Reflection and Transmission of Laminated Structures Consisting a Wire Grid and a Dipole Array Sheet and Dielectric Layer

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Abstract—This paper proposes the reflection and transmission control structure using the artificially designed materials and a dielectric layer. As the artificially designed material, finite- and infinite-length metal wire array sheets are used here. The reflection and transmission characteristics of the laminated structures are evaluated experimentally in free space.

Keywords—laminted structure; finite- and infinite-length metal wire arrays; reflection and transmission characteristics

I. INTRODUCTION

Electromagnetic (EM) wave absorbers and shielding materials are frequently used to prevent microwave EM interferences between electronic devices and equipment. In recent years, frequency selective shielding technologies have been developed in the view point of new EM devices [1]–[3].

In this paper, the laminated structures consisting of the artificially designed materials and dielectric layer are proposed as a reflection-transmission controlling structure, such as, the incident waves are totally reflected at a particular frequency, and are transmitted with no loss at another frequency. As the artificially material, two-dimensional dipole array sheet (finite-length metal wire array sheet) and wire grid (infinite-length metal wire array sheet) are used [4], [5]. When the incident wave polarization is parallel to the metal wire array, and the wave hits the wire array at normal direction, the infinite-length metal wire array functions as the wire grid, whose equivalent relative permittivity shows negative value [6], [7].

First, the design method of the laminated structures is investigated. Next, the reflection and transmission coefficients of the laminated structures are measured in free space. Finally, the new designed metal wire array sheets consisting of a dipole array and a wire grid in same plane are proposed.

II. DIPOLE ARRAY SHEET AND WIRE GRID

A. Construction and Equivalent Relative Permittivity of the Sheet

Fig. 1(a) shows a dipole array sheet (finite-length metal wire array sheet). The total thickness of this sheet is 275 μm.

To keep the metal wires at right position, the wire array is sandwiched by two thin polyethylene films (thickness: 100 μm, relative permittivity: 3.2). The metal wire is a bundle of dozens of silver coated polyester fine fiber.

The equivalent relative permittivity \( \varepsilon_r \) of this sheet shows the resonant type dispersion [4]. Fig. 2 shows the equivalent relative permittivity of the metal wire array sheet whose parameters are: \( L=25 \) mm, \( S_x = 40 \) mm, \( S_y = 40 \) mm. The
frequency range is from 3 GHz to 8GHz. The negative permittivity \( \varepsilon_r' \) is observed above the resonant frequency \( f_0 \) (\( = 4.9 \) GHz). Also, the imaginary part \( \varepsilon_r'' \) shows the maximum value at \( f_0 \). In this case, the measured and calculated values were obtained by free space method and transmission line model [5], respectively.

Fig. 1(b) shows one of infinite-length metal wire array sheets (wire grids) used here. The metal wires are periodically aligned in parallel. The thickness is 275 \( \mu \)m, and \( S_d \) is the spacing between the wires. Under the conditions of \( d \ll S_{d1} \) and \( S_{d1} \ll \lambda_0 \) (\( d \): metal wire diameter, \( \lambda_0 \): wavelength in free space), the metal wire array can be expressed as a lumped element \( Y_{ag} \) (\( = Z_0 (S_{d1} \ln (S_{d1} / \pi d)) \), \( Z_0 \): characteristic impedances in free space) [5]. Reflection and transmission characteristics can be calculated by transmission line theory using \( Y_{ag} \).

Fig. 3 shows the equivalent relative permittivity of the infinite-length metal wire array sheet. The samples (A), (B), (C) were used here. \( \varepsilon_r' \) shows the negative value over measuring frequency range, and becomes large as \( S_{d1} \) decreases. \( \varepsilon_r'' \) are almost 0.

B. Laminated Structure Using Artificially Designed Materials and Dielectric Layer

The laminated structure in this study is (i) shown in Fig. 4. Finite- and infinite-length metal wire array sheets are placed on both sides of dielectric material. As the dielectric material, acrylic plate whose relative permittivity is about 2.6 was used so as to give transparence in laminated structure.

III. REFLECTION AND TRANSMISSION CHARACTERISTICS OF LAMINATED STRUCTURE

Reflection coefficients were measured by the arch type free space measurement setup [8]. The distance between antennas and measurement sample is 1.5 m. Transmission measurement coefficients were measured by the free space transmission measurement setup [9]. In this setup, the antennas separated by distance \( r \) (\( = 148 \) cm) are placed so that they faced each other. The measurement sample is placed at the center between antennas.

Since the equivalent relative permittivity of the metal wire array sheet shows the negative value, as shown in Figs. 2, 3, the total permittivity, or the average permittivity of the laminated structure can be unity (=1) at particular frequency, when the structure is considered as homogeneous material. At this frequency, the reflection almost becomes 0, and the maximum transmission can be obtained.

The parameters of laminated structure are shown in Table I. Figs. 5(a), (b) show the measured equivalent relative permittivity and the enlarged result. The frequency range is from 3 GHz to 13 GHz. The equivalent relative permittivity of this structure includes the coupling between finite- and infinite length metal wire sheets. The permittivity shows dispersion, at 4.6 GHz (\( = f_{0(2)} \)), \( \varepsilon_r'' \) becomes maximum, and \( \varepsilon_r' \) becomes unity at 3.3 GHz (\( = f_{0(1)} \)), 8.3 GHz (\( = f_{0(3)} \)).

Fig. 6 shows the measured reflection and transmission coefficients of this structure. Reflection coefficient \( \Gamma \) shows the maximum value at \( f_0 \). On the other hand, transmission coefficient \( |T| \) shows the minimum value at \( f_0 \). These characteristic depend on the finite-length metal wire array structure. Two minimum reflection characteristics occur at \( f_{1(0)} \), \( f_{2(0)} \). In contrast at \( f_{1(0)} \), \( f_{2(0)} \) \( |T| \) shows the maximum values. These characteristics indicate that the permittivity of laminated structure (i) can be unity at 3.3, 8.3 GHz, in other words, this structure becomes equivalent to the free space. In this study, we defined that \( f_{1(0)} \) is the maximum reflection frequency, \( f_{1(0)} \).
Fig. 5. (a) Equivalent relative permittivity of the laminated structure (i) consisting of a finite length metal wire array sheet, a dielectric material and an infinite-length metal wire array sheet, (b) vertical scale is enlarged.

Fig. 6. Measured $|\Gamma|$, $|T|$ values of laminated structure (i).

$f_{1(i)}$, $f_{2(i)}$ are the maximum transmission frequency. From above results, we confirmed that one peak of reflection, almost total reflection, and two maximum transmissions, almost no loss transmission.

The laminated structure (i) would be expected to use as reflection and transmission controlling device, for example, mobile phone EM waves or wireless LAN frequencies are almost passed, while other frequency EM waves are almost reflected. For further investigations, the metal wire parameters dependency of the reflection and transmission characteristics of this structure is necessary.

IV. NEW DESIGNED METAL WIRE ARRAY SHEET

Maximum reflection and transmission frequencies can be controlled by the parameters of laminating finite- and infinite-length metal wire array sheets and dielectric material as stated above section. In order to use these structures in practical use, it is necessary to thin the total thickness of the laminated structure. In this study, the new designed sheet with finite- and infinite-length metal wire arrays in same plane is proposed.

Figs. 7(a), (b) show the construction and photo of the new designed metal wire array sheet. In this study, the laminated structure (ii) shown in Fig. 4 is investigated. Fig. 8 shows the measured permittivity of the structure (ii) ($L=25$ mm, $S_{xf}=40$ mm, $S_{yf}=40$ mm, $S_{xi}=40$ mm). Fig. 9 shows the measured reflection and transmission coefficients of this structure. Maximum transmission and reflection frequencies $f_{1(ii)}$, $f_{2(ii)}$ agree well to the results of Fig. 6. On the other hand, $f_{2(ii)}$ is different from $f_{2(i)}$. At present, this difference is investigated by confirming the measurement repeatability.

From above results, we confirm that the reflection and transmission characteristics of the structure consisting of finite- and infinite-length metal wire arrays and a dielectric material show almost the same characteristics of the laminated structure (i). For further investigations, the reflection and transmission calculations by transmission line model are now in progress.

Since the metal wire arrays of the sheet shown in Fig. 7 are periodically aligned along y axis direction, the reflection and transmission of the laminated structure depend on the incident wave polarization. In practical use, the polarization dependency is not preferable. In order to obtain the isotropic polarization characteristic, the authors are proposed the metal wire array sheet as shown in Fig. 10.
Fig. 8. Equivalent relative permittivity of the laminated structure (ii) consisting of a new designed metal wire array sheet and a dielectric material.

Fig. 9. Measured $|\Gamma|$ and $|T|$ values of laminated structure (ii).

Fig. 10. (a) Cruciform metal wires array sheet, (b) photo of the sheet.

Fig. 11 shows the measured reflection and transmission coefficients of the laminated structure when the sample rotated from x ($0^\circ$) to y ($90^\circ$) axis. The parameters $L$, $S_\alpha$, $S_\beta$, $S_{ij}$ are 25, 40, 40, 40 mm, respectively, and the dielectric material is the same as Table I. The measured $|\Gamma|$ and $|T|$ values at each angle are almost the same. This indicates that the isotropic reflection and transmission characteristics can be achieved by using the metal wire array sheet shown in Fig. 10.

V. CONCLUSION

The laminated structures consisting a wire grid and a dipole array sheet and dielectric layer are proposed. By using the metal wire array sheets having negative permittivity, two maximum transmission frequencies and a maximum reflection frequency can be obtained.

The new designed metal wire array sheet consisting of finite- and infinite-length metal wire arrays in same plane is proposed. The reflection and transmission characteristics of the laminated structure using above sheet were investigated.

REFERENCES