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A Study on Fabrication and Evaluation of Ferrite Electromagnetic Wave Absorber

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Abstract

According to the progress of the electronic industry and radio communication technologies, mankind might enjoy its abundant life. On the other hand, many social problems such as EMI, and unnecessary electromagnetic wave occur due to the increased use of electromagnetic wave. Therefore, the organiztions such as CISPR, FCC, ANSI, etc. have provided the standard of electromagnetic wave enviroment for the countermeasure of the EMC. It had been required that the absorbing ability of an electromagnetic wave absorber is more than 20 dB, the bandwidth of which is required through 30 MHz to 1,000 MHz for satisfying the international standard about an anechoic chamber for EMI/EMS measurment. From November of 1998, however, the CISPR11 has accepted the extended frequency band from 1 GHz to 18 GHz additionally in the bandwidth of EMI measurement[1]. In this paper, we proposed a new type absorber satisfying the above requirements and carried out broadband design using the equivalent material constants method. Futheremore, the experiments were carried out over the frequency band from 30 MHz to 2 GHz, and hence, the validity of the proposed design theory was confirmed.

Ⅰ. INTRODUCTION

The electromagnetic wave absorber is used to construct an anechoic chamber to test and measure the EMI and EMS, To satisfy, however, the international standard such as ANSI C63.4-1991, CISPR A SEC.109, or IEC 801-3, the absorption ability of electromagnetic wave absorber for anechoic chamber is needed over 20 dB, the bandwidth of which is required through 30 MHz to 18 GHz by the CISPR11[1].

However, a conventional single-layered ferrite absorber composed of the sintered ferrite tiles covers only 30 MHz to 400 MHz under the tolerance limits of 20 dB in absorption. In addition, the grid ferrite electromagnetic wave absorber covers only from 30 MHz to 800 MHz.

In this paper, we proposed a new type ferrite absorber with the cutting cone-shaped ones, which is located on the ferrite tile. The equivalent material constants[2]~[4] of the proposed electromagnetic wave absorber were calculated and designed. The proposed broadband electromagnetic absorber could satisfy the international standard.

Ⅱ. EQUIVALENT MATERIAL CONSTANTS METHOD

2-1 Equivalent Permittivity

When a current flow along the z-direction as shown in Fig. 1, we can calculate the capacitance C per unit length. Here, W is the width of the parallel plate transmission line and g is the distance between the two plates.

The capacitance per unit length is obtained by eq. (1), where ε is the permittivity of the material filled in the transmission line.

$$\frac{C}{a} = \frac{\varepsilon W}{g} \tag{1}$$

If the capacitance filled the plates by vacuum or air between be C_0, the relative equivalent permittivity ε_r is given by eq. (2).

$$\varepsilon_r = \frac{C}{C_0} \tag{2}$$

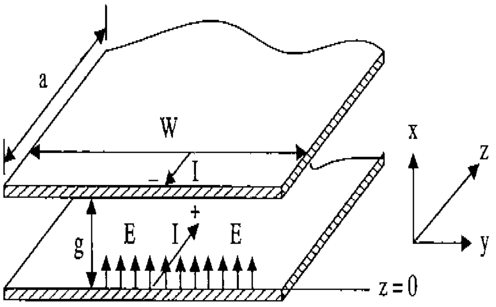

Fig. 1. Parallel Plate Transmission Line.

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2-2 Equivalent Permeability

Similarly, the inductance per unit length in the area of ga is given by eq. (3).

$$\frac{L}{a} = \frac{g\mu}{W} \tag{3}$$

If the inductance filled in the plates by vacuum or air between be L_0, the relative equivalent permeability μ_r is given by eq. (4).

$$\mu_r = \frac{L}{L_0} \tag{4}$$

Ⅲ. DESIGN OF THE WAVE ABSORBER

The proposed wave absorber is shown in Fig. 2. Fig. 3 exhibits a side view and a floor plan of the proposed electromagnetic wave absorber.

As shown in Fig. 2 and 3, it consists of ferrite tile, ferrite post in the cutting cone-shaped type, and cylinder-typed ferrite layer on metal plates. Since the first-layer is tile-typed ferrite filled with ferrite fully, the equivalent permittivity and the equivalent permeability of first-layer are the same as the just ferrite material.

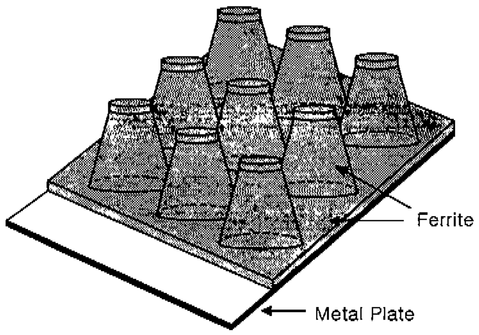

Fig. 2. Bird's eye of the proposed wave absorber.

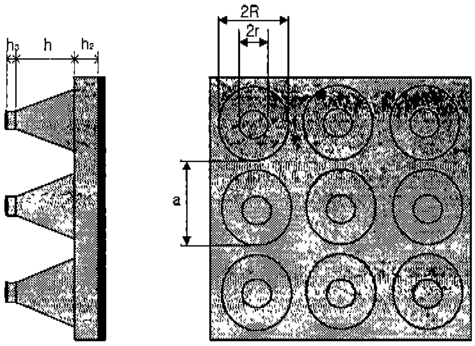

Fig. 3. Side view and floor plan of the proposed wave absorber.

As the 2nd cutting cone-shaped layer and the 3rd cylinder type layer are mixed with ferrite and air parts, we can obtain the effective permittivity and permeability by using the synthesized capacitance and the synthesized inductance models, respectively.

Thus, the equivalent permittivity and permeability of the 2nd-layer can be calculated by using the equivalent circuits as shown in Fig. 4 and 5, respectively. For the 2nd-layer, the equivalent permittivity ε_{eff} and the equivalent permeability μ_{eff} are obtained by eqs. (5) and (6), using Figs. 4 and 5, respectively[5],[6].

$$\begin{aligned}\varepsilon_{eff} &= \frac{a[(a-\Delta t)\varepsilon_r+\Delta t]}{a(x_{n+1}-x_n)\varepsilon_r} \\ &+\frac{[(a-x_n+n\Delta t)(x_{n+1}-x_n)]\varepsilon_r}{a(x_{n+1}-x_n)\varepsilon_r}\end{aligned} \tag{5}$$

$$\begin{aligned}\mu_{eff} &= \frac{a[(a-x_n)\mu_r+(x_n-n\Delta t)]}{a\Delta t\mu_r} \\ &+\frac{(a-x_n+n\Delta t)\mu_r}{a\mu_r}\end{aligned} \tag{6}$$

where, a is a period of the cones, x_n is a radius of a

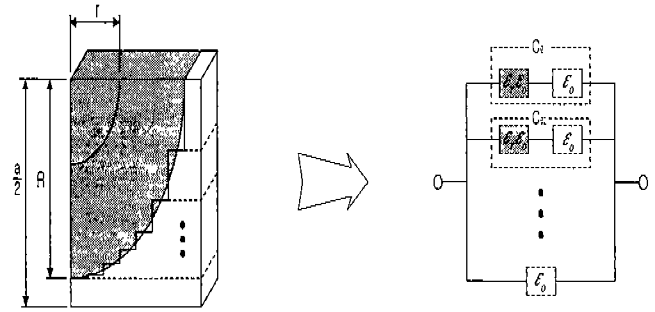

Fig. 4. Equivalent Capacitance model of 2nd layer.

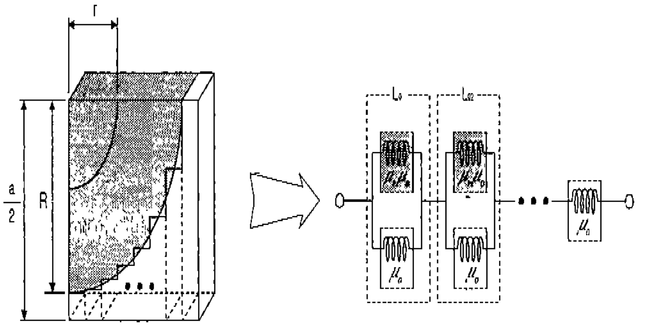

Fig. 5. Equivalent Inductance model of 2nd layer.

n-region and Δt is a thickness of a divided cutting-cone for analysis.

For the 3rd-layer, the basic principle is similar to the cutting cone-shaped type, i.e., except for a 90 degree slope. Therefore, the equivalent permittivity and the equivalent permeability can be obtained by eq. (7) and (8), respectively.

$$\varepsilon_{eff} = \frac{h_1\,\varepsilon_r}{(a-r)\varepsilon_r + r} \tag{7}$$

$$\mu_{eff} = \frac{h_1\,\mu_r}{(a-r)\mu_r + r} \tag{8}$$

where, h_1 is the height of cylinder and r is the radius of cylinder.

Ⅳ. FREQUENCY DISPERSION CHARACTERISTICS OF FERRITE MATERIAL

Since the ferrite wave absorber is used in microwave band, the relative permittivity ε_r of ferrite is almost constant. In this paper, we put $\varepsilon_r = 14$. However, the relative permeability μ_r of ferrite heavily depends on the frequency. Thus, we must note the above point, when the ferrite is used in broad-band.

4-1 Naito's Dispersion Formula

It has been reported that the actual frequency dispersion characteristics for the relative permeability or complex permeability of ferrite, comparatively correspond to that of the formula proposed by Y. Naito[7]. However, as shown in Fig. 6, the serious errors occur between the calculated values and the measured ones of the relative permeability near 100 MHz. Equation (9) shows the Naito frequency dispersion formula.

$$\mu_r = 1 + \frac{\mu_i}{1 + j\dfrac{f}{f_m}} \tag{9}$$

where, μ_i is the initial permeability, f is the used frequency, and f_m is the relaxation frequency.

4-2 Corrected Dispersion Formula

In this section, to obtain simulated result with accuracy, we have proposed the corrected frequency dispersion formula. The equation (10) shows the corrected dispersion formula.

$$\mu_r = \mu' - j\mu'' \tag{10}$$

where,

$$\mu' = 1 + \frac{(\mu_i - 1)}{1 + k_1\,|\,f_1^{\,2} - f_p^{\,2}|^{k_0}\,|\,f^2 - f_p^{\,2}|^{k_0}\,|\,f^2 - f_1^{\,2}|^{k_0} f^{k_0}}$$

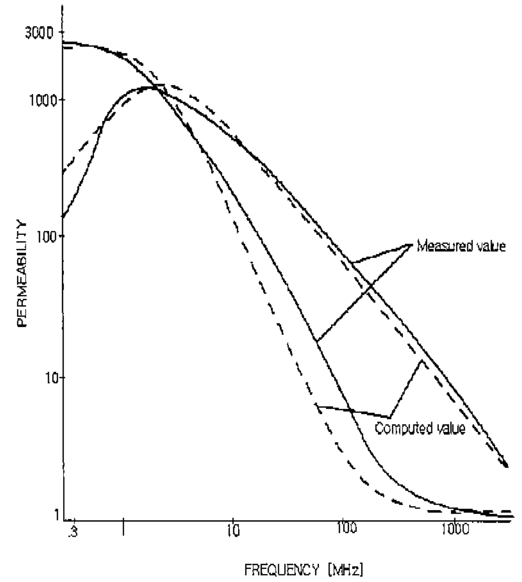

Fig. 6. Comparison of complex permeability between the simulated values by Naito's formula and the measured ones.

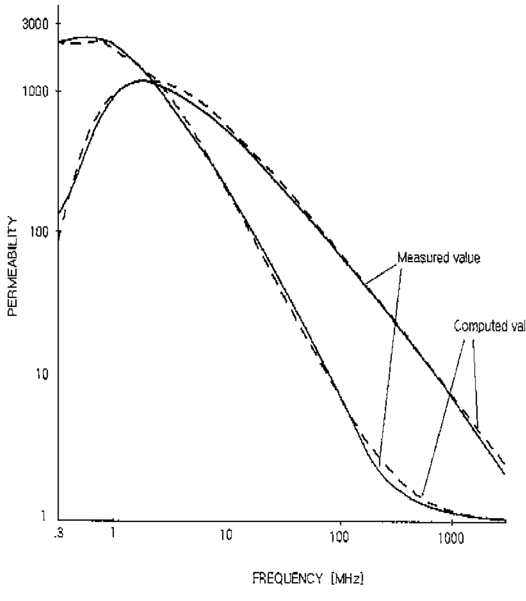

Fig. 7. Comparison of complex permeability between the simulated values of the corrected dispersion fomula and the measured ones.

$$\mu'' = \frac{(\mu_m - 1)[(f - f_s)/f]^6}{1 + k_2(f - f_m)^2/(f f_m)}$$

and μ' depends on μ_i, f_1, f_p, and k_0, as well as μ'' depends on μ_m, f_m, f_s, and k_2. Then all of parameters must be determined by experimental values.

Fig. 7 shows comparison between the calculated values of the corrected frequency dispersion fomula compared to the measured ones. As shown in Fig. 7, the calculated values agree well with the measured ones.

V. FABRICATION AND MEASURED RESULTS

Fig. 8 shows the simulation result for the fabricated wave absorber. Table 1 exhibits the value of simulated wave absorber.

As shown in the simulation result, it was shown clearly that the wave absorber has over 20 dB electromagnetic wave absorption ability in 30 MHz to 100 GHz. Since the total height of the absorber is only 26.5 mm, it is recognized that it has the advantage of expanding effective space in the anechoic chamber when the absorbers used.

Table 2 shows the value of actually produced wave absorber. Fig. 9 shows the measuring set-up, where the strip line used for experiments. Thus the frequency range is limited by 2 GHz.

Fig. 10 shows the actually measured results of produced wave absorber. The measured results agree well with the designed ones in the frequency range in spite of fabrication error.

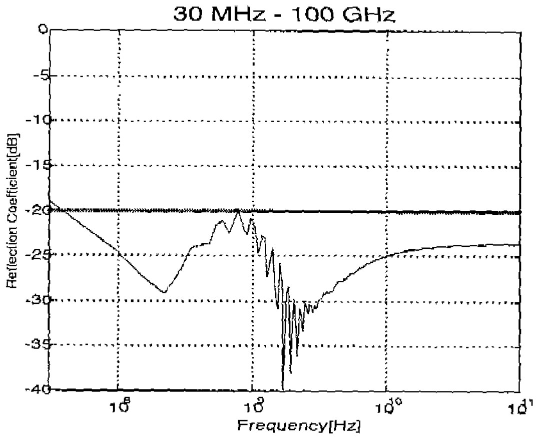

Fig. 8. The frequency characteristics of the simulated wave absorber.

Table 1. Dimensions of the wave absorber used in simulation

Dimension	2R	2r	h	h1	h2	a
Size (mm)	18	10	18	2	6.5	20

Table 2. Dimensions of the wave absorber used in actually fabrication

Dimension	2R	2r	h	h1	h2	a
Size (mm)	18	14	25	2	7.2	20

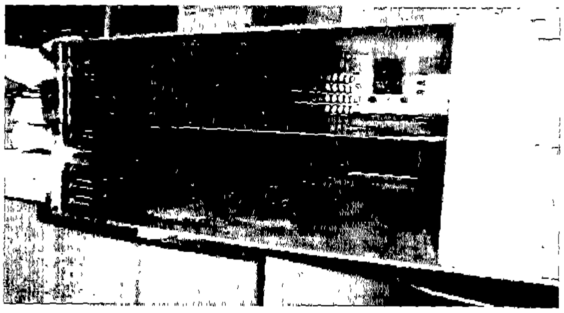

Fig. 9. Experimental Set-up.

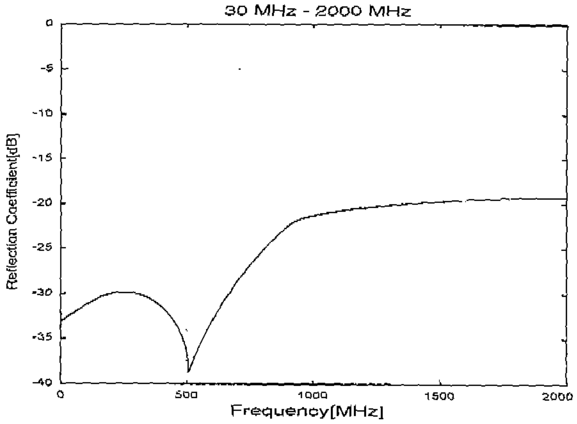

Fig. 10. Measured frequency characteristics of the fabricated wave absorber.

VI. CONCLUSION

In this paper, we have desinged a new-type absorber with broad-band frequency characteristics. The results of a simulation for the proposed absorber show that it has the absorption ability more than 20 dB for electromagnetic wave in 30 MHz to 100 GHz.

REFERENCES

[1] CISPR/B/220/RVC, CISPR11, Nov. 8, 1998.

[2] Dong Il Kim, M. Takashashi, H. Anzai, and S. Y. Jun, "Electromagnetic Wave Absorber with Wide-Band Frequency Characteristics Using Exponentially Tapered Ferrite", *IEEE Trans. EMC*, vol. 38, no. 2, pp.173-177, Feb., 1996.

[3] Dong Il Kim and S. Y. Jun, "Design of Improved Grid Type Electromagnetic Wave absorber Using Exponentially Tapered Ferrite", *Proceedings of the 1996 KJJC-EMCT*, pp.627-630, Sept., 1996.

[4] Dong Il Kim, S. Y. Jun and Se Mo Chung, "The Development of 2nd-layer Broadband Electro- magnetic

Wave Absorber with Cross-Shaped at 2nd-layer", *Proceedings of Korea Electro-Magnetic Engineering Society*, pp.8-13, 1995.

[5] Dong Il Kim, Ch. G. Park and Y. S. Won, "Broad-Band Design of Ferrite Absorbers in Cross-Shaped Projection Type", *Proceedings of Korea Electro-magnetic Engineering Society*, vol. 11, no. 3, pp.372-378, Apr., 2000.

[6] Dong Il Kim, Ch. G. Park, Y. S. Won and Y. G. Lee, "A Study on Development of Ferrite Wave Absorber with Cutting Cone-Shaped Type", *Proceedings of Korea Electro-Magnetic Engineering Society*, vol. 4, no. 2, pp.153-156, Aug., 27, 2000.

[7] Y. Naito et al., "Formulation of frequency dispersion of ferrite permeability", *IEICE Japan*, vol. J59-C, no. 5, pp. 297-304, May, 1976.

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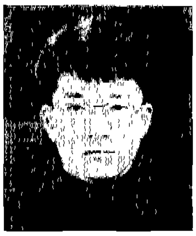

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