Reflection and Transmission of Laminated Structures Using Metal Wire Array Sheet

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***Abstract*— This paper proposes reflection and transmission controlling materials using the artificially designed material. As the artificially designed material, the metal wire array sheets are used here. The laminated structures consisting of the metal wire array sheet and dielectric layer are proposed. Reflection and transmission characteristics of these structures can be controlled by changing the sheet parameters such as wire diameter and spacing between the wires. The reflection and transmission of the constructed material are calculated by the transmission line theory. Both characteristics are confirmed by measurement.**

I. INTRODUCTION

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

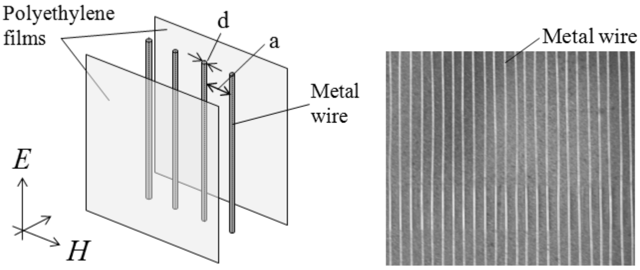
In this paper, the laminated structures consisting of the artificially designed materials and dielectric layers are proposed as the new frequency selective shielding material. As the artificially designed material, two-dimensional metal wire array sheet have been studied [4], [5]. When the incident wave polarization is parallel to the wires, and the waves hit the array at normal direction, the two-dimensional wire array functions as the metal grid, whose relative permittivity shows negative value. The reflection and transmission characteristics of the laminated structure can be controlled by changing the diameter of the metal wire and the spacing between wires.

First, the design method of the structures stated above is investigated. Next, the reflection and transmission coefficients of the laminated structures are calculated by transmission line model. After that, both calculated results are confirmed by measurement.

II. LAMINATED STRUCTURES CONSISTING OF METAL WIRE ARRAY SHEET AND DIELECTRIC LAYER

A. Metal Wire Array Sheet and Relative Permittivity

Fig. 1(a) shows a metal wire array sheet used here. Metal wires are periodically aligned in parallel. In this sheet, *d* and *a* are the metal wire diameter and spacing between wires, respectively. To support the wire array structure, metal wires are sandwiched by two thin polyethylene films (thickness: 100μm, relative permittivity: 3.2). Fig. 1(b) is a photo of the metal wire array sheet. The copper metal wires are used here.



(a) (b)

Fig. 1. (a) Construction of the metal wire array sheet, (b) photo of the metal wire array sheet

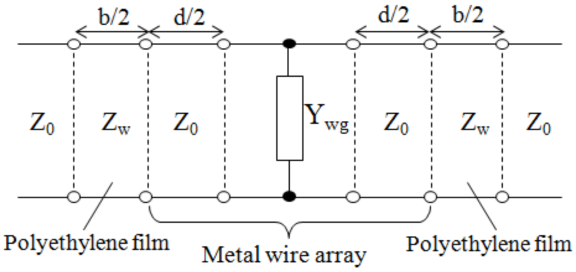


Fig. 2. Transmission line model for Fig. 1(a)

Under the conditions of $d << a$, and $a << \lambda_0$ (λ_0 is the wavelength in free space), the metal wire array can be expressed as a lumped element Y_{wg}. Y_{wg} is given as follows [1], [4].

$$Y_{wg} = -\frac{j\lambda_0}{Z_0 a \cdot \ln\left(\frac{a}{\pi d}\right)} \qquad (1)$$

Fig. 2 shows the transmission line model for the metal wire array sheet shown in Fig. 1(a). In here, b/2 is the thickness of the polyethylene film. Z_m and Z_0 are the characteristic impedances of the film and free space, respectively. Reflection and transmission characteristics can be calculated by transmission line model [4].

Fig. 3 shows the measured relative permittivity ε_r (= ε_r'-$j\varepsilon_r$"). The frequency range is from 3 GHz to 8 GHz. This result was measured by free space method stated following

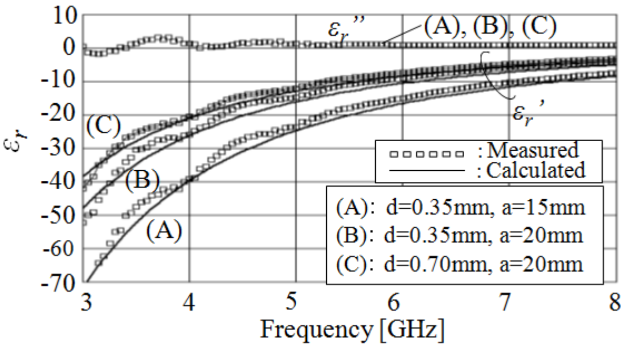
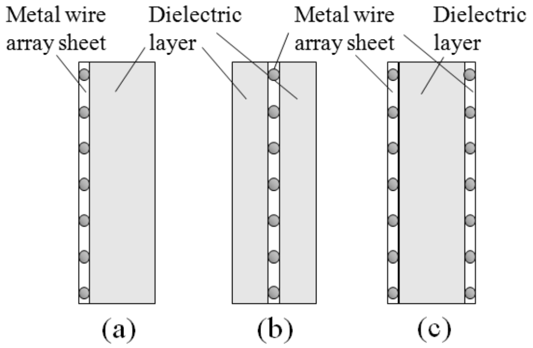


Fig. 3. Measured relative permittivity of metal wire array sheet



(a) (b) (c)

Fig. 4. Laminated structures consisting of metal wire array sheet and dielectric layer, (a) metal wire array sheet is placed on one side of dielectric layer, (b) metal wire array sheet is placed between two dielectric layers, (c) metal wire array sheets are placed on both sides of dielectric layer

section III. The metal wire array sheets (A), (B), (C) shown in Fig. 3 were used here. ε_r' shows the negative value over whole frequency range, and becomes large as both *a* and *d* decrease. On the other hand, imaginary part ε_r'' are almost 0. By using this typical characteristic, reflection and transmission controlling materials can be designed.

B. *Laminated Structures Using Metal Wire Array Sheet*

The laminated structures consisting of metal wire array sheet and dielectric layer are designed. In this study, the laminated structures shown in Figs. 4(a), (b), (c) are proposed. In Fig. 4(a), the metal wire array sheet is placed on one side of dielectric layer. In Fig. 4(b), the metal wire array sheet is placed between two dielectric layers with same thickness. Also, in Fig. 4(c), metal wire array sheets are placed on both sides of dielectric layer.

As the dielectric layer, grass plate was used so as to give transparence in laminated structure. In this study, the relative permittivity of grass plate is almost 6.8.

III. REFLECTION AND TRANSMISSION CHARACTERISTICS OF LAMINATED STRUCTURE

TABLE I
PHYSICAL DIMENSIONS OF LAMINATED STRUCTURE (B)

spacing between wires: a		a_1: 2.5mm
		a_2: 3.5mm
		a_3: 7.0mm
diameter of metal wire: d		d_1: 0.1mm
		d_2: 0.2mm
		d_3: 0.3mm
dielectric film	thickness: b/2	0.1mm
	relative permittivity ε_m	3.2
dielectric layer	thickness: t	1.76mm
	relative permittivity ε_d	6.8

Since the relative permittivity of the metal wire array sheet shows the negative value, as shown in Fig. 3, the total relative permittivity, or the average relative 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 becomes 0. Based on this qualitative understanding, reflection and transmission are investigated.

Reflection coefficients were measured in far-field region by the arch type free space measurement setup [6]. The double-ridge guide horn antennas (Agilent Technologies 11966E) were used as transmitting and receiving antennas. In this setup, the distance between antennas and the sample is 1.5 m. To measure the reflection coefficient, the antennas are connected to Network Analyzer (Agilent Technologies N5230A) ports through 50 Ω coaxial cables.

Transmission coefficient of the laminated structures was measured by the free space transmission measurement setup [7]. The transmitting and receiving antennas used for this setup were the double-ridge guide horn antennas (Schwarzbeck Mess-Elektronik BBHA 9120D). 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. The transmission coefficient was measured by Network Analyzer (Hewlett Packard 8720B).

The laminated structure (a) in Fig. 4, the matching condition is achieved approximately only when the dielectric layer is very thin compared to the wavelength [8]. In following part, the reflection and transmission of laminated structures (b), (c) will be discussed.

In this study, the parameters of laminated structure (b) are shown in Table I. Fig. 5 shows the measured reflection coefficients. In addition, the calculated results by transmission line model are shown in Fig. 5. In these results, the diameter of the sheet is fixed d_2 (=0.2mm).The calculated values for a_1, a_2, a_3 are mostly the same as the measured values.

From the results, the reflection characteristics depend on the spacing between metal wires. In the case of spacing a_2 (=3.5mm), the matching condition (smaller than -20dB) of the reflection characteristic is achieved from 9.4 GHz to 13.2 GHz in calculated result. The matching frequency range is 3.8 GHz. In contrast, the matching frequency range is not appeared in the results of a_1 (=2.5mm).

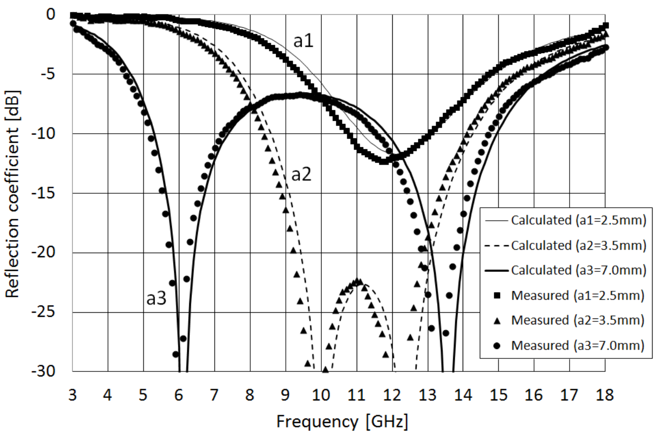


Fig. 5. Measured and calculated reflection coefficients of the laminated structure (b) when the spacing *a* changes (d_2=0.2mm)

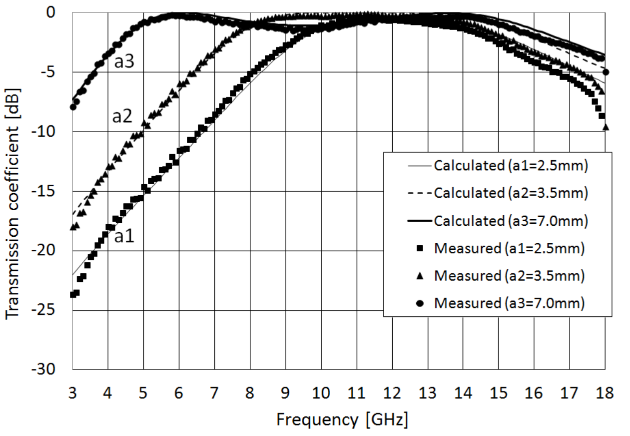


Fig. 6. Measured and calculated transmission coefficients of the laminated structure (b) when the spacing *a* changes (d_2=0.2mm)

Next, the measured and calculated transmission coefficients are shown in Fig. 6. The transmission characteristics become small as frequency decreases. In the result of a_2, the transmission coefficient almost becomes 0dB at around 9.3 GHz to 13.1 GHz. The frequency range of 0dB almost corresponds to the matching frequency range of reflection characteristic of Fig. 5.

Figs. 7, 8 show the reflection and transmission coefficients when the diameter *d* was changed. Both reflection and transmission depend on the diameter. In the case of d_2, the matching frequency of Fig. 7 can be obtained from 9.5 GHz to 13.2 GHz in calculation.

From above results, we find that the reflection and transmission characteristics can be controlled by changing the parameters *a*, *d* of metal wire array sheet. The transmission around 0dB can be achieved by the laminated structure (b) over broad frequency range.

Next, the laminated structure (c) shown in Fig. 4 is considered here. The parameters of structure (c) are shown in Table II. Fig. 9 shows the calculated transmission coefficients. The diameter *d* is fixed 0.2mm. In this result, two typical peak characteristics occur at low and high frequencies, for example, 7.7 GHz and 15.8 GHz in the result of a_1 (=2.5mm). When the spacing between wires becomes large, the peak frequencies (= 0dB frequency) decreases. And there is a tendency that the transmission band (the transmission bandwidth in -1dB line) becomes large. Also, the transmission coefficient reaches -∞

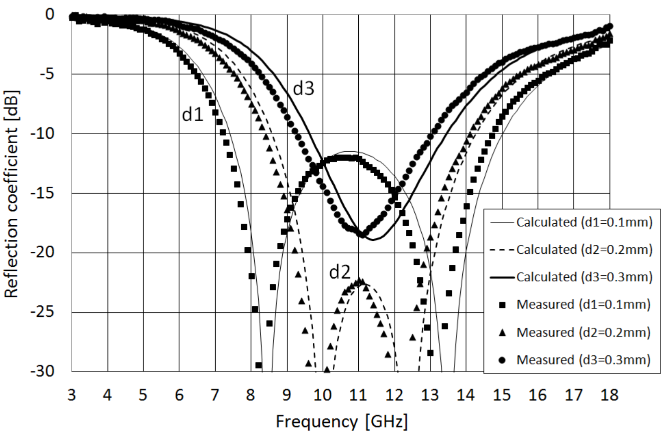


Fig. 7. Measured and calculated reflection coefficients of the laminated structure (b) when the diameter *d* changes (a_2=3.5mm)

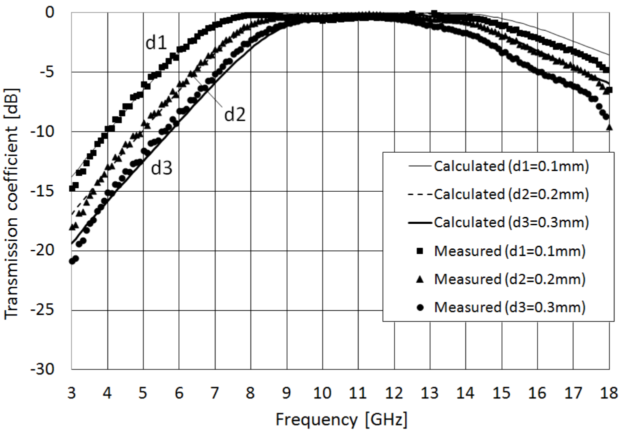


Fig. 8. Measured and calculated transmission coefficients of the laminated structure (b) when the diameter *d* changes (a_2=3.5mm)

TABLE II
PHYSICAL DIMENSIONS OF LAMINATED STRUCTURE (C)

spacing between wires: a		a_1: 2.5mm
		a_2: 3.5mm
		a_3: 5.0mm
		a_4: 7.0mm
diameter of metal wire: d		0.2mm
dielectric film	thickness: b/2	0.1mm
	relative permittivity ε_m	3.2
dielectric layer	thickness: t	5.8mm
	relative permittivity ε_d	6.8

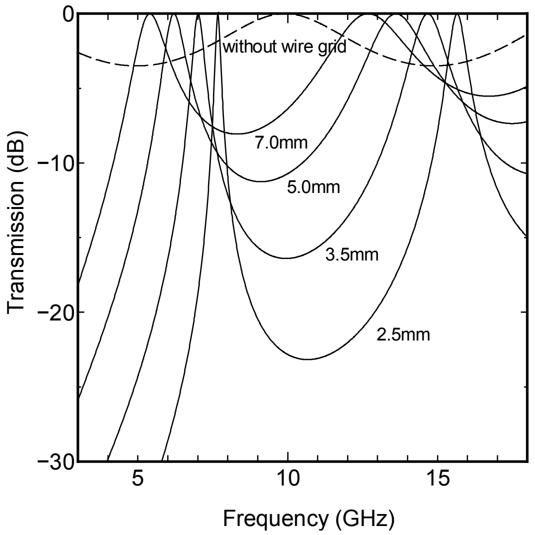


Fig. 9. Calculated transmission coefficients of the laminated structure (c) when the spacing *a* changes (*d*=3.5mm)

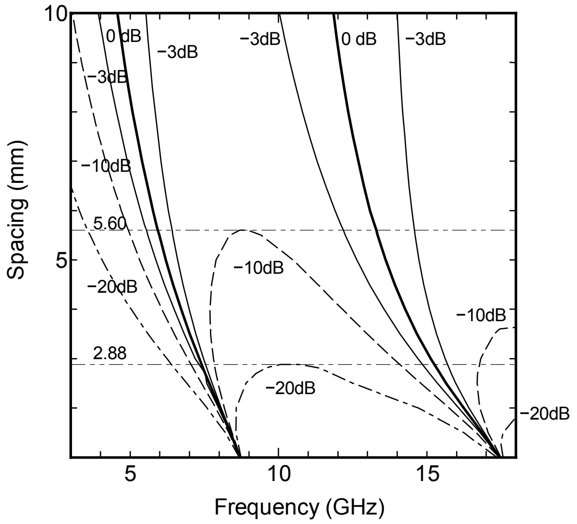


Fig. 10. Calculated transmission coefficients vs. spacing between metal wires

dB as frequency decreases. Fig. 10 shows the result of calculated transmission coefficients vs. spacing between metal wires. From the result, we confirmed that the minimum transmission coefficient becomes less than -20dB when the spacing is lower than 2.88.

Finally, the new laminated structure using the metal wire array sheet will be introduced. The proposed structures (d) and (e) are shown in Fig. 11. In the structures, foam materials (thickness: 5.0mm, relative permittivity: 1.1) were used as the dielectric layer, and parameters *a*, *d* of the sheet are 15mm, 0.2mm, respectively. The total thickness of the sheet is 0.4mm. In these structures, the metal wire array sheet and dielectric layer were increased compared to the structure (c).

Fig. 11 shows the calculated reflection and transmission coefficients. In the results, the transmission results almost equal 0dB above 9 GHz. In contrast, the reflection results become small more than 8 GHz. This indicates that the structure (c), (d), (e) proposed here behave as the high-pass filter. For further investigations, the metal wire parameters dependency of the transmission characteristics of these structures is necessary.

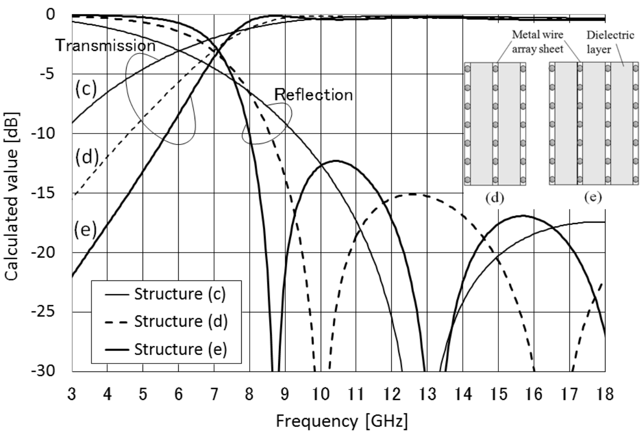


Fig. 11. Calculated reflection and transmission coefficients of the laminated structures (c), (d), (e)

IV. CONCLUSION

The laminated structures using the metal wire array sheet and dielectric layer are proposed. From calculated and measured characteristics, it is confirmed that the reflection and transmission of laminated structures can be controlled by changing the wire array parameters, such as the metal wire diameter and spacing.

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