Equivalent PMC Structure of Frequency Selective Surface with Ground Plane

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1. Introduction

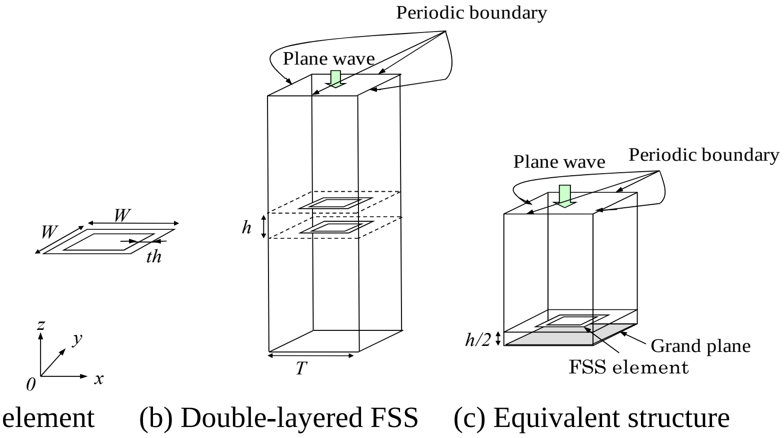
FSS(Frequency Selective Surface) is composed of metal patches arranged at narrow intervals, and has the frequency-band-rejection and the frequency-band-pass characteristics[1]. On the other hand, AMC(Artificial magnetic conductor) is one of artifical materials, and has the PMC(Perfect Magnetic Conductor) characteristics in any frequency band. On the PMC surface, the high-frequency current isn't propagating. In addition, electromagnetic wave is reflected at the surface without phase rotation[2][3].

This paper describes the reflection and transmission characteristics of a double-layered FSS and its equivalent structure with the ground plane, and also discusses the relation between the filtering characteristics of a double-layered FSS and the PMC characteristics of the equivalent structure with the ground plane.

2. Analysis Models

Figure 1 shows the analysis models of a double-layered FSS and the equivalent structure with the ground plane.

Figure 1(a), 1(b) and 1(c) show a FSS element, a double-layered FSS and the equivalent structure with the ground plane, respectively. As shown in Fig. 1, the shape of FSS elements is a rectangular loop. The width W of the FSS element is 38mm, and the period of arrangement T is 40mm. The distance between the FSS element and the ground plane of the equivalent structure is a half of the distance h between FSS elements of a double-Layered FSS. FSS elements are arranged along the x-axis and the y-axis infinitely. Here, in order to calculate various characteristics of the infinite structures, the periodic boundary conditions (PBC) is utilized. FDTD method (EEM-FDM) is used.



(a) FSS element with ground plane (b) Double-layered FSS (c) Equivalent structure

Figure 1: Analysis models of FSS

3. Filtering Characteristics of Double-layered FSS and PMC Characteristics of Equivalent Structure with Ground Plane

Figure 2 shows the reflection and transmission characteristics of the plane wave which propagates from the normal direction (*z*-axis) to the double-layered FSS as shown in Fig. 1(b). In Fig.2, the solid line and the dashed line show the amplitude of S_{11} and S_{21}, respectively. It is found from Fig.2 that the amplitude of S_{11} is significantly small and the amplitude of S_{21} is 0 dB at the frequency of 1.1GHz. In other words, the double-layered FSS operates as a band-pass filter (BPF) at the frequency. On the other hand, it is found that the amplitude of S_{21} is small enough and the amplitude of S_{11} is 0 dB at the frequency of 1.8GHz. Consequently, the double-layered FSS operates as a band-rejection filter (BRF) at the frequency.

Figure 3 shows the reflection phase of the plane wave which comes from a normal direction to the equivalent structure with the ground plane as shown in Fig. 1(c). The reflection phase means the phase difference between a reflection wave and incident wave at the surface of FSS elements. It is found from Fig.3 that the reflection phase of the reflected wave from the equivalent structure with the ground plane at 1.2GHz is 0 degree, that is, an electromagnetic wave reflects at the surface of the equivalent structure without phase rotation at the frequency. As the result, it is clarified that the surface of the equivalent structure with the ground plane is regarded as the AMC at the frequency. This frequency is nearly equal to the frequency in which the double-layered FSS operates as BPF.

Therefore, it is probable to suppose that the equivalent structure with the ground plane has the PMC characteristics at the frequency in which the double-layered FSS operates as a BPF.

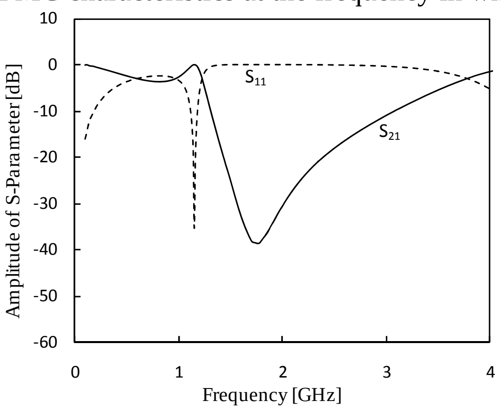


Figure 2: Reflection and transmission characteristics of double-layered FSS

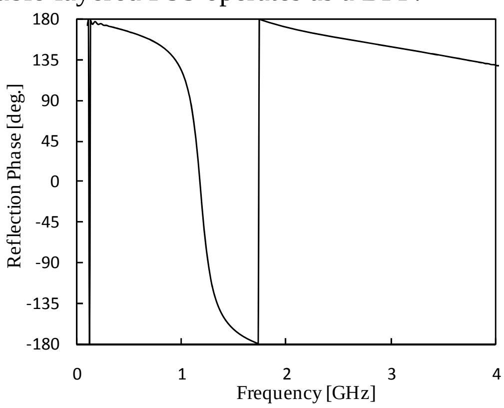


Figure 3: Reflection phase characteristics of equivalent structure with the ground plane

4. Effects of Shape of FSS Elements on Filtering and PMC Characteristics

4.1 Effects of thickness *th* of loop

Figures 4 and 5 show the transmission(S_{21}) and reflection(S_{11}) characteristics of the double-layered FSS on the thickness *th* of loop, respectively. Here, the frequencies f_{BPF} and f_{BRF} are defined as the frequencies in which the double-layered FSS operates as BPF and BRF, respectively. It is found from Figs.4 and 5 that the frequencies f_{BPF} and f_{BRF} are shifted to higher frequency as the thickness *th* of loop is increased. The frequencies f_{BPF} are 1.15GHz, 1.22GHz and 1.28GHz in the cases of *th*=2, 4 and 6 mm, respectively. The frequencies f_{BRF} are 1.76GHz, 2.09GHz and 2.57GHz in the cases of *th*=2, 4 and 6 mm, respectively.

Figure 6 shows the reflection phase characteristics of the equivalent structure with the ground plane on the thickness *th* of loop. Here, the frequency f_{PMC} is defined as the frequencies in which the equivalent structure with ground plane operates as the PMC. As shown in Fig. 6, it is found that the frequency f_{PMC} is shifted to higher frequency as the thickness *th* of loop is increased. The frequencies f_{PMC} are 1.17GHz, 12.5GHz and 1.32GHz in the cases of *th*=2, 4 and 6mm, respectively. As the above mentioned, these frequencies are approximately equal to the frequencies where the double-layered FSS operates as the BPF.

Figure 7 shows the relation between the frequency f_{BPF} of the double-layered FSS and the PMC bandwidth of the equivalent structure with the ground plane on the thickness *th* of loop. Here, the "PMC bandwidth" is defined as the frequency band within the ±90 degree reflection phase. And, the "highest PMC" and the "lowest PMC" are defined as the maximum frequency and the minimum frequency of the PMC bandwidth. The solid lines and the dashed line show the PMC bandwidth and the frequency f_{BPF} in Fig.7.

As shown in Fig.7, it is found that the frequencies f_{BPF} and highest PMC and lowest PMC are shifted to the higher frequency as the thickness *th* of loop is increased. And, the frequency f_{BPF} is within the PMC bandwidth regardless of the thickness *th* of loop.

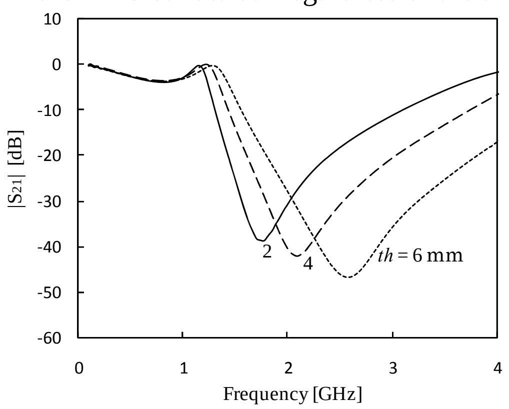


Figure 4: S_{21} amplitude characteristics of double-layered FSS

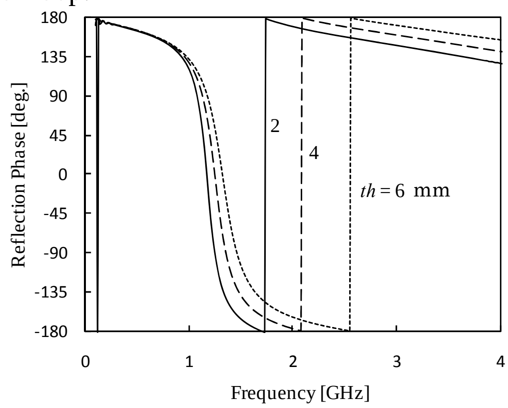


Figure 6: Reflection phase characteristics of equivalent structure with the ground plane

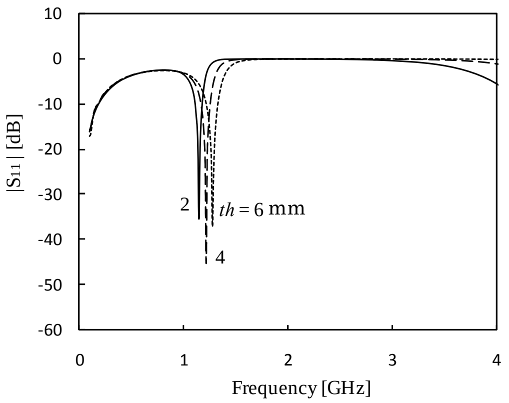


Figure 5: S_{11} amplitude characteristics of double-layered FSS

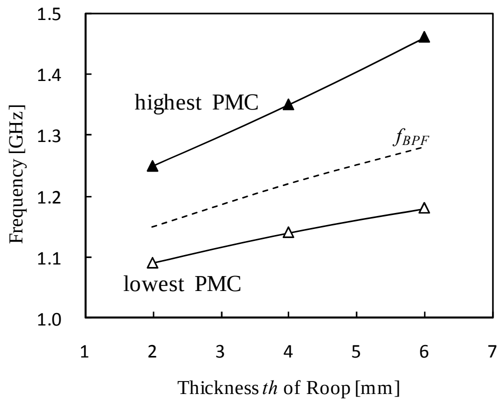


Figure 7: Relation between f_{BPF} and PMC bandwidth

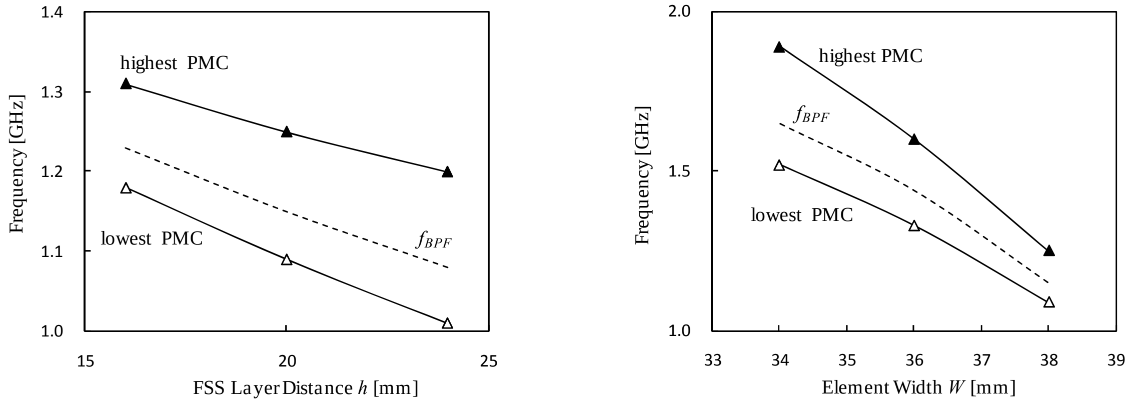
4.2 Effects of the other parameters of the shape of FSS elements

The other parameters of a shape of FSS elements except *th* are the element width *W* and the FSS layer distance *h*. Here, we discuss the effects of these parameters on the frequency f_{BPF} and the PMC bandwidth. Figure 8 shows the relation between the frequency f_{BPF} of the double-layered FSS and the PMC bandwidth of the equivalent structure with the ground plane on the each parameter. In Figs.8(a) and 8(b), the parameters are the FSS layer distance *h*, and the element width *W*, respectively.

As shown in Fig. 8(a), it is found that the frequencies f_{BPF}, the highest PMC and the lowest PMC are shifted to the lower frequency as the FSS layer distance *h* becomes longer, and the PMC bandwidth becomes wider as the FSS layer distance *h* becomes longer.

Similarly, as shown in Fig.8(b), it is found that the frequencies f_{BPF}, the highest PMC and the lowest PMC are shifted to the lower frequency as element width *W* becomes wider, and the PMC bandwidth becomes narrower as the element width *W* becomes Wider.

In each case, the frequency f_{BPF} is within the PMC bandwidth regardless of the FSS layer distance *h* and the element width *W*.



(a) Effect of FSS layer distance h (b) Effect of element width W

Figure 8: Relation of f_{BPF} and PMC bandwidth

Figure 9 shows the near-electric field of the double-layered FSS and the equivalent structure with the ground plane. We can see in Fig. 9 that the electric field strength of the equivalent structure with ground plane is higher than that of the double-layered FSS. It is because the equivalent structure with the ground plane has the ground plane. Thus, all the power of the incident wave is reflected at ground plane and returned.

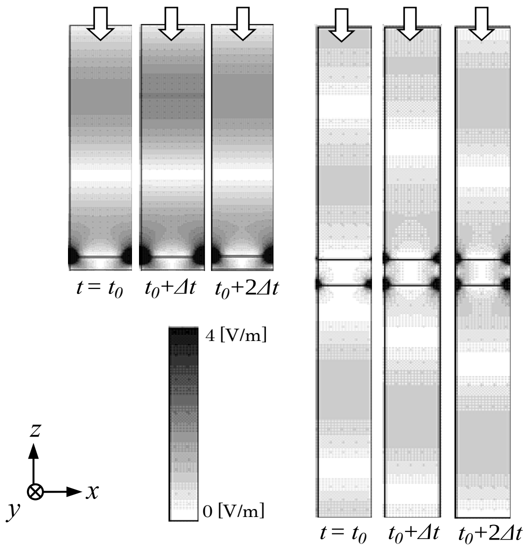


Figure 9: Near-electric field

5. Conclusion

The reflection and transmission characteristics of the double-layered FSS and its equilavent structure with ground plane were discussed. Based on the calculated results, it was shown that the double-layered FSS had the BPF and the BRF characteristics and the equivalent structure with ground plane had the PMC characteristics. In addition, it was found that the equivalent structure with ground plane could operated as the PMC at the frequency in which the double-layered FSS could operated as BPF.

References

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