

Design Method of Unit Cell Structure for Realizing Broadband Artificial Magnetic Conductor

Masaru NAGATA, Toshikazu HORI, and Mitoshi FUJIMOTO
 Graduate School of Engineering, University of Fukui 3-9-1, Bunkyo, Fukui, 910-8507 Japan

Abstract - This paper focuses on an AMC (Artificial Magnetic Conductor) composed of a FSS (Frequency Selective Surface) and the ground plane, and describes the design method of the unit cell of the AMC to realize PMC (Perfect Magnetic Conductor). The FSS that consists of a patch type FSS and a medium is proposed to realize broadband PMC characteristics. A frequency characteristics of the relative permittivity of the medium is calculated by equivalent circuit analysis. In addition, a near-ideal reflection phase is obtained by applying the medium.

Index Terms — AMC, PMC, FSS, Equivalent circuit, Relative permittivity.

1. Introduction

An AMC (Artificial Magnetic Conductor), that consists of a FSS (Frequency Selective Surface) and the ground plane, is an artificial structure to realize PMC (Perfect Magnetic Conductor) characteristics at a specified frequency. An electromagnetic wave is reflected without phase rotation at the surface of the AMC with PMC characteristics. A high gain and low-profile antenna is realized by using the AMC reflector as one of antenna application.

However, it is difficult that the AMC applies to broadband antennas and any broadband application, because the AMC realizes PMC characteristics at just one frequency. Therefore, this paper clarifies the design method of the unit cell structure of the broadband AMC by using ideal filter.

2. Configuration of AMC with FSS

Fig. 1 shows a configuration example of an AMC composed of FSS and the ground plane. The reflection phase of the AMC is expressed by Eq. (1) [1]. Here, ϕ_s , S_{11} , S_{21} , ϕ_{11} , ϕ_{21} , ϕ_h are reflection phase of the AMC, reflection coefficient of the FSS, transmission coefficient of the FSS, reflection phase of the FSS, transmission phase of the FSS, and a quantity of total phase rotation of distance between the FSS and the ground plane. ϕ_h is expressed by Eq. (2). λ is wavelength.

$$e^{j\phi_s} = |S_{11}|e^{j\phi_{11}} + \frac{|S_{21}|e^{j(2\phi_{21}+\phi_h)}}{1 - |S_{11}|e^{j(\phi_{11}+\phi_h)}} \quad (1)$$

$$\phi_h = 2\frac{2\pi h}{\lambda} + \pi \quad (2)$$

If the distance between the FSS and the ground plane h is determined, the reflection phase of the AMC is derived from the filtering characteristics of the FSS through Eq. (1).

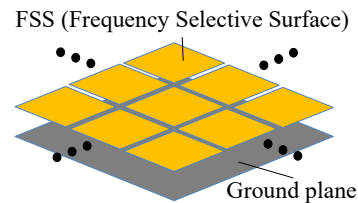


Fig. 1. Configuration example of AMC.

3. Ideal Filtering Characteristics of FSS for Realizing PMC

Equation (1) can derive the filtering characteristics for realizing PMC characteristics without frequency dependence when $\phi_s = 0$ [deg.] [2]. Fig. 3 shows the result by using Eq. (1). In addition, Fig. 4 shows the filtering characteristics of the patch type FSS as an example of filtering characteristics of the conventional FSS. It is found that the ideal filtering characteristics is a band pass filtering characteristics as shown Fig. 3. However, the realization of the ideal filtering characteristics using the conventional FSS is difficult because the phase rotation direction is opposite composed to conventional FSS as shown Fig. 4.

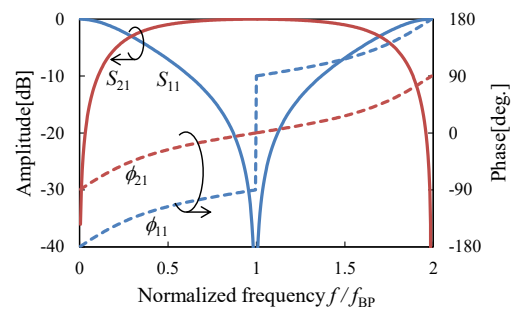


Fig. 2. Ideal filtering characteristics for realizing PMC.

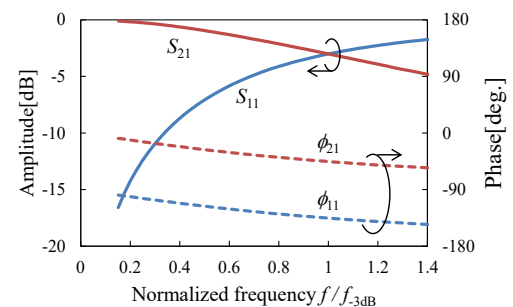


Fig. 3. Filtering characteristics of patch type FSS.

4. Configuration of Unit Cell for Broadband AMC

(1) Design Method of Proposed FSS

The filtering characteristics of the FSS is influenced by the relative permittivity and the relative permeability of a medium which covers FSS. Therefore, this paper proposes the unit cell structure that has the patch type FSS covered by a medium. The proposed FSS is designed by equivalent circuit analysis.

Fig. 4 shows the equivalent circuit model of the proposed FSS. The impedance of the patch type FSS in the medium of the relative permittivity ϵ_r and the relative permeability μ_r is expressed by Eq. (3). Here, X and B are the inductive reactance and the capacitive susceptance.

$$Z_0 = j\mu_r X + \frac{1}{j\epsilon_r B} \quad (3)$$

The impedance of the ideal filtering characteristics is expressed by Eq. (4).

$$Z_{IF} = \frac{|S_{21}|e^{j\phi_{21}}}{2 - 2|S_{21}|e^{j\phi_{21}}} \quad (4)$$

The fundamental matrix of the equivalent circuit shown in Fig. 4 is expressed by Eq. (5) with Eq. (3) and Eq. (4). t is thickness of the medium. β is phase constant and is expressed by Eq. (6).

$$\begin{bmatrix} 1 & 0 \\ 1/Z_{IF} & 1 \end{bmatrix} = \begin{bmatrix} \cos(\beta t/2) & j\sqrt{\mu_r/\epsilon_r} \sin(\beta t/2) \\ j\sqrt{\epsilon_r/\mu_r} \sin(\beta t/2) & \cos(\beta t/2) \end{bmatrix} \quad (5)$$

$$\times \begin{bmatrix} 1 & 0 \\ 1/Z_0 & 1 \end{bmatrix} = \begin{bmatrix} \cos(\beta t/2) & j\sqrt{\mu_r/\epsilon_r} \sin(\beta t/2) \\ j\sqrt{\epsilon_r/\mu_r} \sin(\beta t/2) & \cos(\beta t/2) \end{bmatrix}$$

$$\beta = \frac{2\pi}{\lambda} \sqrt{\mu_r \epsilon_r} \quad (6)$$

The relative permittivity and the relative permeability of the medium which is required by the FSS to realize the ideal filtering characteristics are obtained by Eq. (5).

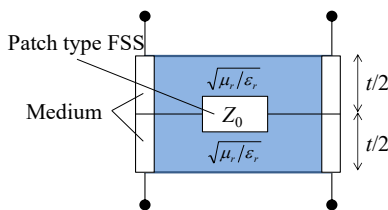


Fig. 4. Equivalent circuit model of proposed FSS.

(2) Configuration of AMC using Proposed FSS

Fig. 5 shows the unit cell structure of the AMC using the proposed FSS. In addition, Fig. 6 shows the relative permittivity of the medium, that is required in the proposed unit cell to realize PMC characteristics in range of 0.5 ~ 2 GHz when the relative permeability of the medium is 1. Fig. 7 shows the reflection phase of the AMC that is calculated by the electromagnetic field analysis. It is found that the broadband AMC is realized by the proposed unit cell

structure because the reflection phase close to PMC characteristics in broadband.

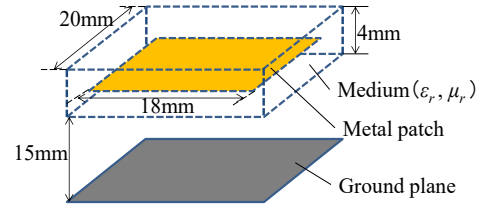


Fig. 5. Unit cell structure of AMC using the proposed FSS.

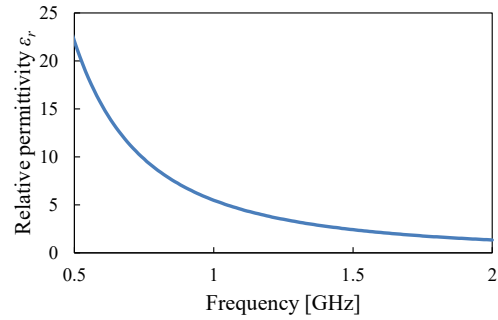


Fig. 6. Relative permittivity derived by equivalent circuit.

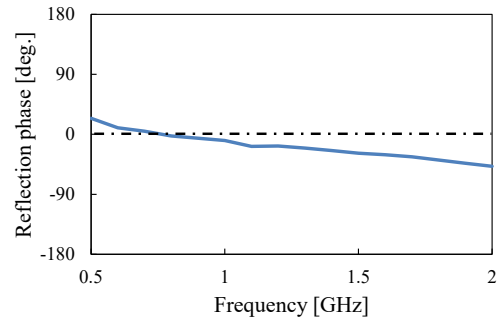


Fig. 7. Reflection phase of proposed AMC.

5. Conclusion

The design method of the unit cell structure to realize the broadband AMC was clarified. The unit cell structure that had the patch type FSS covered by a medium was proposed to realize an ideal filtering characteristics. The relative permittivity of the medium was clarified by equivalent circuit when the relative permeability of the medium was 1. In addition, it was found that the broadband AMC was realized by the proposed unit cell structure.

References

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