ENHANCEMENT OF PRINTED DIPOLE ANTENNAS CHARACTERISTICS USING SEMI-EBG GROUND PLANE

F. Yang, V. Demir, D. A. Elsherbeni, and A. Z. Elsherbeni

Center of Applied Electromagnetics Systems Research (CAESR)
Department of Electrical Engineering
The University of Mississippi
University, MS 38677, USA

A. A. Eldek

Department of Computer Engineering
Jackson State University
Jackson, MS 39217, USA

Abstract—Electromagnetic band gap (EBG) structures have been used in many antenna designs to improve their performance. This paper investigates the performance of a dipole antenna near the edge of a ground plane, a popular setup in various wireless communication systems. To increase the radiation efficiency, a printed dipole antenna with semi-EBG ground plane is proposed. Both FDTD simulations and experimental results demonstrate the validity of this antenna design.

1. INTRODUCTION

Electromagnetic band-gap (EBG) structures are novel periodic composites exhibiting desirable electromagnetic properties that may not occur in nature. They have been implemented in a wide range of applications in antennas, electromagnetic compatibility, microwave circuits, and radar systems. Among various EBG structures, planar EBG designs such as the mushroom-like structure [1] and the uni-planar design [2] demonstrate great potential for wireless communication systems because of their low profile configurations.
One important application of EBG structures is to serve as the ground plane for a low profile dipole antenna [3–8]. Dipole antenna is a simple and fundamental radiator in antenna engineering. However, it cannot radiate efficiently near a perfect electric conductor (PEC) ground plane due to the reverse image currents. To solve this problem, an electromagnetic band-gap (EBG) ground plane with an in-phase reflection coefficient has been developed to replace the traditional PEC ground plane to improve the efficiency of low profile dipole antennas.

Previous publications all focus on a dipole antenna that is positioned above a ground plane as shown in Fig. 1(a). In some wireless communication systems [9], it is also required that a dipole antenna needs to work efficiently near the edge of a ground plane, as shown in Fig. 1(b). A representative example is an internal antenna design for wireless local area network (WLAN) subsystem of a notebook computer, where the antenna is located in the narrow rim above the LCD screen that has a metal conductor on the back.

![Figure 1. Geometries of (a) a dipole antenna above a ground plane and (b) a dipole antenna near the edge of a ground plane.](image)

This paper first investigates the performance of a dipole antenna near the edge of a PEC ground plane. Then a mushroom-like EBG is used to improve the antenna efficiency and a satisfactory result is obtained. Printed dipole antennas with a semi-EBG ground plane are designed and validity of this novel antenna design is demonstrated by simulation and experimental results. This antenna structure provides a promising solution for many wireless communication systems where a PEC conductor exists near the working environment of an antenna.

2. DIPOLE ANTENNA NEAR THE EDGE OF A GROUND PLANE

2.1. Dipole Antenna Near the Edge of a PEC Ground Plane

A half-wavelength dipole antenna radiates efficiently in free space. When it is placed close to a PEC ground plane, surface currents are
Figure 2. Comparison of dipole performance in different environments. When a dipole is placed close to the edge of a conventional PEC ground plane, it cannot radiate efficiently.

induced on the ground plane to satisfy boundary conditions. When the dipole is located near the PEC ground plane, the radiation of the induced currents will cancel the radiation from the dipole, resulting in low radiation efficiency.

Figure 2 compares the FDTD simulated return losses of dipole antennas in three environments: dipole in free space, dipole above a PEC ground plane, and dipole near the edge of a PEC ground plane. A strip dipole is used in the simulation with a length of 0.50 $\lambda_{8\text{GHz}}$ and width of 0.02 $\lambda_{8\text{GHz}}$, where $\lambda_{8\text{GHz}}$ is the free space wavelength at 8 GHz. A finite PEC ground plane with a size of $1\lambda_{8\text{GHz}} \times 1\lambda_{8\text{GHz}}$ is used in the simulation. The distance between the dipole and the PEC ground plane is 0.02 $\lambda_{8\text{GHz}}$. A gap source [10] is used to feed the dipole in the simulations.

It is observed that the dipole achieves a good return loss in free space. When the dipole is placed above a PEC ground plane, the return loss is close to zero, which means that very little energy is radiated in this situation. The reason is that the radiation from the reverse image current cancels the radiation from the original dipole due to their close proximity. When the dipole is put near the edge of the PEC ground plane, the return loss is better than the previous case because the image theory is not applicable here. The radiation from induced currents on the ground plane, however, still cancels most of the radiation from the
dipole because the dipole is very close to the ground plane. Thus, the return loss is poor as well, which is only $-2\,\text{dB}$.

### 2.2. Return Loss Improvement of the Dipole Using an EBG Ground Plane

The performance of a dipole antenna above a ground plane, as shown in Fig. 1(a), has been improved using an EBG surface in previous literatures [3]. It is the goal of this paper to investigate the performance improvement of a dipole near the edge of a ground plane, as shown in Fig. 1(b). A mushroom-like EBG ground plane is used to replace the conventional PEC ground plane, as shown in Fig. 3(a). Periodic square patches are mounted on a grounded dielectric slab with $0.04\lambda_{8\,\text{GHz}}$

![Figure 3. A dipole antenna near the edge of an EBG ground plane: (a) antenna geometry and (b) FDTD simulated return loss results. Good return loss is obtained when the EBG ground plane is used instead of the PEC ground plane.](image-url)
thickness and a dielectric constant of 2.94. The width of periodic patches is 0.12λ_{GHz} and the gap width between adjacent patches is 0.02λ_{GHz}. Center vias with 0.005λ_{GHz} radius are used to connect the patches to the bottom PEC conductor. The selection of these parameters follows the guidelines developed in [4]. The dipole dimensions are the same as described in previous section.

Figure 3(b) compares the return losses of dipole antennas near the edge of an EBG ground plane and near the edge of a PEC ground plane. It is observed that the return loss of the dipole has been significantly improved from −2 dB to −16 dB. This result demonstrates the ability of the EBG ground plane to enhance the radiation efficiency of a nearby dipole.

2.3. Parametric Study of the Dipole Height Effect

Parametric studies have been performed to develop engineering guidelines for antenna designs. Figure 4 depicts the effect of dipole height selections. When the dipole is located on the same plane as the top periodic patches of the EBG structure, the height is 0.04λ_{GHz}. The height is zero when the dipole is located on the same plane as the bottom conductor of the EBG structure. A negative height means that the dipole is below the bottom conductor of the EBG structure.

When the dipole height is 0, the return loss is around −4 dB. Both the EBG structure and PEC surface affect the dipole radiation and limited improvement is obtained compared to the dipole near a pure PEC ground plane. When the dipole height is increased, the EBG structure plays a dominant role in affecting the dipole radiation. Thus the return loss is improved significantly. A −27 dB return loss is obtained when the height is 0.06λ_{GHz}.

Several dipole positions below the bottom conductor are also simulated and the data are plotted in Fig. 4(b). In this situation, the PEC plays a dominant role in determining the antenna efficiency. Therefore, the return loss is not as significantly improved as in Fig. 4(a). When the height decreases, only a slight enhancement is noticed because of the increasing distance between the dipole and the PEC ground plane.

2.4. Parametric Study of the Dipole Length Effect

Figure 5 illustrates the dipole length effect on the antenna performance. In this study, the dipole is located on the same plane as the top periodic patches of EBG structures (height = 0.04λ_{GHz}). When the dipole length is increased, the resonant frequency decreases. Meanwhile, the return loss value and the antenna bandwidth change as well. It is
Figure 4. Parametric study of the dipole height effect (Unit: $\lambda_{8\,\text{GHz}}$). When the dipole is located on the same plane as the bottom conductor of the EBG surface, the height is zero. The height is 0.04 when the dipole is located on the same plane as the top periodic patches of the EBG surface.
Figure 5. Parametric study of the dipole antenna length effect (Unit: $\lambda_{8\text{GHz}}$). The return losses are calculated using the FDTD method.

noticed that when the resonant frequency of the antenna falls in the range of 6.5–8.3 GHz, the dipole can obtain a good return loss better than $-10$ dB. This frequency range is known as the operating band of the EBG structure to work as the ground plane for a nearby planar dipole antenna. This phenomenon agrees with the observation in [4]. If one would like to design a dipole antenna working outside of this frequency band, it is then necessary to scale the parameters of both the dipole and the EBG ground plane accordingly.

3. PRINTED DIPOLE ANTENNA DESIGNS

The EBG structure has demonstrated its capability to improve the radiation efficiency of a nearby dipole antenna. An ideal gap source is used to excite the dipole antenna in previous FDTD simulations. In practical applications, the feed structure needs to be carefully designed. Two microstrip-fed printed dipole designs are described in this section. They are easy to fabricate and the performance are tested through experimental results.

3.1. Design 1

The geometry of the first printed dipole design is shown in Fig. 6. The antenna structure is built on a 1.5 mm thick dielectric substrate with
Printed dipole antenna design 1: dipole arms are located on two sides of the substrate. (a) Front view, (b) back view, and (c) FDTD calculated return loss. The semi-EBG ground plane improves the return loss of the antenna.

$\varepsilon_r = 2.94$. A 50 Ω microstrip transmission line is used to feed the dipole in order to obtain a conformal design. One arm of the dipole is fabricated on the top layer of the substrate and is directly connected to the microstrip feed line. The other arm of the dipole is printed on the bottom layer of the substrate and is connected to the PEC ground of the microstrip line. The length of each arm is 6.75 mm and the width is 0.75 mm. A semi EBG ground plan is used to improve
the dipole performance and its dimensions are the same as described in Section 2.2. It is worthwhile to point out that the distance between the printed dipole and the semi-EBG ground plane is only 0.75 mm, which satisfies the compact size requirement in many wireless communication systems.

Figure 6(c) presents the return loss of the dipole computed using the FDTD method. The antenna resonates at 7.8 GHz with an impedance bandwidth of 6.9% ($S_{11} < -10$ dB). The printed dipole antenna with a conventional PEC ground plane is simulated as a reference and the data are also shown in Fig. 6(c). Because of the close proximity of the dipole and the ground plane, the return loss cannot match well to $-10$ dB. It is clear from the comparison that the semi-EBG ground plane helps the dipole antenna to radiate efficiently.

3.2. Design 2

To further improve the return loss and enlarge the bandwidth of the antenna structure, a second printed dipole is designed. As we learn from the parametric study of the dipole height effect in Section 2.3, the return loss of the dipole will improve when the height of the dipole is increased. Therefore, printed dipole design 1 is modified in the way that both arms of the dipole are fabricated on the top layer of the substrate, as shown in Fig. 7(a). The gap between the two arms is 0.75 mm. Note that the right arm is connected to the bottom PEC conductor through a metal via. Other parameters of the antenna structure are the same as those given in the previous section.

The FDTD computed return loss of the dipole near the semi-EBG ground plane is plotted in Fig. 7(b), as well as that of a dipole near a conventional PEC ground plane. Again, the semi-EBG ground plane improves the return loss of the nearby dipole antenna. Compared to the first printed dipole antenna design in Fig. 6, the resonant frequency slightly shifts down to 7.64 GHz. The return loss value at the resonant frequency is improved to $-23$ dB and the bandwidth is broadened to 9.0%.

3.3. Experimental Results

Experiments are carried out to demonstrate the design concept of the printed dipole near the semi-EBG ground plane. Figure 8 shows the photos of the fabricated antenna, including the front view, back view, and the final product with a 50 $\Omega$ SMA connector. The antenna structure is built on a 60 mil (1.524 mm) thick RT/Duroid 6002 substrate ($\varepsilon_r = 2.94 \pm 0.04$). The antenna parameters are the same as the second printed antenna design.
Figure 7. Printed dipole antenna design 2: both arms of the dipole are located on the top layer of the substrate. (a) Geometry of the dipole antenna and (b) FDTD calculated return loss. The semi-EBG ground plane improves the return loss of the antenna.
Figure 8. Photos of a fabricated dipole antenna near a semi-EBG ground plane. (a) Front view, (b) back view, and (c) antenna with a SMA connector.

Figure 9. Measured return losses of the printed dipole antennas. When the semi-EBG ground plane is used, the dipole antenna resonates at 7.84 GHz with a 9.4% bandwidth.
Figure 9 presents the measured return loss results of the printed dipole antenna with semi-EBG ground plane and another reference dipole antenna with PEC ground plane. As predicted in Fig. 7(b), when the semi-EBG ground plane is used, the return loss improves significantly. The antenna resonates at 7.84 GHz with a good return loss of −20 dB. A 9.4% impedance bandwidth is achieved in this design. The measured results agree with the FDTD simulations. A slight
frequency shift is observed, which is due to the fabrication discrepancy. The antenna patterns are measured at 8 GHz and the $xz$, $yz$, and $xy$ plane patterns are sketched in Fig. 10. It is observed that complex interaction occurs between the dipole and the EBG ground plane. The total radiation pattern is contributed by the direct radiation from the dipole and diffraction from the EBG ground plane. It can be inferred from Fig. 10 that the total radiation power is nearly omni-directional.

4. CONCLUSIONS

This paper proposes a printed dipole antenna design with a semi-EBG ground plane. The radiation efficiency of the dipole antenna is significantly improved when a PEC ground plane is replaced by the EBG ground plane. An antenna prototype is designed, fabricated, and tested, which resonates at 7.84 GHz with a 9.4% bandwidth and an omni-directional pattern. This design is useful for wireless communication systems such as internal WLAN antennas of laptop computers.

REFERENCES


