed that when patch width is increased, the frequency band decreases. Furthermore, this phenomenon can be explained using the lumped LC model. According to (2), a wider patch width leads to larger capacitance C. Thus, the frequency reduces.

h2 is used to control the frequency behavior. It is changed from 0.04λ to 0.10λ. The insertion loss with different h_2 are shown in Fig. 18. It is observed that if h2 is increased, the frequency decreases. This is similar to the effect of the patch width W_3 and W_4.

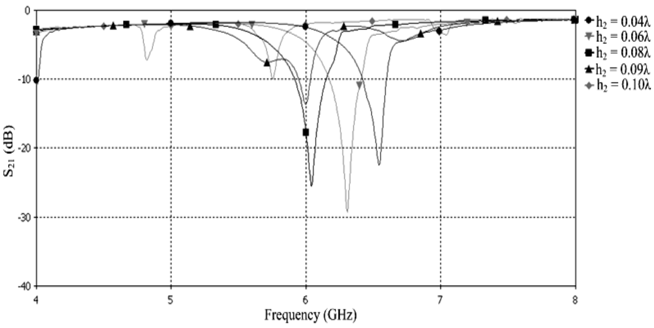
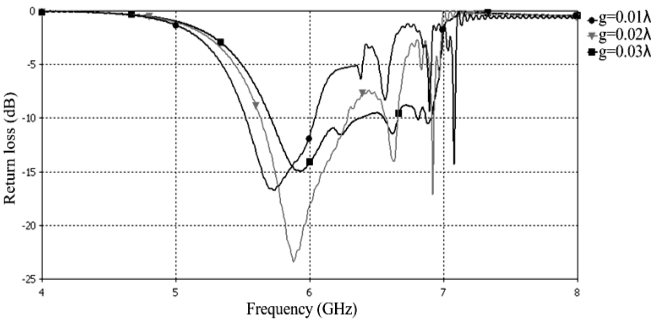
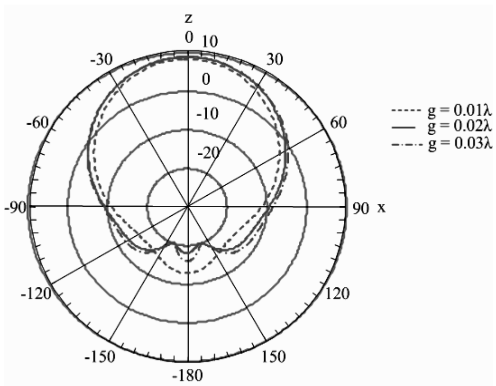


Fig. 18 insertion Loss of the Adjustment of h_2



(a)



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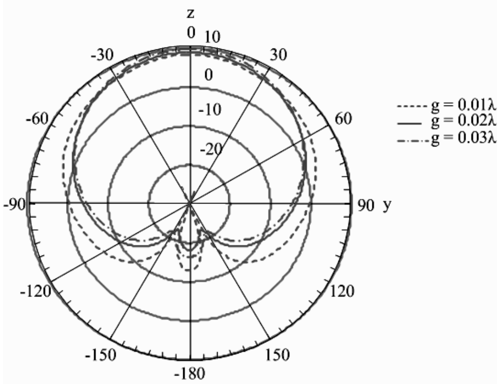


(c)

Fig. 19 return loss and radiation pattern of wire dipole above novel EBG reflector with different gap spacing: (a) return loss, (b) E-plane, and (c) H-plane

Finally, we continue to study about the impacts of gaps spacing g between conducting patches of EBG structure by varying g = 0.01 $\lambda_{5.8\ GHz}$, 0.02 $\lambda_{5.8\ GHz}$, and 0.03$\lambda_{5.8\ GHz}$, respectively, at the desired frequency of 5.8 GHz. The height of the radiating dipole over the EBG surface is fixed at 0.02λ5.8 GHz. The simulation results of return loss and radiation pattern, which are influenced by gaps spacing are shown in Fig. 19.

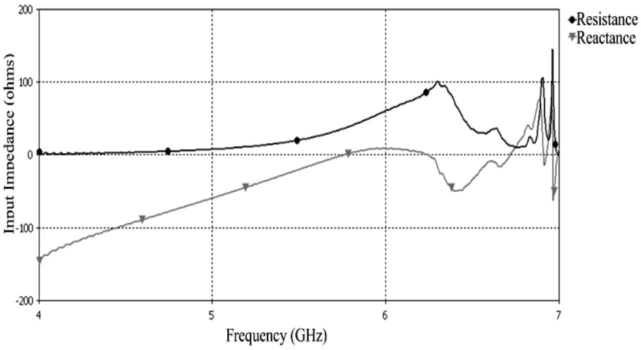


Fig. 20 input impedance of wire dipole above novel EBG reflector

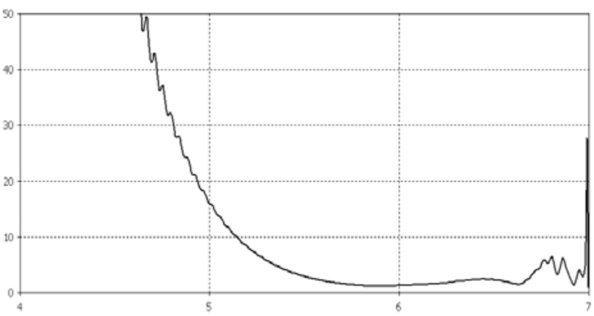


Fig. 21 VSWR of wire dipole above novel EBG reflector

As resulting, we found that the resonant frequency of the proposed antenna and its radiation pattern were affected by the influences of gaps spacing g. In Fig. 19 (a), it shows that the antenna can be matched well for every value of g. Moreover we found that if gaps spacing is increased, then the resonant frequency will be shifted up to higher frequency. However, the proper spacing will be chosen at g = 0.02λ5.8 GHz, due to the best matching and the highest directive gain (9.06 dBi) at the desired frequency of 5.8 GHz. For Fig. 19 (b) and (c), it is found that with the same spacing, the back lobe both in E- and H-plane of the proposed antenna will be most eliminated and consequently provide the highest directive gain. According to the result in Figs. 20 and 21 that yields input impedance and VSWR of wire dipole above novel EBG reflector very close 50 +j0 ohms and 1.25, respectively, at resonance frequency of 5.8 GHz.

IV. Experimental Validation

To verify the simulation results, a prototype of the wire dipole antenna on novel resonant EBG ground plane is fabricated as shown in Fig.22. When the wire dipole with novel resonant EBG reflector is passed the matching test, it is mounted over the EBG ground plane with h_1 = 0. 02$\lambda_{5.8\ GHz}$. The return loss is measured by using an HP8722D Network Analyzer. The antenna is trimmed equal both ends off for matching impedance. Therefore, the length of antenna prototype is decrease that is a good effect for the low profile antenna.

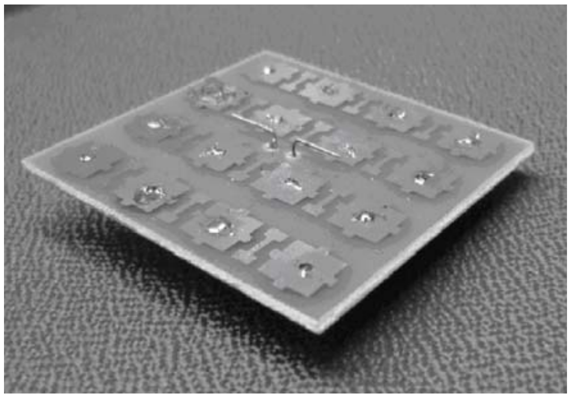


Fig. 22 the prototype of proposed antenna

In order to verify the simulation results by means of measurements, the wire dipole with novel resonant EBG reflector have been fabricated using our in-house facility, as shown in Fig. 22.

Fig. 23 as shown the measured reflection characteristics, the 4×4 elements can be matched well from 5.6 GHz to 6.3 GHz, which are below -10 dB that is cover all of frequency band for IEEE standard (802.11a/g). The measurement is in a good agreement with the simulation result. The remaining mismatch is mainly due to etching tolerances and via misalignments, which can be directly seen from the fabricated EBG structures.

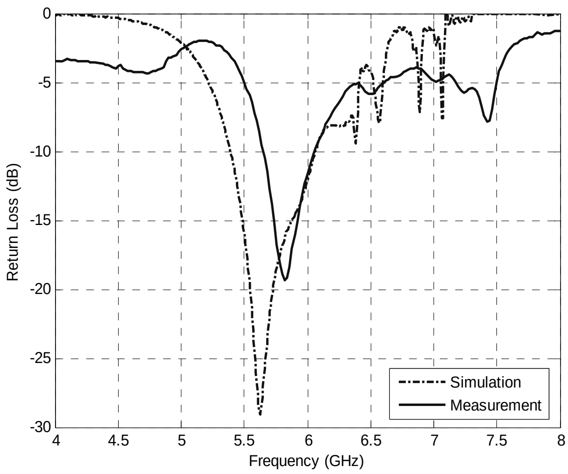
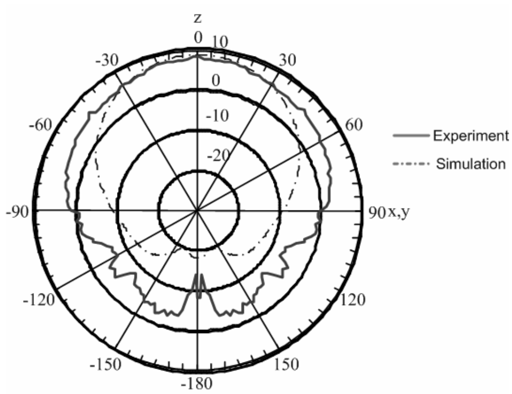
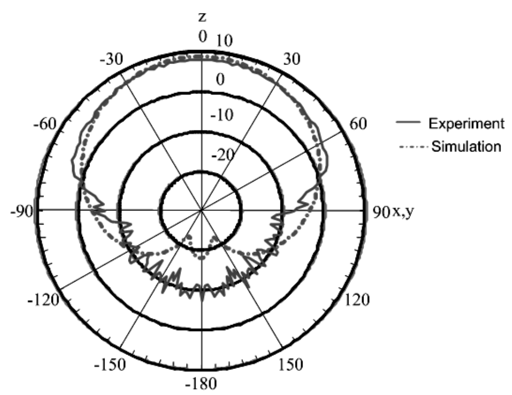


Fig. 23 the simulated and measured result



(a)



(b)

Fig. 24 Radiation pattern of wire dipole above novel EBG reflector: (a) E-plane and (b) H-plane

Fig.24 shows the comparison of the simulated and measured results for the total far-field radiation patterns in E-plane and H-plane. The maximum radiation occurs in the normal direction to a reflector plane. We have achieved a maximum gain of 7.86 dB which is higher than that of a traditional half-wave dipole. Moreover, it had the half power beamwidth E- and H-plane are $80°$ and $100°$, respectively. The results of gain, HPBW, and patterns are well agreement of antenna for wireless local area (WLAN) system.

V. Conclusion

A wire dipole antenna with novel resonant EBG reflector has been studied experimentally with CST software in laboratory. The experiments with CST program have shown that the proposed antenna can be realized for utilization in WLAN applications for IEEE standard (802.11a/g) with simple structure and easy fabrication. The radiation of electromagnetic field occurs in the boresight, which is proper to install this antenna at the wall of building. The maximum gain is 9.06 dBi at 5.8 GHz with dipole length and gaps spacing is $0.38_{\lambda 5.8\ \mathrm{GHz}}$ and $0.02_{\lambda 5.8\ \mathrm{GHz}}$, respectively. In addition, this antenna provides the frequency bandwidth about 950 MHz that large band enough for applications in such IEEE standard. From the study, we found that the structure of EBG resonator contributed eliminating the surface waves at edge of reflector and decreasing back lobes of the proposed antenna. Therefore, the almost electromagnetic fields are radiated in boresight of antenna contributing the directive gain is increased, consequently. However, besides WLAN applications, many applications can be conceived for a wire dipole with novel resonant EBG reflector due to its geometrical and electromagnetic.

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