Switched-Beam Slot Antenna over Electromagnetic Band-Gap Reflector

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Abstract

This paper presents the switched-beam slot antenna over the electromagnetic band-gap (EBG) reflector. This antenna is composed of two slot elements fed with phase difference and the EBG reflector, which is applied in order to realize the low profile structure. The radiation characteristics of this antenna are calculated using the FDTD method. The calculated results show that the antenna height over the EBG reflector can be reduced by 60 % compared with that over the perfect electric conductor (PEC) reflector. The equivalent radiation characteristics are obtained in both of the above two conditions at the center of the operating frequency band. It is shown that the elevation angle of the main beam varies corresponding to the operating frequency, and the variation in the case of the EBG reflector is caused by its frequency-dependent reflection phase. Moreover, the radiation pattern of the fabricated antenna is measured, and the results demonstrate that the low profile design can be achieved by using the EBG reflector.

1. INTRODUCTION

In high-speed wireless communication systems such as the wireless local area network (WLAN), the effect of the multi-path fading and the shadowing must be reduced in order to achieve the high data transmission speed. The sector antenna is one of the techniques to overcome this problem. Various sector antennas for the mobile terminal have recently been proposed [1]-[3], and we also have proposed the four-sector antenna using the switched-beam slot antenna [4]. The feature of this sector antenna is that the planar size is small because of the simple structure comprising the four slot elements arranged in the square configuration over the perfect electric conductor (PEC) reflector. However, in order to obtain the sector-beam tilted to the horizontal direction, the antenna height (the distance between the PEC reflector and the slot element) for this sector antenna requires more than one-quarter wavelength. For instance, the antenna height to obtain the tilted angle of 40 degrees is more than 0.4 λ_0, where λ_0 is the wavelength in free space. Thus, the antenna height must be reduced in order to mount this sector antenna on the mobile terminal.

One way to overcome this problem is the use of the electromagnetic band-gap (EBG) reflector with the mushroom-like structure [5]. The EBG reflector has been used as the ground plane of the wire antenna to achieve the low profile design [6], [7]. However, for the slot antenna with the tilted beam, such as the switched-beam slot antenna, it is not clear whether the utilization of the EBG reflector yields the low profile antenna. Even if the low profile slot antenna is achieved, there is a possibility that the radiation characteristics deteriorate by the coupling between the ground plane with the slot element and the EBG reflector.

In this paper, the radiation characteristics of the switched-beam slot antennas over the PEC and EBG reflectors are calculated using the FDTD method and discussed. The EBG reflector has the mushroom-like structure, and its reflection phase is 0 degree at the test frequency of 5 GHz. It is revealed that the use of the EBG reflector reduces the antenna height. Additionally, the radiation characteristics of the fabricated switched-beam slot antenna over the EBG reflector are measured at 5 GHz band. From the measured results, it is shown that the low profile design is realized.

2. ANTENNA DESIGN AND CALCULATED RESULTS

Fig. 1(a) and 1(b) show the switched-beam slot antennas over the PEC and EBG reflectors, respectively. The switched-beam slot antenna is composed of two slot elements formed on the ground plane of the side length L_g. Two slot elements, each of which has a length of L_s and a width of W_s, are fed with the phase difference $\delta\,(= \phi_1 - \phi_2)$, where ϕ_1 and ϕ_2 are the phases of the slot element #1 and #2, respectively. The gap ports are located at the center of the slot elements. The main beam of this antenna is tilted to the horizontal direction due to the phase difference δ. In addition, its direction can be switched by inverting the phase difference δ. In this paper, δ is set to the constant value because the purpose of this study is to reveal the radiation characteristics of the antenna over each

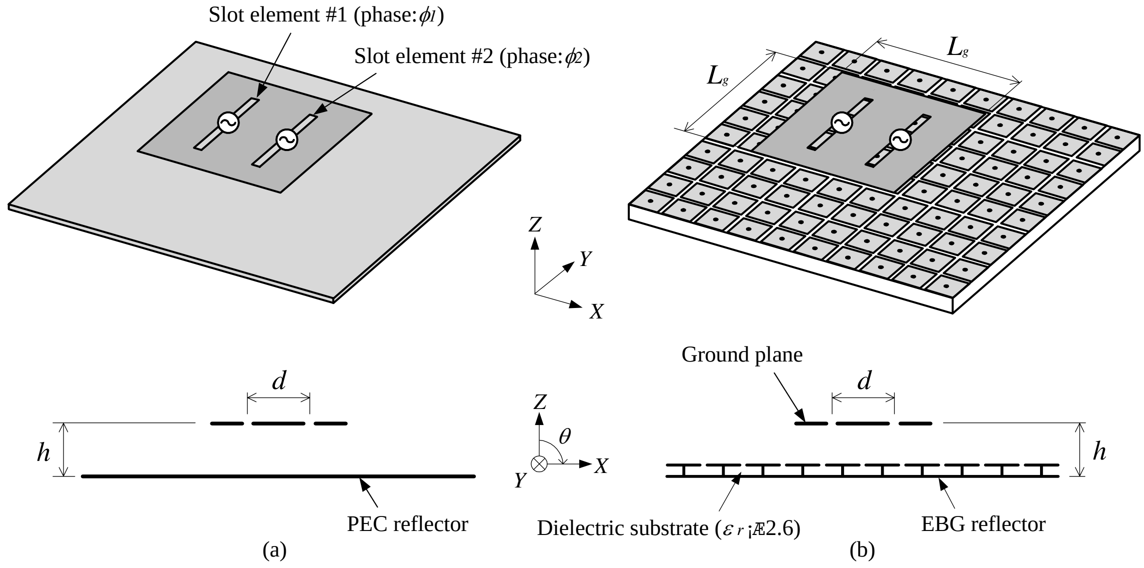

Fig. 1 Switched-beam slot antennas over the PEC and EBG reflectors.

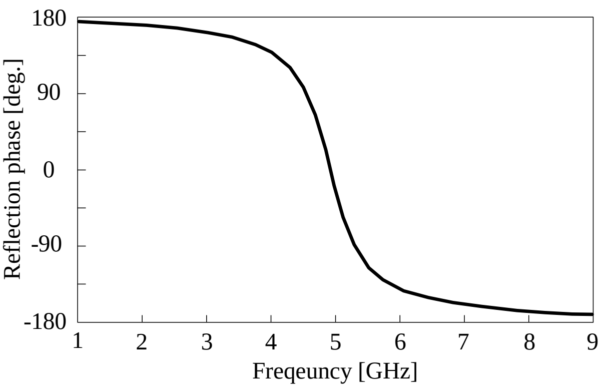

Fig. 2 Reflection phase as a function of frequency.

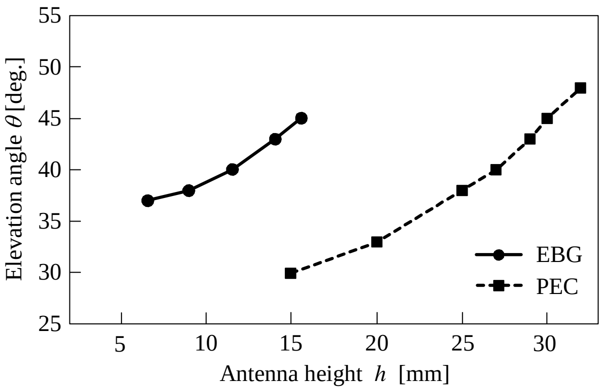

Fig. 3 Elevation angle of main beam as a function of antenna height.

reflector. The height of the slot elements over the PEC is set to h. In Fig. 1(b), the overall height of the slot elements from the bottom plane of the EBG reflector is set to h.

The EBG reflector is composed of numerous square patches, a dielectric substrate, the conducting ground plane and the vias. The patches are arranged in a reticular pattern on the $+Z$ side plane of the dielectric substrate. The conducting ground plane is formed on the $–Z$ side plane of the dielectric substrate. The vias connect between the centers of the patches and the conducting ground plane. The dimensions and the substrate properties at the test frequency of 5 GHz are set to W = 14 mm (0.23 λ), G = 1 mm (0.017 λ), t = 1.6 mm (0.027 λ), ε_r = 2.6, and r = 0.25 mm (0.0042 λ), where W is the patch width, G is the gap between the neighboring patches, t is the thickness of the dielectric substrate, ε_r is the relative permittivity of the dielectric substrate, r is radius of the vias, and λ is the free space wavelength at 5 GHz. The reflection phase of the designed EBG reflector when the reflector size is infinite is shown in Fig. 2. As seen from this figure, the designed EBG reflector has the reflection phase of approximately 0 degree at 5 GHz.

The radiation characteristics of the switched-beam slot antennas over the PEC and EBG reflectors shown in Fig. 1 are calculated using the FDTD method. Fig. 3 shows the elevation angle of the main beam as a function of antenna height h at 5 GHz. The switched-beam slot antenna has the following parameters: L_s = 25 mm (0.42 λ), W_s = 1 mm (0.017 λ), L_g =50 mm (0.83 λ), d = 20 mm (0.33 λ), and δ = 80 degrees. The PEC and EBG reflectors have the finite sizes of 149 mm × 149 mm (2.48 λ × 2.48 λ). The number of patches for the EBG reflector is 10 × 10 elements. In Fig. 3, it is found that the main beam of the switched-beam slot

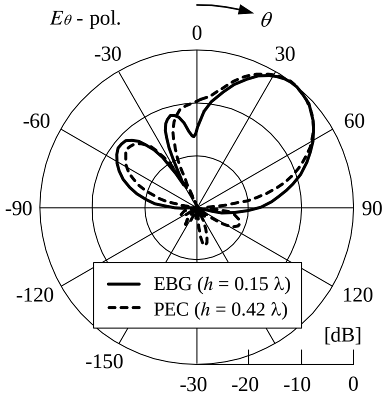

Fig. 4 Radiation patterns in the *XZ* plane for the switched-beam slot antennas over the EBG and PEC reflectors.

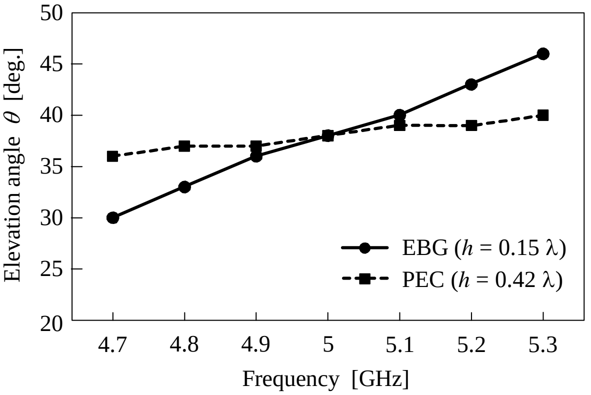

Fig. 5 Elevation angle of main beam as a function of frequency.

antenna over the EBG reflector is tilted at small antenna height. The antenna height over the EBG reflector to obtain the main beam with the elevation angle of 38 degrees is 9.1 mm (0.15 λ), which is about 60 % smaller than the antenna height over the PEC reflector (25 mm (0.42 λ)).

Fig. 4 shows the radiation patterns of the *XZ* plane for the switched-beam slot antennas over the EBG and PEC reflectors, where the antenna heights over the EBG and PEC reflectors are 9.1 mm (0.15 λ) and 25 mm (0.42 λ), respectively. The radiation pattern of the switched-beam slot antenna over the EBG reflector is almost in agreement with that of the switched-beam slot antenna over the PEC reflector. This result shows that the deterioration of the radiation characteristics is hardly seen even if the slot elements are located close to the EBG reflector. In other words, the coupling between the ground plane with the slot elements and the EBG reflector is small. In Fig, 4, the directivity of the switched-beam slot antenna over the EBG reflector is 11.2 dBi.

Next, the frequency response of the switched-beam slot antenna over the EBG reflector is discussed. Fig. 5 shows the elevation angle of the main beam as a function of frequency. It is found that the variation of the elevation angle of the main

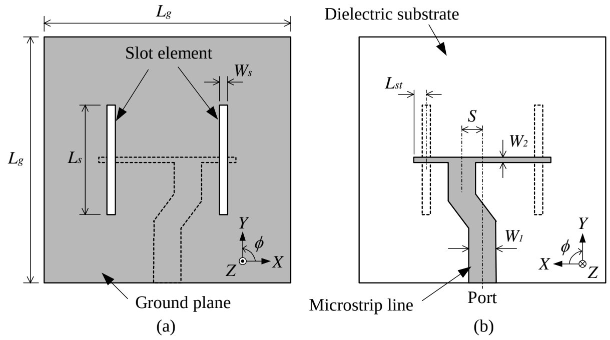

Fig. 6 Configuration of the fabricated switched-beam slot antenna.

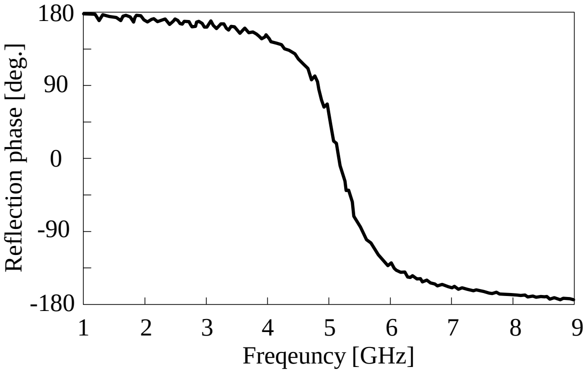

Fig. 7 Measured reflection phase as a function of frequency.

beam for the antenna over the EBG reflector is larger than that over the PEC reflector. This is because the reflection phase of the EBG reflector is frequency-dependent.

3. MEASURED RESULTS

The switched-beam slot antenna over the EBG reflector is fabricated and its characteristics are measured in order to verify the calculated results described in Section 2. In the measurement, the T-branch microstirp line (MSL) is used in order to feed two slot elements at the same time.

The configuration of the fabricated switched-beam slot antenna is shown in Fig. 6. Two slot elements are formed on the +*Z* side plane of the dielectric substrate with the relative permittivity ε_r and the thickness *t*. The T-branch MSL is printed on the –*Z* side plane of the dielectric substrate. Two slot elements are fed by electromagnetic coupling with the T-branch MSL. The branch position of the T-branch MSL is shifted from the center point of the MSL to feed two slot elements, and thus two slot elements are fed with the phase difference. The impedance matching between the slot elements and the T-branch MSL can be realized by adjusting the open stub length L_{st}. The EBG reflector is placed at distance of *h* from the slot element plane. In the measurement, the switched-beam slot antenna over the EBG reflector is designed at 5 GHz band.

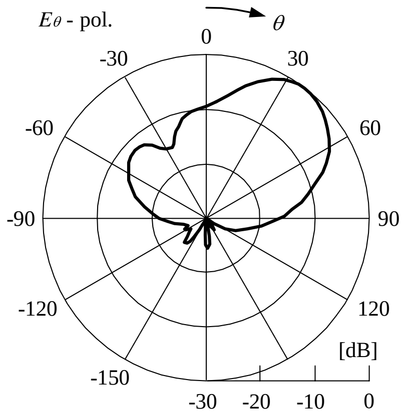

Fig. 8 Measured radiation pattern in the *XZ* plane for the switched-beam slot antenna over the EBG reflector.

Fig. 7 shows the reflection phase of the fabricated EBG reflector. The EBG reflector has the parameters as those used for the EBG reflector described in Section 2. The reflection phase is measured using two microwave horns and the network analyzer in an anechoic chamber [5]. From the measured result, it is found that the frequency at the reflection phase of 0 degree is about 5.2 GHz, which is about 4 % higher than that of the calculated result.

Next, the radiation patterns for the switched-beam slot antenna over the EBG reflector, which has the reflection phase as shown in Fig. 7, are measured. Fig. 8 shows the measured radiation patterns in the *XZ* plane at 5.2 GHz. The parameters of the fabricated switched-beam slot antenna are as follows: L_s = 19.5 mm (0.325 λ), W_s = 2 mm (0.033 λ), L_g = 42 mm (0.7 λ), d = 20 mm (0.33 λ), W_1 = 4 mm (0.067 λ), W_2 = 1 mm (0.017 λ), L_{st} = 2 mm (0.033 λ), S = 4 mm (0.067 λ), h = 9.1 mm (0.15 λ), ε_r = 2.6, and t = 1.6 mm (0.027 λ). It can be seen that the tilted beam characteristics are obtained at the low profile design like the calculated results described in Section 2. This result shows that the validity of the analysis design is confirmed, and that the realizability of the low profile design is achieved. The elevation angle of the main beam and the actual gain are 40 degrees and 8.2 dBi, respectively. The bandwidth of VSWR < 2 is about 9 %. The measured gain is lower than the calculated result shown in Section 2. It is thought that this is caused by the loss of the feed line, the dielectric substrate, the EBG reflector, and so on. The future study is to recognize the amount of each loss.

4. CONCULUSION

The switched-beam slot antenna over the PEC and EBG reflectors have been investigated. By the FDTD calculation, it is found that the utilization of the EBG reflector with the mushroom-like structure yields the antenna height reduction of more than 60 % compared with the switched-beam slot antenna over the PEC reflector. It is also revealed that the deterioration of the radiation pattern at the operating frequency band is not seen even if the low profile design is realized by using the EBG reflector. It is found that the elevation angle of the main beam in the vicinity of the operating frequency is drastically varied in the case of the EBG reflector. Moreover, the measured results show that the tilted beam with the actual gain of 8.2 dBi and the elevation angle of 40 degrees is obtained, and the low profile design is achieved using the EBG reflector.

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