Low-Profile Design and Bandwidth Characteristics of AMC with Dielectric Substrate

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Abstract

This paper describes the low-profile design and bandwidth characteristics of AMC (artificial magnetic conductor) with the dielectric substrate. It was clarified by the simulation results that the thickness of AMC which had the maximum PMC bandwidth was 0.25 wavelength and 1/5.5 wavelength in the cases of the loop-slot type AMC and the loop type one, respectively.

Keywords : AMC PMC Dielectric Substrate

1. Introduction

An artificial magnetic conductor (AMC) with PMC (perfect magnetic conductor) characteristics has been studied for antenna applications. The electromagnetic waves can be reflected at the surface of PMC without phase rotation [1][2]. The AMC is composed of the FSS (frequency selective surface) and the ground plane. And, a dielectric substrate is arranged between the FSS and the ground plane [3][4].

This paper describes the low-profile design and bandwidth characteristics of AMC (artificial magnetic conductor) with the dielectric substrate. Here an influence of the relative permittivity on the thickness of AMC with dielectric substrate and its band width characteristics are studied.

2. Analysis Model

Figure 1 shows he analysis models for the design of low-profile AMC structures by using FSS. Figures 1(a), 1(b) and 1(c) show the FSS element, the FSS structure and the AMC structure, respectively. Here, the FSS structure is composed of loop-slots or loops. The loop-slot and loop type FSSs have complementary structures in each other. The FSS elements are arranged infinitely in x-axis and y-axis. Figure1(c) shows the structure of the AMC with dielectric substrate of relative permittivity ε_r that is arranged between the FSS and the ground plane. If thickness d of dielectric substrate is set properly, PMC characteristics can be obtained in particular frequency band [4]. In order to analyze the infinite structures, the periodic boundary condition (PBC) is utilized in the FDTD analysis(EEM-FDTD).

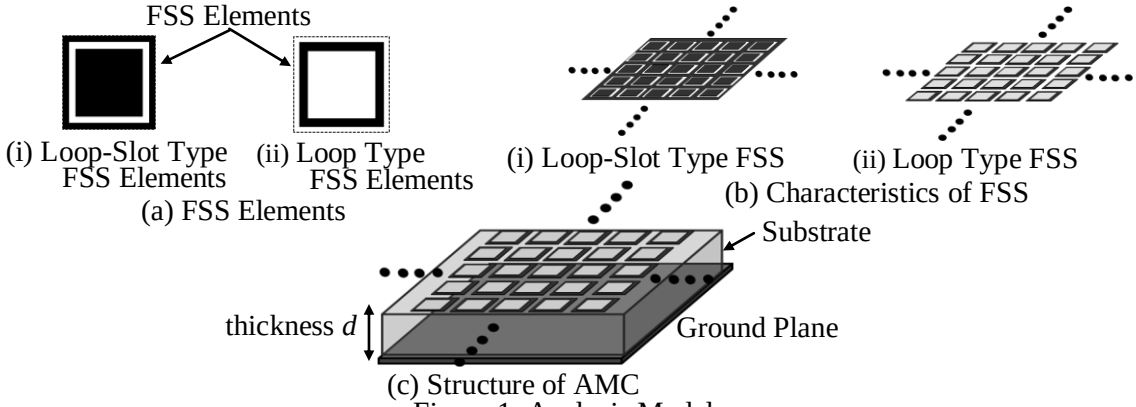


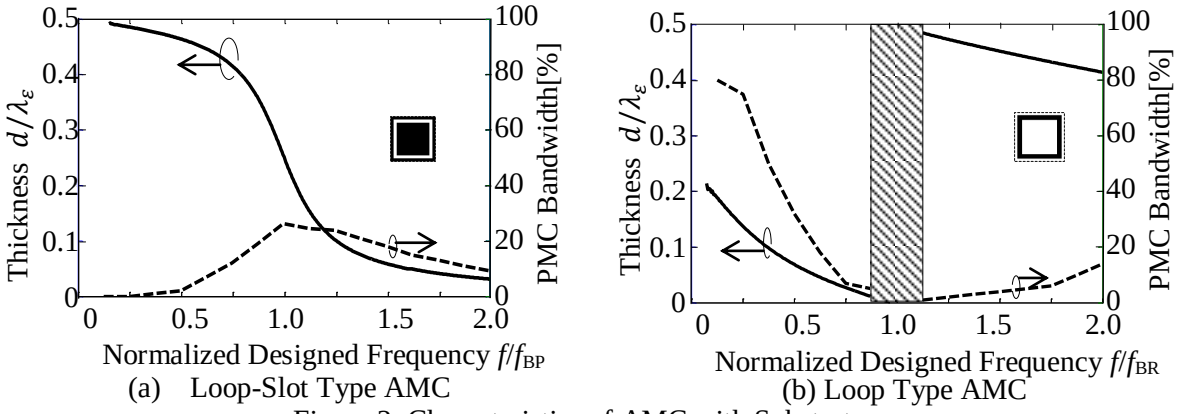
Figure 1: Analysis Model

3. Low-Profile Design of AMC using FSS

The loop-slot type FSS and the loop type FSS are a band pass filter (BPF) and a band rejection filter (BRF), respectively [4]. The loop-slot type FSS has the BPF characteristics at the

frequency f_{BP} when relative permittivity ε_r equals 1. And, the loop type FSS has the BRF characteristics at frequency f_{BR} when the same condition.

Figure 2 shows the relation between the normalized designed frequency and the thickness of the AMC that has PMC characteristics. And, the relation between the normalized designed frequency and the PMC bandwidth is also shown in Fig. 2. Here, the PMC bandwidth is defined as the frequency bandwidth with the reflection phase of 90 degrees. The thickness of AMC is designed so as to that the phase of the composite electric field of reflected wave equal to 0 degree [3][4].



(a) Loop-Slot Type AMC (b) Loop Type AMC

Figure 2: Characteristics of AMC with Substrate

The horizontal axes of Figs. 2 (a) and 2 (b) are the designed frequency normalized by each of f_{BP} and f_{BR}. The vertical axes of both Figs. 2 (a) and 2 (b) are the thickness of the AMC which has the PMC characteristics and the PMC bandwidth. Here, the thickness is normalized by the wavelength in the dielectric substrate. In both figures, the solid lines and the dashed lines represent the thickness and the PMC bandwidth, respectively. The hatched area in Fig. 2 (b) is the area where the AMC can't be designed. As the loop type FSS has the BRF characteristics, most of all power of the electromagnetic wave is reflected in the BRF band. And, the electromagnetic wave can't propagate into dielectric sybstrate in the AMC.

In Fig. 2, it is understood that the thickness of the AMC with PMC characteristics are changed by normalized designed frequency. From Fig. 2 (a), it is also understood that the thickness of the AMC can be designed more thinly than the 0.25 wavelength, when the normalized designed frequency is higher than the band pass frequency of the loop-slot type FSS. When the normalized designed frequency is lower than the band pass frequency, the thickness of the AMC is thicker than 0.25 wavelengths. On the other hand, from Fig. 2 (b), it is understood that the thickness of the AMC can be designed more thinly than the 0.25 wavelengths, when normalized designed frequency is lower than the band rejection frequency of the loop type FSS. When the normalized designed frequency is higher than the band rejection frequency, thickness of AMC is thicker than 0.25 wavelengths. Therefore, when design the AMC using the loop-slot type FSS, the normalized designed frequency should be higher than the frequency f_{BP}. When design the AMC using the loop type FSS, the normalized designed frequency should be lower than the frequency f_{BR}.

Moreover, the PMC bandwidth are also changed by the normalized designed frequency. From Fig. 2 (a), we can find the PMC bandwidth of the loop-slot type AMC has the peak. The maximum PMC bandwidth is 26% when the normalized designed frequency is 0.25 f_{BP}. In the areas except the peak, the PMC bandwidth becomes narrow gradually. Figure 2 (b) shows that the PMC bandwidth of the loop type AMC becomes wide by decreasing the normalized designed frequency. From Figs. 2 (a) and 2 (b), it is understood that the PMC bandwidth of both loop-Slot type and loop type AMC becomes wide when the thickness is close to the 0.25 wavelength.

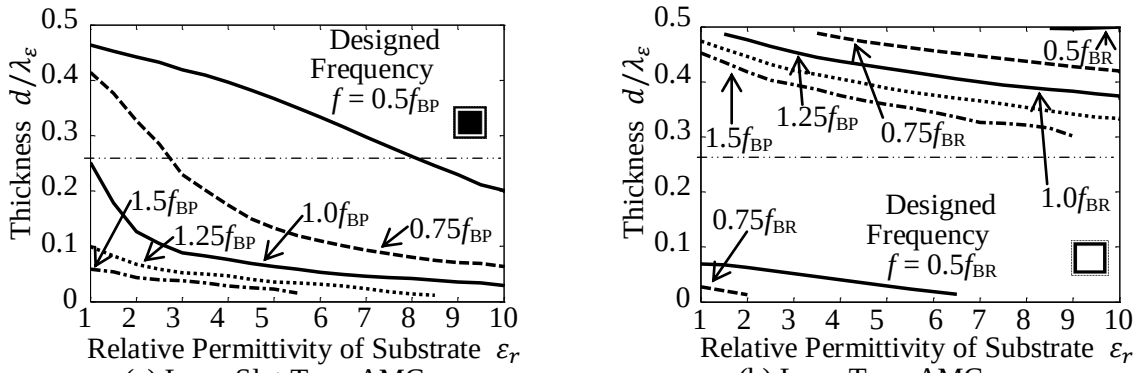
4. Design of AMC with Dielectric Substrate

4.1 Low-profile Design of AMC with Dielectric Substrate

Figure 3 shows the relationship between the relative permittivity and the thickness of the AMC. The parameter is the normalized designed frequency. Figures 3(a) and 3 (b) indicate the loop-slot type AMC and loop type AMC, respectively. The horizontal axes of Figs. 3 (a) and 3 (b)

are the relative permittivity. The vertical axes are the thickness that is normalized by the wavelength in the dielectric substrate.

From Fig. 3, it is understood that the low-profile AMC can be designed by using the dielectric substrate. Figure 3 (a) shows that thickness of the loop-slot type AMC can be thinned more than 0.25wavelength even when the normalized designed frequency is higher than $0.5f_{BP}$. On the other hand, Fig. 3 (b) shows that the thickness of the loop type AMC is thick more than the 0.25 wavelength when the normalized designed frequency is 0.5 f_{BR} and the relative permittivity is 6.5. Here, it is a reason that the band rejection frequency is decreased by the influence of the dielectric substrate. It is clarified from Fig. 3 that the low-profile structure is achieved more than the effect of the relative dielectric constant when the thickness is decreased compared to the relative dielectric constant in Fig. 3. Moreover, by inclination of the lines are larger, the effect of the low-profile design is larger. Please compare the loop-slot type AMC with the loop type AMC of using the dielectric substrate. The inclination of the lines of the loop-slot type AMC is larger than that of the loop type AMC. It is indicate that influence of the dielectric substrate is larger in case of the loop-slot type AMC.



(a) Loop-Slot Type AMC (b) Loop Type AMC

Figure 3:Thickness of AMC with Dielectric Substrate

4.2 PMC Bandwidth of AMC with Dielectric Substrate

Figure 4 shows the influence of the dielectric substrate and the designed frequency on PMC Bandwidth. Figures 4 (a) and 4 (b) indicate the loop-slot type AMC and the loop type AMC. The horizontal axes of Figs. 4 (a) and 4 (b) are the relative permittivity ε_r. And, the vertical axes are the normalized designed frequency for each FSS. The hatched area shows the area where the AMC cannot be designed. From the Fig. 4, we can find that the PMC bandwidth is decreased, whenever the relative permittivity is increased. Moreover, the PMC bandwidth is decreased by the influence of dielectric substrate, but it has peak of bandwidth in each of the relative permittivity. Figure 4 (a) shows that the maximum PMC bandwidth of the loop-slot type AMC is 26% when the relative permittivity is 1.0 and the normalized designed frequency is $1.0f_{BP}$. On the other hand, Fig. 4 (b) shows that the PMC bandwidth of the loop type AMC is increased when the relative permittivity is small and the normalized designed frequency is low. The PMC bandwidth of the loop type AMC is wider than that of the loop-slot. And the maximum value is about 100%.

The following Eq. (1) and (2) are the approximated equation of the normalized designed frequency of the loop-slot /loop type AMCs that have the maximum PMC bandwidth using f_{BP} and f_{BR}.

■ The Frequency of maximum PMC bandwidth of Loop-Slot type AMC $\fallingdotseq f_{BP}/\{(1+\sqrt{\varepsilon_r})/2\}$ (1)

□ The Frequency of maximum PMC bandwidth of Loop type AMC $\fallingdotseq 0.125 f_{BP}$ (2)

It is shown by the above equations that the frequency of the maximum PMC bandwidth of the loop-slot type AMC is changed by the relative permittivity. On the other hand, the maximum PMC bandwidth of the loop-type AMC is not changed regardless of the relative permittivity.

Figure 5 shows the maximum PMC bandwidth and the thickness in each the relative permittivity. The horizontal axis of Fig. 5 is the relative permittivity ε_r. And the vertical axes are the PMC

bandwidth and the thickness which is normalized by the wavelength in the dielectric substrate. From Fig. 5, we can find that the thickness of the maximum PMC bandwidth is always 0.25 wavelength and 1/5.5 wavelength in the case of the loop-slot type AMC and the loop type AMC, respectively.

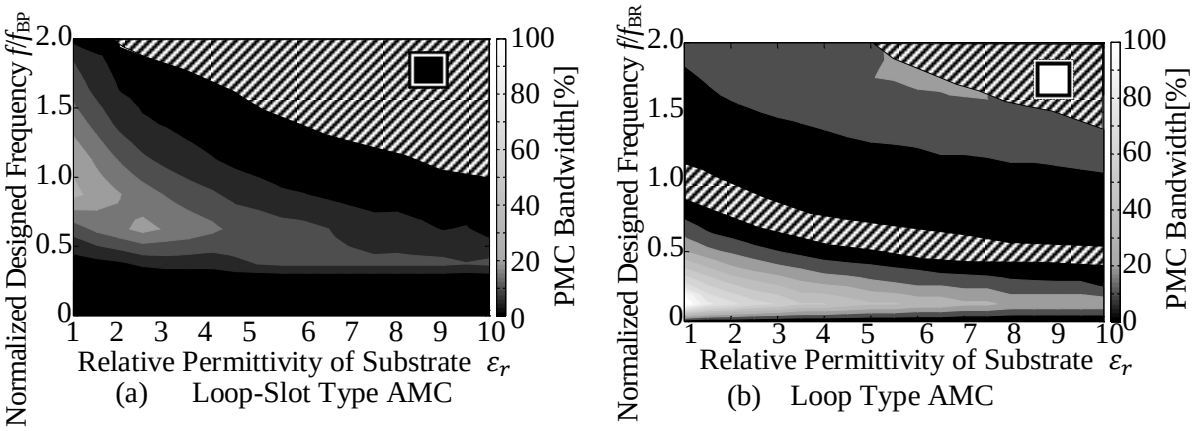


Figure 4: PMC Bandwidth of AMC with Dielectric Substrate

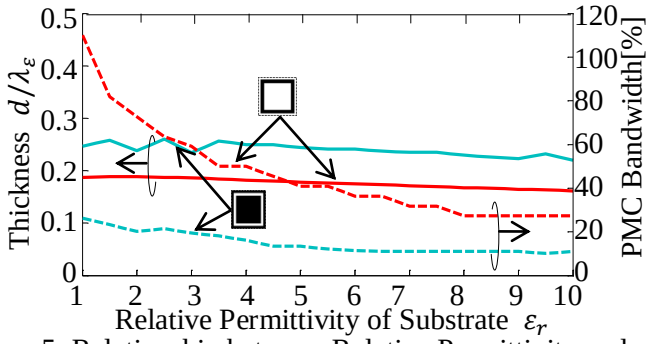


Figure 5: Relationship between Relative Permittivity and Thickness of AMC with Maximum PMC Bandwidth

5. Conclusion

The low-profile design and bandwidth characteristics of AMC with the dielectric substrate was described. Here, the dielectric substrate was applied to the AMCs using the FSSs that have the BPF/BRF characteristics. It was clarified by the simulation results that the AMC of the thin structure from a permittivity effect could been designed by using the dielectric substrate. It was also clarified that the loop-slot type AMC had larger influence of the dielectric substrate than the case of loop type AMC. Moreover, the PMC bandwidth was narrower by the dielectric substrate, but the loop type AMC had about 100% bandwidth. It was shown that the thickness of the AMC which had the maximum PMC bandwidth steadies regardless of the relative permittivity. The thickness of the maximum PMC bandwidth was 0.25 wavelength and 1/5.5 wavelength in the case of the loop-slot type AMC and the loop type AMC, respectively.

References

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