Mutual Coupling Suppression Property by Three Dimensionally Arranged EBG Structures

#Yuki KAWAKAMI[1], Toshikazu HORI[1], Mitoshi FUJIMOTO[1],
Ryo YAMAGUCHI[2] and Keizo CHO[2]
[1] Graduate School of Engineering, University of Fukui
3-9-1, Bunkyo, Fukui, 910-8507 Japan, E-mail: y.kawakami@m.ieice.org
[2] NTT DOCOMO, INC.
3-5, Hikarinooka, Yokosuka, Kanagawa, 239-8536 Japan

1. Introduction

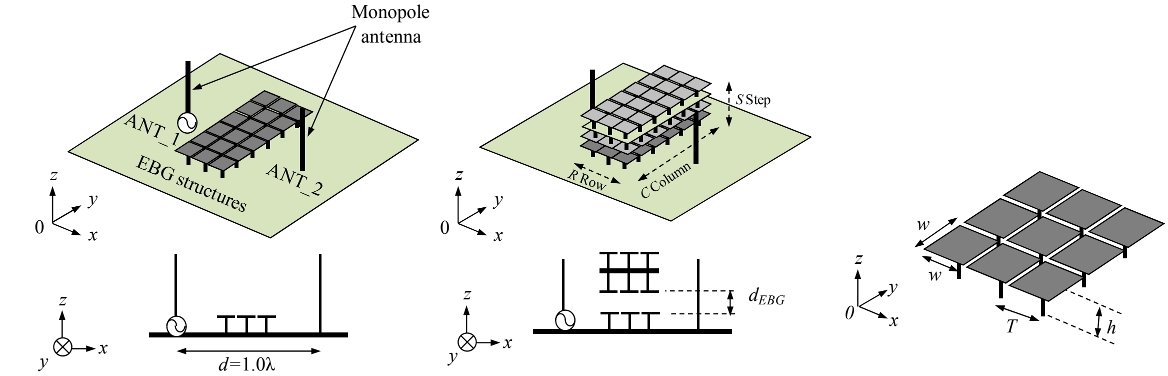
EBG (Electromagnetic Band-Gap) Structures composed of metal patches arranged at small intervals have the frequency-band-rejection characteristics. Thus, it can reduce the undesired electromagnetic waves [1]. From the unique characteristics, EBG structures have been studied to apply to antennas for the suppression of the mutual coupling and the improvement of the radiation property [2][3]. The mutual coupling suppression property by two-dimensionally arranged EBG structures was already clarified [4].

In this paper, a three-dimensionally arranged EBG structure is proposed. And, the effects of the arrangement method of the EBG elements on the suppression characteristics of the mutual coupling are studied. The paper first explains the suppression effects of a two-dimensionally arranged EBG structure on mutual coupling. Then, the effects in the case of the three-dimensionally arranged EBG will be explained. Finally, the optimum arrangement method of the EBG structure is presented.

2. Analysis Models

Figure 1 shows the analysis models of monopole antennas with mushroom type EBG structures. Figure 1(a), 1(b) and 1(c) show a two-dimensionally (2D) arranged model, a three-dimensionally (3D) arranged model and a size of EBG elements, respectively. As shown in Figure 1(a) and 1(b), the mushroom type EBG structures are located between the monopole antennas. In 2D arranged model, EBG elements are arranged in 2D. In case of 3D model, the elements are arranged in 3D. The number of EBG elements arranged in *x*, *y* and *z* axis are defined as the number of EBG rows *R*, columns *C* and steps *S*, respectively. 2D arranged model has one EBG step and 3D arranged model has more than two EBG steps.

In Fig. 1(a), the number of the EBG elements along the *x*, *y*, and *z* axis is 3, 6, and 1. This EBG structure is defined as 3×6×1 EBG. Similarly, the EBG structure in Fig. 1(b) is called 3×6×3 EBG. In case of 3D arranged model, the EBG elements in second or third step are shorted on the



(a) 2D arranged model (3×6×1) (b) 3D arranged model (3×6×3) (c) Size of EBG elements
Figure 1: Analysis models

same finite metal plate. Only the elements in second step are located inversely. The distance d_{EBG} is the distance of EBG elements between second and third step. As shown in Fig. 1(c), the parameters of T, w, and h are the period of arrangement, the width of a metal patch and the distance between the patch and the ground plane, respectively. The frequency f_0 is the resonant frequency of the monopole antennas. The utilised mushroom type EBG structure has the band gap characteristics from 0.6 f_0 to 1.2 f_0. The distance d between monopole antenna elements is equal to λ_0. Here, the wavelength λ_0 is that of the wave at frequency f_0.

The parameters of these models are the number of Row R, Column C, Steps S, and the distance d_{EBG}. In this paper, the number of the EBG columns C and the distance d_{EBG} are fixed on 6 and $0.05\lambda_0$. The mutual coupling suppression property by EBG structures is analyzed when the number of the EBG column C and the row R are varied. The moment method (EEM-MOM) is utilised in the analysis.

3. Mutual Coupling Suppression Property by 2D Arranged EBG

Figure 2 shows the frequency response of the normalized mutual coupling $C_{21}/C_{21\mathrm{ref}}$ between monopole antenna elements in case of 2D arranged model. Here, the couplings C_{21} and $C_{21\mathrm{ref}}$ are the coupling between antenna elements with EBG and without EBG. The parameter is the number of EBG row R.

We can see from Fig.2 that the normalized coupling $C_{21}/C_{21\mathrm{ref}}$ is smaller than 0dB in specific frequency band regardless of the number of EBG row R. In other words, the mutual coupling between antenna elements is suppressed by 2D arranged EBG. The coupling is suppressed at the frequencies where the EBG structure has the band-gap characteristics. In case of the number of EBG row R=4, 31dB coupling suppression is achieved. The suppression frequency band become wider as the number of EBG row R is increased. For example, the frequency band where the normalized coupling $C_{21}/C_{21\mathrm{ref}}$ is less than -20dB for R=4 is wider than that for R=2.

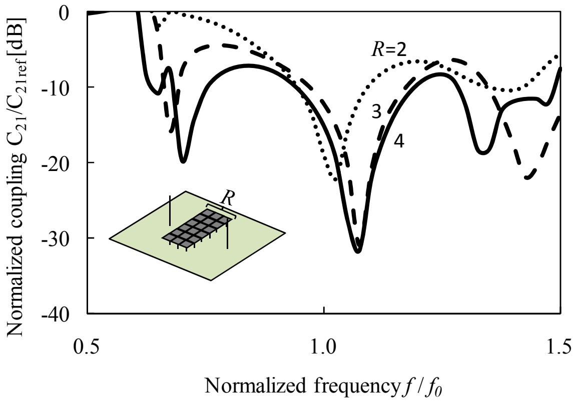
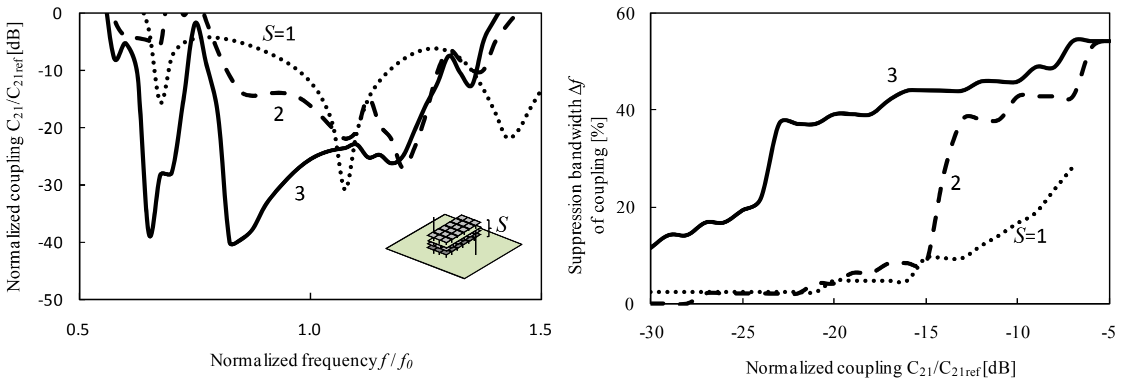


Figure 2: Normalized coupling $C_{21}/C_{21\mathrm{ref}}$ for 2D arranged model

4. Mutual Coupling Suppression Property by 3D Arranged EBG

4.1 Comparison with 2D Arranged EBG

Figure 3 shows the mutual coupling suppression property in case of 3D arranged EBG. Figure 3(a) shows the frequency response of the normalized mutual coupling $C_{21}/C_{21\mathrm{ref}}$, and



(a) Normalized coupling

(b) Relation between normalized coupling and coupling suppression bandwidth

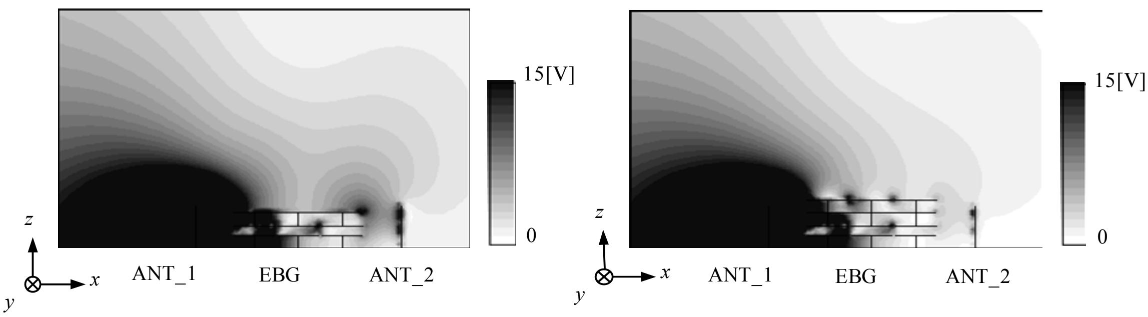
Figure 3: Suppression property of coupling by 3D arranged EBG

Fig.3 (b) shows the relation between the normalized mutual coupling C_{21}/C_{21ref} and the coupling suppression bandwidth Δf. Here, the coupling suppression bandwidth Δf is defined as the frequency band where the normalized mutual coupling C_{21}/C_{21ref} become smaller than the specific value. The solid line and dashed line indicate the calculated results for the EBG steps S = 3 and 2, respectively. For reference, the results for S = 1, which is the case of 2D arranged model, is shown in dotted line.

It is found from Fig. 3(a) that the mutual coupling between the antennas is reduced by the EBG structures regardless the number of the EBG steps S. In case of S = 3, we can obtain the coupling suppression effects of 40dB the coupling. As shown in Fig. 3(b), more wideband suppression effect can be achieved as the number of the EBG steps is increased. When the number of the EBG steps S = 3 and the normalized coupling C_{21}/C_{21ref} = -20 dB, the suppression bandwidth Δf = 39%, that is, the suppression effects of 20 dB or more can be obtained in the frequency band of 39%. In summary, 3D arranged EBG can suppress the mutual coupling more than 2D arranged EBG.

4.2 Near-electric Field around 3D Arranged EBG

To consider the effects of the number of EBG steps S on the coupling suppression property, the near-electric field around the monopole antennas with 3D arranged EBG at f_0 is indicated in Fig. 4. Figure 4(a) and 4(b) are the cases of the number of the EBG steps S = 2 and 3, respectively. In case of S = 2, it is found that the electric field strength at the edge of the finite metal plate, which the EBG elements in second step are shorted in, is high. The results mean that the wave radiated from antenna ANT_1 is propagated along the finite metal plane, then the wave is reradiated at the edge of the metal plane. The electric field strength around the antenna ANT_2 also becomes high due to the reradiation. On the other hand, in case of S = 3, the electric field strength around the antenna ANT_2 is not so high. It is due to the suppression of the wave which propagates on the finite metal plane by EBG elements in third step.



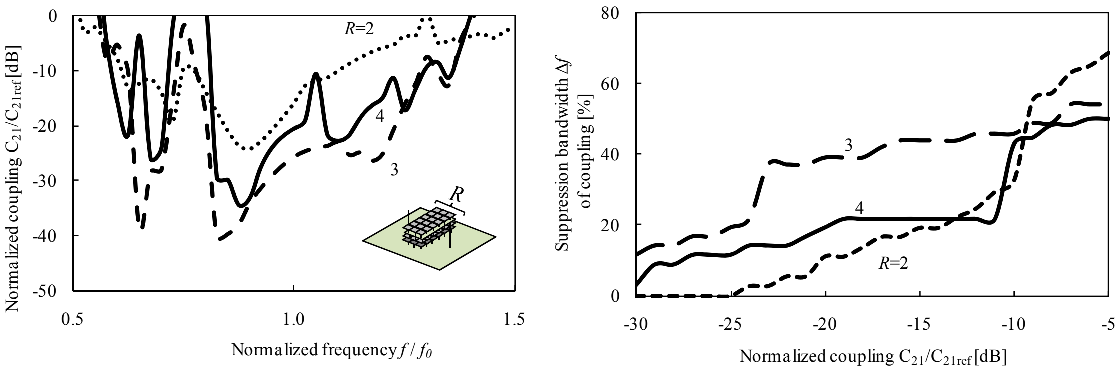
(a) EBG step S = 2 (b) EBG step S = 3

Figure 4: Near-electric field around the monopole antennas with 3D arranged EBG

4.3 Optimum Configuration of 3D Arranged EBG

In this section, we discuss the optimum configuration of 3D arranged EBG for the coupling suppression. Figure 5 shows the mutual coupling suppression property in case of 3D arranged model when the number of EBG steps S = 3. Figure 5(a) shows the frequency response of the normalized mutual coupling C_{21}/C_{21ref}, and Fig. 5(b) shows the relation between the normalized mutual coupling C_{21}/C_{21ref} and the coupling suppression bandwidth Δf. The solid, dashed and dotted line indicate the calculated results for the number of EBG Rows R = 4, 3 and 2, respectively.

From Fig. 5(a), it is clarified that the mutual coupling is suppressed by EBG structures regardless the number of EBG rows R. The highest suppression effects can be achieved at 0.8 f_0 in case of R = 3. As shown in Fig. 5(b), we can also obtain the wideband suppression effects when the number of EBG rows R = 3. In case of R = 4, the distance between the antenna and the EBG element equals 0.08 λ_0, that is, these are located very near. Thus, the coupling suppression bandwidth for R = 4 is narrower than that for R = 3. It means that there is the optimum number of the EBG rows R_{opt}.



(a) Normalized coupling

(b) Relation between normalized coupling and coupling suppression bandwidth

Figure 5: Suppression property of coupling by 3D arranged EBG (S = 3)

4.4 Relation between Antenna Distance *d* and Optimum Number of EBG Row R_{opt}

In this section, we consider the effects of the distance d between antennas on the optimum number of EBG rows R_{opt}. Figure 6 shows the coupling suppression bandwidth Δf when the distance $d = 1.0\lambda_0$ and $1.5\lambda_0$. The solid and dashed line indicate the calculated results for the distance $d = 1.5\lambda_0$ and $1.0\lambda_0$, respectively. It is found in Fig. 6 that there is the optimum number of the EBG rows R_{opt} regardless the distance d. The optimum number R_{opt} is 3 when the distance $d = 1.0\lambda_0$. In case of $d = 1.5\lambda_0$, the number R_{opt} is 5. In both cases, the suppression effects of 20 dB or more can be achieved in the frequency band of 39%.

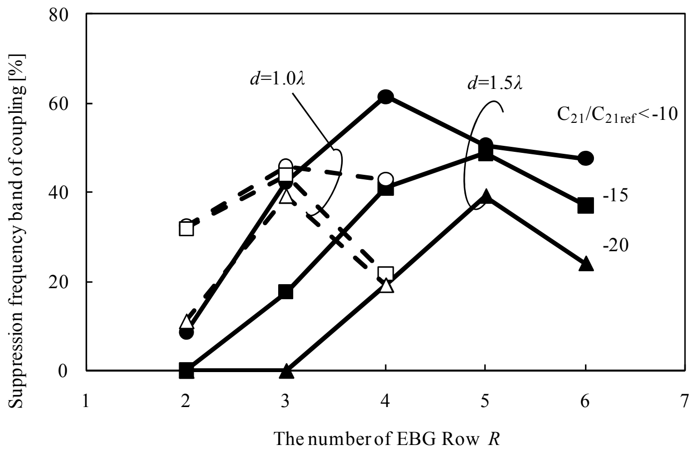


Figure 6: Effects of distance d between antennas on optimum number of EBG rows R_{opt}

5. Conclusion

3D arranged EBG structures were proposed, and the coupling suppression property by the EBG structures was discussed. Based on the calculated results, it was clarified that 3D arranged EBG could suppress the mutual coupling more than 2D arranged EBG. In addition, it was found that the optimum number of the EBG rows R_{opt} depended on the distance d between the antennas. In case of $d = \lambda_0$, the suppression effects of 20 dB or more could be achieved in the frequency band of 39% by using 3×6×3 EBG.

References

[1] F. Yang and Y. Rahmat-Samii, *Electromagnetic band gap structures in antenna engineering*. Cambridge University Press, 2009.

[2] F.Yang and Y.Rahmat-Samii, ”Microstrip Antennas Integrated with Electromagnetic Band-Gap (EBG) Structures”, IEEE Trans. AP, vol.51, no.10, pp.2936-2946, Oct.2003.

[3] Y.Kawakami, T.Hori, M.Fujimoto, R.Yamaguchi and K.Cho, “Polarization properties of Mushroom-Type EBG Structures”, 2008 IEICE Society Conf., B-1-58, 2008.

[4] Y.Kawakami, T.Hori, M.Fujimoto, R.Yamaguchi and K.Cho, “Suppression effects of antenna coupling by mushroom-type EBG structures”, 2007 IEICE Society Conf., B-1-68, 2007.