Bandwidth Characteristics of Loop-slot AMC with Dielectric Layer

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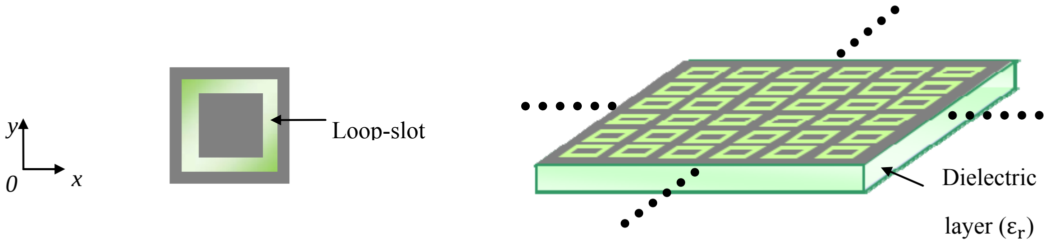
1. Introduction

A FSS (Frequency Selective Surface) which comprises periodic arrays of patches or apertures in a conducting screen and finds important applications as filters in microwaves and optics, is discussed [1]. And it has frequency-band-rejection characteristics or frequency-band-pass characteristics. On the other hand, Artificial Magnetic Conductor (AMC) is a kind of artificial materials, and AMC has PMC (Perfect magnetic conductor) characteristics in a specific frequency. On the PMC surface, incident waves are reflected without phase shift [2][3]. Furthermore, in order to reduce the size of devices on integrated circuits, it has become necessary to use conductive materials having low resistivity and insulators having low dielectric constant to reduce the capacitive coupling between adjacent metal lines.

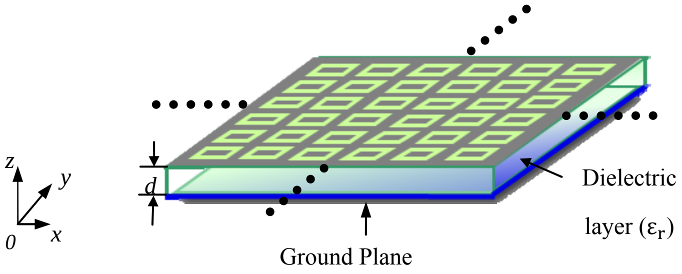
In this paper, a design method for AMC with dielectric layer by using a loop-slot FSS is described. Based on the method, the bandwidth characteristics of a designed AMC with dielectric layer are clarified.

2. Analysis Model of FSS and AMC



(a)Top View FSS Cell

(b) Bird's-eye View of FSS



(c) Bird's-eye View of AMC

Fig.1 Analysis Model of FSS

Figure 1 shows the analysis models of FSS and AMC used in this paper. Figure 1 (a) shows a square loop-slot FSS cell. Figure 1 (b) and (c) are bird's-eye views of FSS and AMC, which are arranged infinitely. The AMC is composed of FSS and ground plane. In this research, the dielectric layer is inserted between FSS and the ground plane. The dielectric constant is ε_r and the thickness of dielectric layer for AMC is *d*.

In order to analyze the infinite structures, the periodic boundary condition (PBC) is utilized in FDTD analysis (EEM-FDM).

3. Design Method of AMC with Dielectric Layer

The design method of AMC with dielectric layer at the frequency f_0 is discussed. When the AMC is used in a free space, a reflection coefficient S_{11} from the upper side of FSS is the same with S_{22} which is that of the underside of the FSS. This is because that the ε_r is the same in both side of the FSS. In this paper, however, S_{11} and S_{22} should be considered individually due to dielectric layer. It is also in case of S_{12} and S_{21}. Figure 2 shows the route of reflected waves conceptually. Here, the incident wave is assumed as $E_{in} = 1$. E_{total} is defined as the total electric field of all the reflected waves, and it is a function of number of reflected waves.

First of all, the incident wave from z-direction arrives at FSS above dielectric layer. The wave causes the reflected wave with $|S_{11}|$ times of the amplitude and phase of ϕ_{11}. It is considered as n=0 (Eq.1). Then, the remaining part pass through the FSS with $|S_{21}|$ times of the amplitude and phase of ϕ_{21}, and it travels to the ground plane with phase rotation of ϕ_{ε}. After that, it is reflected at the ground plane with phase rotation of ϕ_{ref}, and returns to the FSS with phase rotation of ϕ_{ε}, and pass through FSS with $|S_{12}|$ times of amplitude and phase of ϕ_{12}. This route is defined as n=1 (Eq.2). Furthermore, when n=2 (Eq.3) as shown in Fig.2, the wave arrives at FSS is reflected on the up-side of the dielectric layer with $|S_{22}|$ times of amplitude and phase of ϕ_{22}. Then, the wave continues to travel with reflection and rotation as former, until N times of the rotations.

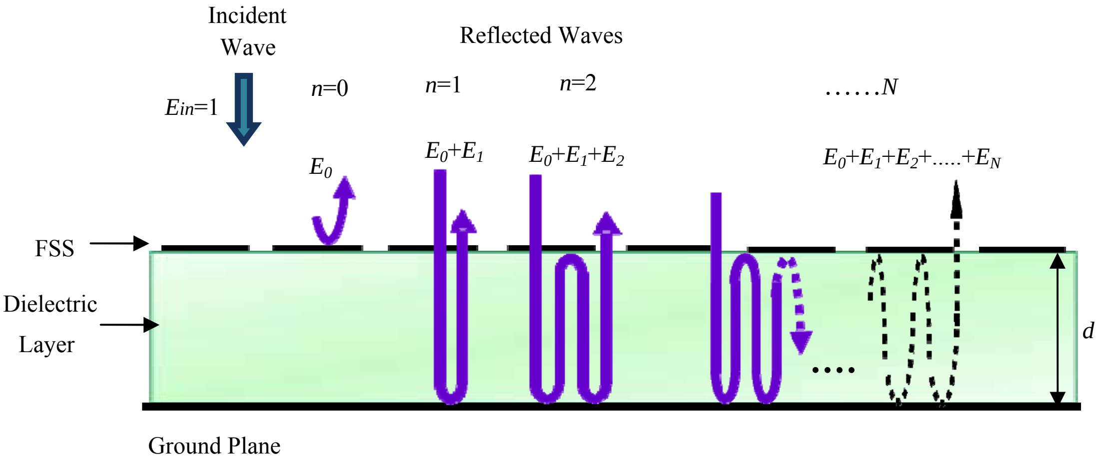


Fig.2 Route of Reflected Waves

During this period, n=0, 1, 2,…*N*, and the electric field of reflection waves can be described as

$$E_0=|S_{11}|e^{j\emptyset_{11}}, \tag{1}$$

$$E_1=|S_{21}||S_{12}|e^{j(\emptyset_{21}+\emptyset_{12}+2\emptyset_{\varepsilon}+\emptyset_{ref})}, \tag{2}$$

$$E_2=|S_{21}||S_{12}||S_{22}|e^{j(\emptyset_{21}+\emptyset_{12}+\emptyset_{22}+4\emptyset_{\varepsilon}+2\emptyset_{ref})}. \tag{3}$$

According to above, it can be figured out that this set of equations of E_n is a geometrical progression which has the first term is E_1,

$$\text{common ratio} =|S_{22}|e^{j(\emptyset_{22}+2\emptyset_{\varepsilon}+\emptyset_{ref})} \tag{4}$$

when n≥1. Therefore, the total electric field E_{total} of all the reflected waves from n=1 to *N* can be described as

$$\begin{aligned} E_{total} &= E_0 + \sum_{n=1}^{N} E_n \\ &= E_0 + \frac{E_1(1-r^N)}{1-r}. \end{aligned} \tag{5}$$

When the incident wave is reflected on FSS without phase rotation, and real part is positive value, the electric field E_{total} satisfies Eq.(6).

$$\mathrm{Im}(\mathrm{E_{total}}) = 0,\ \mathrm{Re}(\mathrm{E_{total}}) > 0. \qquad (6)$$

Namely, the AMC composed with FSS and ground plane has the PMC characteristics when Eq. (6) is satisfied.

In this paper, the AMC with dielectric layer is designed by calculating the thickness *d*, so that the electric field E_{total} satisfies Eq.6.

4. Design of AMC with Dielectric Layer

4.1 Transition of Electric Field E_{total}

Recently, the design method for an AMC by using a FSS in a free space is studied [4][5]. In these researches, the dielctric layer whoes dielectric constant is 1.8 is inserted between the FSS and the ground plane. Figure 3 shows the transition of the electric field E_{total} at f=0.867f_{BP} when the number of the reflected wave N is varied. Here, f_{BP} is the band-pass frequency of the FSS. As an example for the designed thickness of dielectric layer, these curves are drawn by changing the thickness *d*, and N is changed from 0 to 10. The transition of the electric field E_{total} is the sum from E_0 to E_{10}. And it can be noticed that the electric field E_{total} is converged in certain point. It is also shown that the converged electric field depends on the thickness *d* between the FSS and the ground plane.

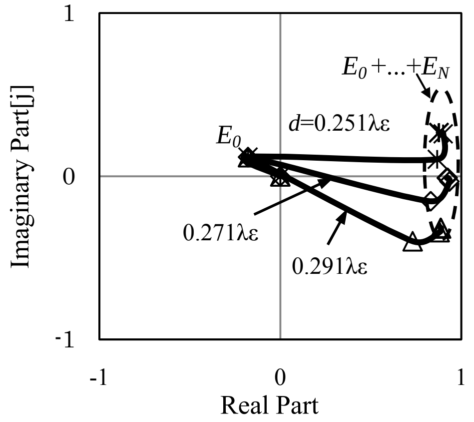


Fig.3 Transition of E_{total} (f=0.271f_{BP})

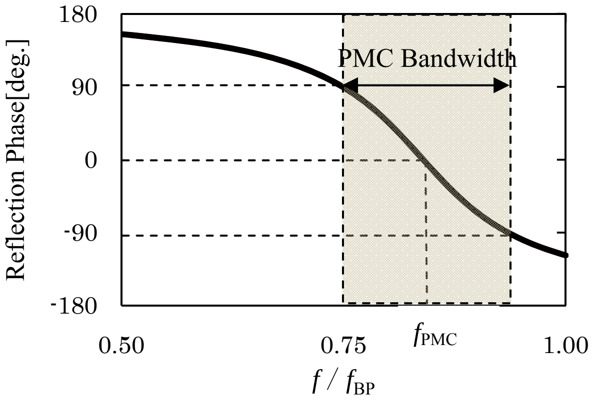


Fig.4 Reflection Phase Characteristics of Designed AMC (d=0.271λ_ε)

Furthermore, according to Eq.(6), it is obvious that when the thickness d=0.271λ_ε, the imaginary part of the electric field E_{total} equals to zero, while the real part of that is larger than zero. In other words, in the case of f= 0.867f_{BP}, the AMC with dielectric layer can be realized by setting the thickness d=0.271λ_ε. Here, λ_ε is the wavelength in the dielectric material.

On the other hand, when the thickness *d* is fixed and frequency is varied, the reflection phase is changed as shown in Fig.4. In this paper, the f_{PMC} and the PMC bandwidth is defined as a frequency without phase rotation and the frequency band within the ±90 degrees of reflection phase, respectively.

4.2 Bandwidth Characteristics of Designed AMC

Figure 5(a), (b) and (c) shows the relation between the thickness, PMC frequency and PMC bandwidth of the designed AMC with dielectric layer when dielectric constant is 1.8. And the result is compared with the case of designed AMC in a free space, simultaneously.

From Fig.5(a), it can be described that when the designed thickness of AMC becomes lower, the PMC frequency becomes higher in all cases. It is also shown that the thickness of AMC can be decreased by using the dielectric layer. Furthermore, Fig. 5(b) shows the bandwidth of designed AMC with dielectric layer which is wider than that of AMC in a free space when the frequency is lower than 0.94f_{BP}. And it is found in Fig.5(c) that the thickness of the AMC becomes lower as the frequency of the AMC becomes higher. At the frequency 0.895f_{BP}, the height of the AMC is 0.25λ_ε. It is also shown that the PMC bandwidth of AMC is changed as the PMC frequency is changed. In addition, it is found that a peak of the PMC bandwidth can be obtained of 34.1% at f=0.865f_{BP} and d=0.27λ_ε.

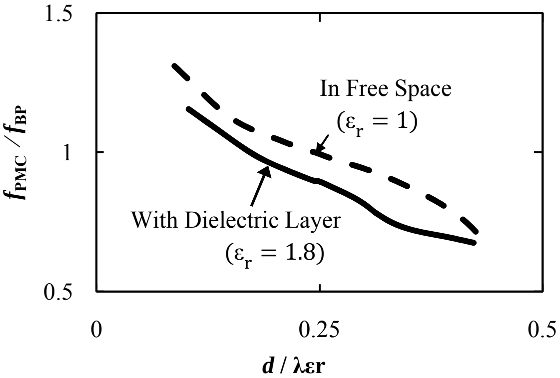


Fig.5 (a) Thickness and PMC Frequency of Designed AMC

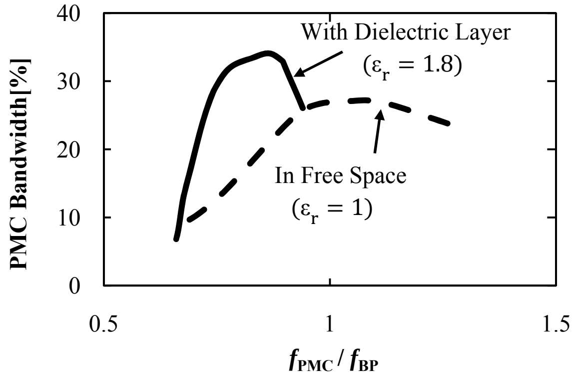


Fig.5 (b) Designed Thickness and Bandwidth of AMC

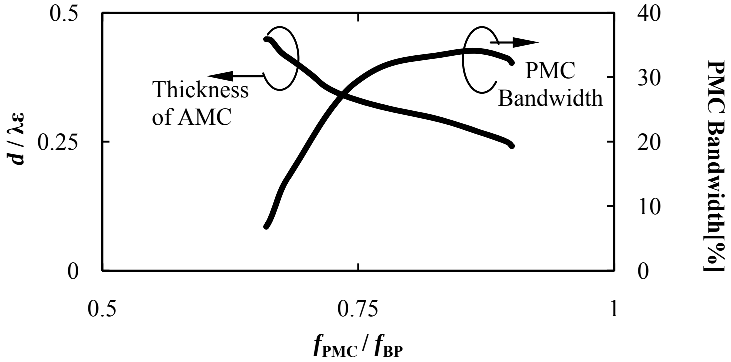


Fig.5 (c) Thickness and PMC Bandwidth of Designed AMC with Dielectric Layer

5. Conclusions

A design method for AMC with dielectric layer by using a loop-slot FSS was described. Based on the method, the bandwidth characteristics of a designed AMC with dielectric layer were clarified.

It was found that the thickness of designed AMC could be decreased by using the dielectric layer. Furthermore, the bandwidth of designed AMC with dielectric layer was wider than that of AMC in a free space when the frequency was lower than 0.94f_{BP}. And there was a peak of the PMC bandwidth. Maximum bandwidth of 34.1% was obtained at f=0.865f_{BP} and d=0.27λ_ε.

References

[1] E. R. Mittra, H. Chan Chi, Tom Cwik, “Techniques for Analyzing Frequency Selective Surfaces,” Proc. IEEE, vol 76, no.12, pp.1593-1615, Dec.1988.

[2] E. A. Parker, S. M. A. Hamdy “Rings as Elements for Frequency Selective Surface,” Electron. Lett., vol.17, no.17, pp. 612-614, Aug. 1981.

[3] A. P. Feresidis, G. Goussetis, S. Wang, and J. C. Vardaxoglou “Artificial Magnetic Conductor Surfaces and Their Application to Low-Profile High-Gain Planer Antennas,” IEEE Trans. AP, vol.53, no.1, pp. 209-215, Jan. 2005.

[4] Y. Kawakami, T. Hori, M. Fujimoto, R. Yamaguchi, K. Cho “Design of AMC by Using Rectangular Loop Slot type FSS, ” 2009 IEICE General Conf., B-1-163, Mar. 2009. (in Japanese)

[5] Y. Kawakami, T. Hori, M. Fujimoto, R. Yamaguchi, K. Cho “Design of Artificial Magnetic Conductor by Using Frequency Selective Surface, ” IEICE Tech. Rep., Macau, A.P 2008-218, Mar. 2009.