Wideband Design of AMC by Considering Filtering characteristics of FSS

#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: kawakami@wireless.fuis.fukui-u.ac.jp
[2] NTT DOCOMO, INC.
3-5, Hikarinooka, Yokosuka, Kanagawa, 239-8536 Japan

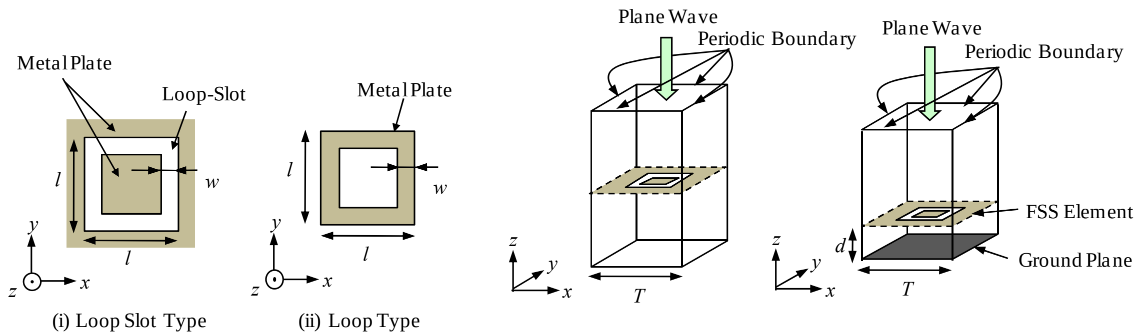
1. Introduction

A FSS (Frequency Selective Surface) is composed of metal patches arranged at narrow intervals, and has the frequency-band-rejection or frequency-band-pass characteristics [1]. On the other hand, an AMC (Artificial Magnetic Conductor) is one of artificial materials, and has the PMC (Perfect Magnetic Conductor) characteristics in the specific frequency band. On the PMC surface, the electromagnetic wave is reflected without phase rotation [2][3]. The authors have reported that the design method for the FSS can be applied to design the AMC [4][5].

In this paper, a design method for an AMC by using a FSS which has band-pass or band-rejection characteristics is presented. And, the effects of the filtering characteristics of a FSS on the PMC characteristics of an AMC are studied.

2. Analysis Models

Figure 1 shows the analysis models of a FSS and an AMC. Figure 1(a), 1(b) and 1(c) show a FSS element, a FSS and an AMC, respectively. As shown in Figure 1(a), a loop-slot and a loop type FSS are used. A Loop-slot type FSS has the band-pass characteristics, and a loop type FSS has the band-rejection characteristics. In this paper, the difference in the PMC characteristics of the AMC which is designed by using a loop-slot type FSS or a loop type is discussed. The FSS is composed of FSS elements arranged along the x-axis and the y-axis infinitely. The AMC is composed of the FSS and the ground plane. The parameters of T, w, d and l are the period of arrangement, the width of a loop-slot/loop, the distance between the FSS and the ground plane and the length of the circumference of a loop-slot/loop, respectively. In order to analyze the infinite structures, the periodic boundary condition (PBC) is utilized in the FDTD analysis (EEM-FDM).



(a) FSS element (b) FSS (c) AMC

Figure 1: Analysis Models

3. Design Method of AMC

The frequencies f_{BP} and f_{BR} are defined as the frequencies where the FSS has the band-pass and band-rejection characteristics, respectively. We discuss the design method of the AMC at a frequency *f*. S_{11} and S_{21} are the reflection coefficient and the insertion loss of the FSS at the frequency *f*, respectively. When the plane wave arrives at the FSS with the ground plane from the vertical direction (*z*-axis), the amplitude of a wave reflected by the FSS layer is the $|S_{11}|$ times of that of the incident wave. The wave whose amplitude is the $|S_{21}|$ times of that of the incident wave passes through the FSS layer. As a result, as shown in Fig.2, there are the various reflected waves whose amplitude, phase and route are different. *n* is the number of times that the wave is reflected at the surface of the ground plane. In particular, all waves pass through the FSS layer at the frequency f_{BP}, that is, only the reflected wave of $n = 1$ is considered as the reflected wave. In opposite, only the wave of $n = 0$ is considered at the frequency f_{BR} because all waves reflected at the surface of the FSS. In case of $n = 0$, 1 and 2, the electric field of reflected waves are represented as

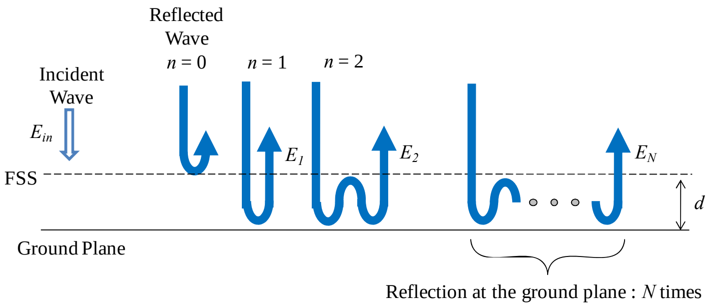


Figure 2: Route of Reflected Waves

$$E_0 = |S_{11}| e^{j\phi_{11}}, \quad (1)$$
$$E_1 = |S_{21}|^2 e^{j(2\phi_{21}+2\phi_\epsilon+\phi_{ref})}, \quad (2)$$
$$E_2 = |S_{21}|^2 |S_{11}| e^{j(\phi_{11}+2\phi_{21}+4\phi_\varepsilon+2\phi_{ref})}. \quad (3)$$

Here, ϕ_{11}, ϕ_{21}, ϕ_ϵ and ϕ_{ref} are the reflection phase of the FSS, the transmission phase of the FSS, the phase rotation between the FSS and the ground plane and the reflection phase of the ground plane, respectively. The equations of the electric field of the reflected waves are a geometrical progression whose first term equal to E_1 and common ratio $r = |S_{11}| e^{j(\phi_{11}+2\phi_\varepsilon+\phi_{ref})}$ when n is larger than 1. Therefore, the electric field E_{total} of the wave which composed of all the reflected waves from $n = 0$ to N can be expressed as

$$E_{total} = E_0 + \sum_{n=1}^{N} E_n = E_0 + \frac{E_1(1 - r^N)}{1 - r} \qquad (n \geq 1). \quad (4)$$

When the electric field E_{total} satisfies Eqn. (5), we can consider that the incident wave is reflected at the FSS surface without phase rotation, namely the FSS with the ground plane has the PMC characteristics.

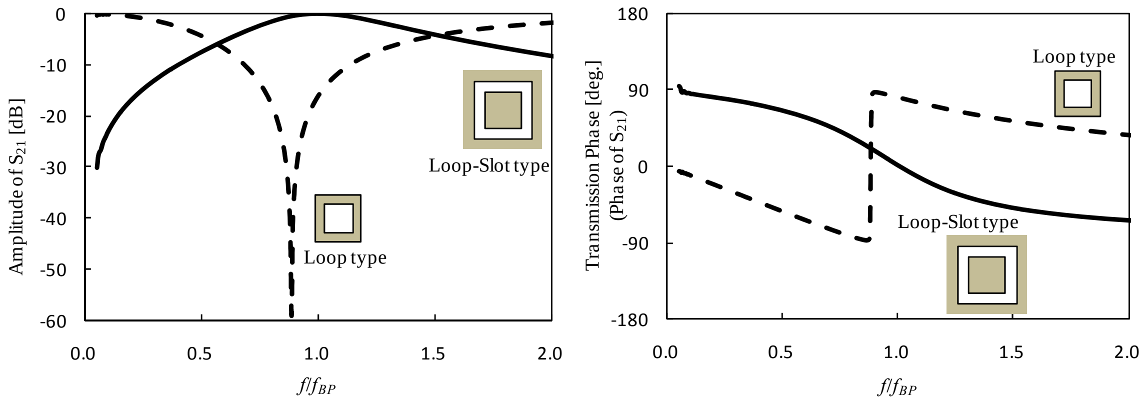
$$Im(E_{total}) = 0, and\ Re(E_{total}) > 0. \quad (5)$$

In this paper, we design the AMC by setting the distance *d* so as to that the electric field E_{total} satisfies the Eqn. (5).

4. Design of AMC by Using FSS

4.1 Filtering Characteristics of FSS

Figure 3 shows the filtering characteristics of the loop-slot and loop type FSS. Figure 3(a) shows the amplitude of S_{21}, and Fig.3 (b) shows transmission phase of the FSS. The solid line and



(a) Amplitude of S_{21} (b) Transmission Phase
Figure 3: Filtering Characteristics of Loop-slot/Loop Type FSS

the dashed line show the characteristics of the loop-slot and loop type FSS, respectively. It is found from Fig.3 (a) that the amplitude of S_{21} is 0 dB at the frequency f_{BP}. In other words, the loop-slot type FSS operates as a band-pass filter at the frequency. In case of the loop type, the amplitude of S_{21} is significantly small at the frequency 0.9 f_{BP}, that is, the loop type FSS operates as a band-rejection filter at the frequency. The loop-slot and loop type FSS have complementary structure in each other. Therefore they have the inverse filtering characteristics. It is shown in Fig.3 (b) that the transmission phase of the FSS is changed as the frequency is changed. In addition, these are different by a kind of the FSS.

4.2 Transition of synthesized electric field E_{total}

In this section, we discuss the reflected waves at the frequencies except the frequencies f_{BP} and f_{BR}. The Figure 4 shows the transition of the synthesized electric field E_{total} at the frequency $0.5f_{BP}$. The solid lines and the dashed lines show the cases of the loop-slot and loop type FSS, respectively. We consider the reflected waves from n = 0 to 50, that is, the transition of the electric field E_{total} composed from E_0 to E_{50} is drawn in Fig. 4. The parameter is the distance d between the FSS layer and the ground plane. It is found in Fig. 4 that the electric field E_0 in case of the loop-slot differs from that of the loop. This is due to the difference of the transmission characteristics of these FSS. In both cases, it is represented that the electric field E_{total} is converged in certain value as the number n of reflected wave is increased. It is also shown that the converged electric field changes as the distance d is changed. In case of loop-slot, when the distance d = 0.463λ, the imaginary part of the electric field E_{total} equal to 0 and the real part of that is larger than 0. Accordingly, the AMC which operates at the frequency 0.5 f_{BP} can be designed by setting the distance d = 0.463λ. Similarly, in case of loop, the AMC which operates at the frequency 0.5 f_{BP} can be designed by setting the distance d = 0.058λ. Consequently, it is clarified that the thinner AMC can be designed by using loop type FSS at the frequency 0.5 f_{BP}.

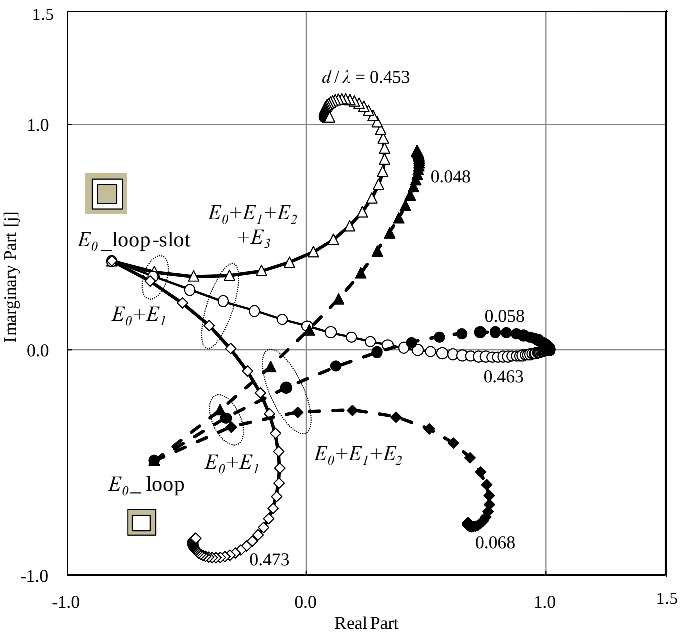


Figure 4: Transition of E_{total} (f=$0.5f_{BP}$, N=50)

4.3 PMC Bandwidth and Thickness of Designed AMC

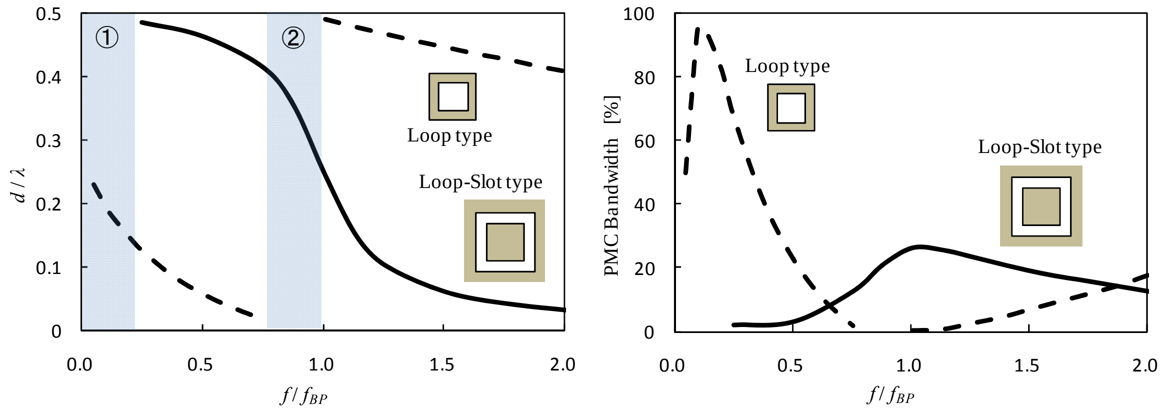
Figure 5 shows the thickness and the PMC bandwidth of the designed AMC. Figure 5(a) shows the thickness, and Fig.5 (b) shows the PMC bandwidth, respectively. Here, the PMC bandwidth is defined as the frequency band within the ±90 degrees reflection phase. In both figure, the solid line and the dashed line show the case of the loop-slot and loop type FSS, respectively.

It is found in Fig. 5(a) that there are the frequency regions ①, ② where the line doesn't exist. The region ① is the frequency region where the AMC cannot be designed by using the loop-slot type FSS, and the region ② is that of the loop type. It is because that the amplitude of S_{21} of the FSS is small at these frequencies, that is, almost all waves are reflected by the FSS layer. From Fig. 3(a) and Fig. 5(a), it is found that the AMC cannot be designed at the frequency where the amplitude of S_{21} of the FSS is lower than -15dB. At other frequencies, we can design the AMC by using proposed method.

In case of loop-slot type, the thickness of the AMC becomes thinner as the frequency where the AMC is designed becomes higher. On the other hand, the thickness of the AMC which is designed at the low frequency is thinner than that is designed at the high frequency in case of loop type. Consequently, the thickness of the AMC in case of loop is thinner/thicker than that of loop-slot at thinner/thicker frequency. In case of loop-slot, we can get the AMC whose thickness is 0.03λ at the frequency $2.0f_{BP}$. On the other hand, in case of loop, the AMC whose thickness is 0.02λ can be obtained at the frequency $0.76f_{BP}$.

It is shown in Fig. 5(b) that the PMC bandwidth of the AMC is changed as the target frequency is changed. In addition, it is found that there is the peak of the PMC bandwidth in both cases. In case of the loop-slot/loop type, the peak is at the frequency $1.0f_{BP}/0.1f_{BP}$. These frequencies are the frequencies where the amplitude of S_{21} of the FSS nearly equals to 0dB. In case of loop-slot, the maximum PMC bandwidth of the AMC is 26.5%. On the other hand, in case of loop, we can get the PMC whose bandwidth is 96%.

To obtain the thin AMC, we have to design at lower/higher frequency by using loop/loop-slot type FSS. And, to obtain the wideband AMC, we have to design at the frequency $1.0f_{BP}/0.1f_{BP}$ in case of the loop-slot/loop type. That is why, it is clarified that the FSS which is suited to design a wideband and thin AMC is the loop type FSS.



(a) Thickness (b) PMC Bandwidth

Figure 5: Thickness and PMC Bandwidth of designed AMC

5. Conclusion

The AMC is designed by using the loop-slot/loop type FSS which has band-pass/band-rejection filtering characteristics. Based on the calculated results, it was clarified that the AMC which has the PMC characteristics at the certain frequency could be designed by using proposed design method. However, there were the frequencies where the AMC could not be designed. In addition, it was found that more wideband and thinner AMC can be designed by using the loop type FSS. In case of the loop type, we achieved to get the AMC whose thickness is 0.02λ at the frequency $0.76f_{BP}$. Furthermore, the AMC whose PMC bandwidth is 96% could be obtained at the frequency $0.1f_{BP}$.

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