Broad-Band Design of Ferrite One-body EM Wave Absorbers for an Anechoic Chamber

Dong Il Kim · June Young Son · Woo Keun Park · Dong Han Choi

Abstract

With the progress of the electronics industry and radio communication technology, certain problems, such as electromagnetic interference(EMI), have arisen due to the increased use of electromagnetic(EM) waves. International organizations such as CISPR, FCC, and ANSI have provided the standards for the EM wave environment and for the countermeasure of the electromagnetic compatibility(EMC). EM wave absorbers are used for constructing an anechoic chamber to test and measure EMI and electromagnetic susceptibility(EMS). In this paper, we have designed an one-body EM(electromagnetic) wave ferrite absorber, based on the equivalent material constants method for both normally and obliquely incident waves, whose absorption abilities are superior to that of the conventional ones. The fabricated absorber has a thickness of 27.68 mm and shows an absorption ability over 20 dB in the frequency from 30 MHz to 6 GHz.

Key words : EMI/EMS, Ferrite Absorber, Anechoic Chamber, EMCM.

Ⅰ. Introduction

With the development of electronics and radio communication technology, the EM wave environment has become complicated and more difficult to control. Organizations such as the International Electro-technical Commission(IEC), Federal Communications Commission (FCC) and the American National Standard Institution(ANSI) have intensified the regulation of EM wave environment for the countermeasure of the EMC for diverse equipments[1]~[4].

In this paper, we propose a new one-body absorber designed by the equivalent material constants method (EMCM) for both normally and obliquely incident waves, which shows better absorption ability than conventional ones.

In addition, the proposed one-body absorber is fire- and water-proof, has a longer lifespan, and does not emit poison gas.

Ⅱ. Design of Multi-Layered Model

Heretofore, to make an EM wave ferrite absorber with broad-band frequency characteristics, attempts were made to change the shape of the absorbers and/or insert an air layer between the ferrite and the metal plate by the combination of several ferrite absorbers with different material constants[5]. Fig. 1 shows a multi-layered absorber with n layers and a metal plate attached at the back. The thickness of i-th layer, the relative permeability, and the relative permittivity are represented by d_i, μ_{ri}, and ε_{ri}, respectively.

When a normal incident plane wave makes contact with the absorber, the normalized impedance z_1, z_2, ⋯, z_i ⋯, z_n can be obtained by eqs. (1), ⋯, (2a), ⋯, and (2b).

$$z_1 = \sqrt{\frac{\mu_{r1}}{\varepsilon_{r1}}} \tanh\left(j\frac{2\pi}{\lambda}\sqrt{\mu_{r1}\varepsilon_{r1}}\, d_1\right) \tag{1}$$

⋮

$$z_i = \sqrt{\frac{\mu_{ri}}{\varepsilon_{ri}}} \frac{z_{i-1} + \sqrt{\frac{\mu_{ri}}{\varepsilon_{ri}}} \tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{ri}\varepsilon_{ri}}\, d_i)}{\sqrt{\frac{\mu_{ri}}{\varepsilon_{ri}}} + z_{i-1}\tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{ri}\varepsilon_{ri}}\, d_i)} \tag{2a}$$

⋮

$$z_n = \sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} \frac{z_{n-1} + \sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} \tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{rn}\varepsilon_{rn}}\, d_n)}{\sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} + z_{n-1}\tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{rn}\varepsilon_{rn}}\, d_n)} \tag{2b}$$

The reflection coefficient S_{11} in the front of the absorber is determined by eq. (3).

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Dept. of Radio Sciences & Engineering, Korea Maritime University, Busan, Korea.

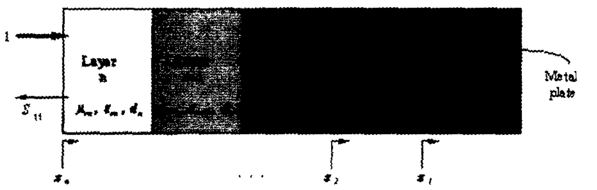


Fig. 1. Multi-layered model for an EM wave absorber.

$$S_{11} = \frac{z_n - 1}{z_n + 1} \tag{3}$$

Usually, a absorber characteristic can be expressed by eq. (4) as the reflectivity R in decibels.

$$R = 20 \log_{10}|S_{11}| \ [\text{dB}] \tag{4}$$

Since the normalized impedance of each layer can be controlled by changing the shape and/or the dimensions of each layer of an absorber, the total impedance can also be controlled by changing the shape and/or dimension of each layer. By using this idea, we designed a broad-band EM wave absorber with superior absorption abilities.

Ⅲ. Equivalent Material Constants Method

3-1 Equivalent Permittivity

When a current flow along the z-direction as shown in Fig. 2, we can calculate the capacitance C per unit length.

The capacitance per unit length is obtained by eq. (5), where ε is the permittivity of the material filled in the transmission line.

$$\frac{C}{a} = \frac{\varepsilon W}{g} \tag{5}$$

If the capacitance filled the plates by vacuum or air between be C_0, the relative equivalent permittivity ε_r is given by eq. (6).

$$\varepsilon_r = \frac{C}{C_0} \tag{6}$$

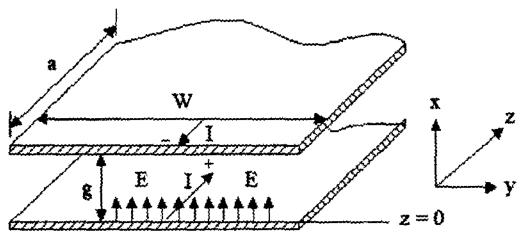


Fig. 2. Parallel plate transmission line.

3-2 Equivalent Permeability

Similarly, the equivalent permeability per unit length L in the ga area is given by eq. (7).

$$\frac{L}{a} = \frac{g\mu}{W} \tag{7}$$

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. (8).

$$\mu_r = \frac{L}{L_0} \tag{8}$$

Ⅳ. Newly Proposed EM Wave Absorber

EM wave absorption abilities increase with sharping tip of pyramid in high frequencies. However, we prepared cutting cone-shaped type with superior EM wave absorption abilities by several times calculation because the pyramid type absorber with sharp tip can be easily broken in manufacturing process and have a high rate of accident.

Fig. 3 show different views of the proposed EM wave absorber. Since the projection layers are composed of ferrite and air, we can obtain the effective permittivity and permeability using the uniformization method.

As shown in Fig. 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. Thus, the equivalent permittivity and permeability of the 3rd-layer can be calculated by using the equivalent circuits. For the 2nd-layer, the equivalent permittivity ε_{eff} and the

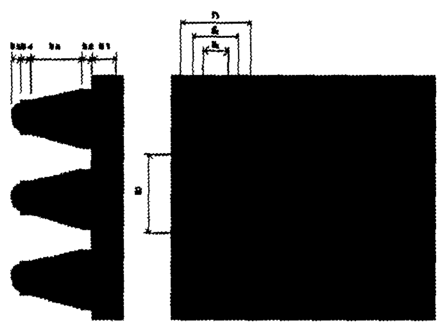


Fig. 3. Side view and floor plan of the newly proposed EM wave absorber.

equivalent permeability μ_{eff} are obtained by eqs. (9) and (10), respectively[6],[7].

$$\varepsilon_{eff} = \frac{a[(a-\Delta t)\varepsilon_r + \Delta t]}{a(x_{n+1}-x_n)\varepsilon_r} + \frac{[(a-x_n+n\Delta t)(x_{n+1}-x_n)]\varepsilon_r}{a(x_{n+1}-x_n)\varepsilon_r} \quad (9)$$

$$\mu_{eff} = \frac{a[(a-x_n)\mu_r + (x_n - n\Delta t)]}{a\Delta t\mu_r} + \frac{(a-x_n+n\Delta t)\mu_r}{a\mu_r} \quad (10)$$

where, a is a period of the cones, x_n is a radius of a n-region and Δt is a thickness of a divided cutting-cone for analysis.

For the 5th-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 eqs. (11) and (12), respectively[6],[7].

$$\varepsilon_{eff} = \frac{h_1 \varepsilon_r}{(a-r)\varepsilon_r + r} \quad (11)$$

$$\mu_{eff} = \frac{h_1 \mu_r}{(a-r)\mu_r + r} \quad (12)$$

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

Table 1 shows the dimensions of the proposed EM wave absorber which are used for the actual fabrication of EM wave absorbers. To obtain the optimized structure, we applied various dimensions to the many structures, repeatedly.

V. Calculation and Measurement

Fig. 4 shows the simulation results of absorption abilities for the proposed EM wave absorber, a tile type absorber, and a grid type absorber. As shown in Fig. 4, the proposed absorber shows better absorption ability than the others[8]~[10]. Fig. 5 shows the calculated values of absorption abilities at 5° and 10° incident angles. Fig. 5(a) shows absorption ability for TE mode and (b) shows absorption ability for TM mode. Fig. 6 shows the calculated values of absorption abilities at 20°, 30°, 45°, 60° and 85° incident angles. Fig. 7 shows pictures of the fabricated EM wave absorber.

Fig. 8 is the comparison between the simulation results using the EMCM and the measurement results for normally incident waves. The horizontal axis pre-

Table 1. The dimensions of the proposed EM wave absorber.

	h1	h2	h3	h4	h5	r1	r2	r3	a
Size (mm)	6.8	1.8	16.5	0.79	2.5	18.05	10.38	7.2	20

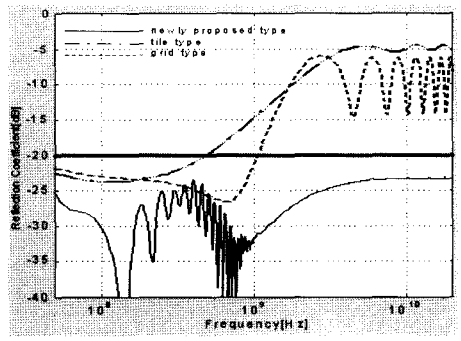
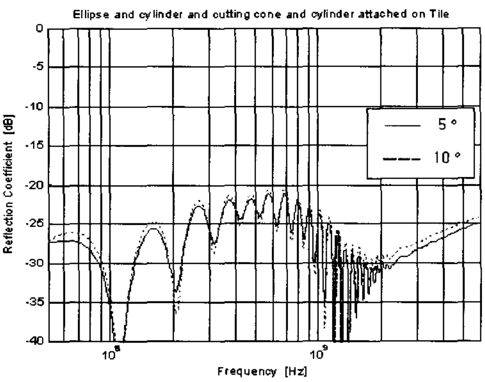
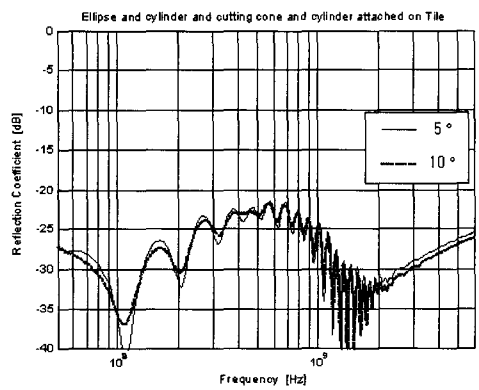


Fig. 4. Comparison of the simulation results between the proposed absorber and the conventional absorbers.

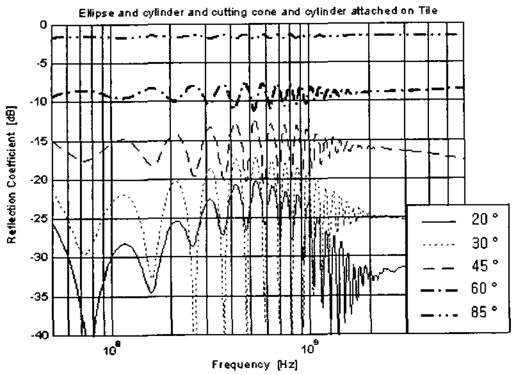


(a) TE mode

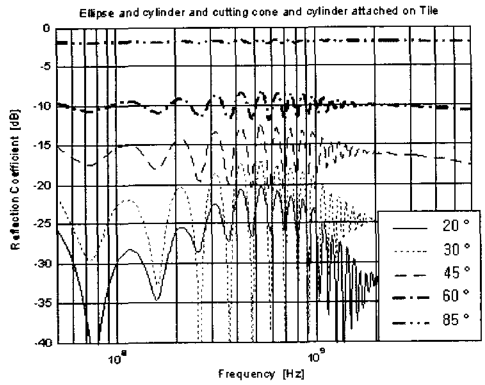


(b) TM mode

Fig. 5. Absorption ability for obliquely incident wave.



(a) TE mode



(b) TM mode

Fig. 6. Absorption ability for obliquely incident wave.

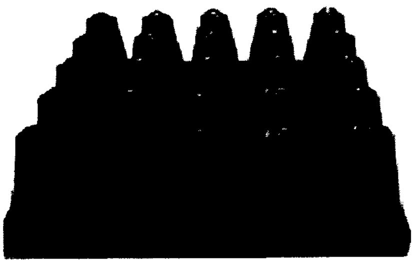


Fig. 7. Fabricated EM wave absorber.

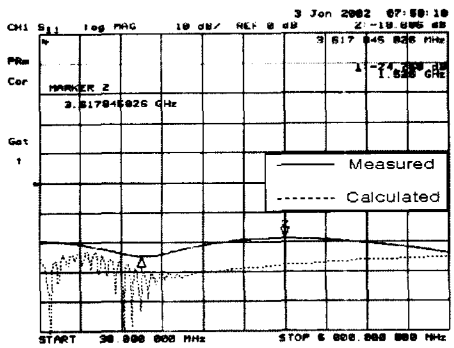


Fig. 8. Comparison of the results between the calculated values and the measured ones.

sents the frequency and the vertical axis is the reflection coefficients. And a notch mark on a scale presents 10 dB and the center line is 0 dB.

As shown in Fig. 8, the results of the calculation and the measurement are very different in the dB scale. However, the difference between the absorbing energies is less than 1 % over the frequence range. So, it was clearly shown that the wave absorber has over 20 dB EM wave absorption ability in the frequency range from 30 MHz to 6 GHz.

Ⅵ. Conclusions

During the course of this research, we have designed a new multi-layer EM wave absorber through the calculation of the absorption abilities for normally and obliquely incident waves. The absorption properties of the proposed EM wave absorbers agree well with the simulated properties in the frequency range from 30 MHz to 6 GHz. In spite of the fact that this is a one-body ferrite absorber, its EM wave absorption properties are superior. And the total height of the absorber is only 27.68 mm, so it has the advantage of expanding the effective space in an anechoic chamber. In addition, the proposed one-body absorber is fire-and water-proof, has a longer lifespan, and does not emit poison gas.

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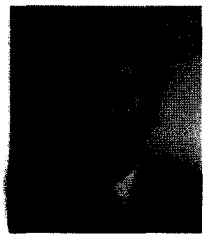
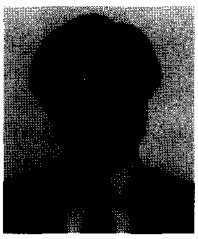
Dong Il Kim



was born in Nonsan, Korea. He received the B.E. and M.E. degrees in nautical science and electronic communications from the Korea Maritime University, in 1975 and 1977, respectively. He received the Ph.D. degree in electronics from the Tokyo Institute of Technology in 1984. Currently, he is professor of the Dept. of Radio Sciences & Engineering at the Korea Maritime University. His research interests include the design of microwave circuits and CATV transmission circuits, development of EM absorber, and EMI/EMC countermeasures.
He received the Academy-Industry Cooperation (A-I-C) Award from Korea A-I-C. Foundation in 1990, Treatise Awards from the Korea Electromagnetic Engineering Society and the Korea Institute of Navigation in 1993 and 1998, and the Korea President's Award from the Promotion of Science and Technology in 1995, respectively. He is a member of IEEE, the Institute of Electronics, Information and Communications of Japan, the IEEC of Korea, the KICS, and the Korea Electromagnetic Engineering Society.

Woo Keun Park

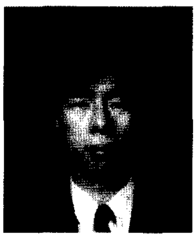


received the B.S. degree in Ulsan University, and the M.S. degree in Dongeui University, Pusan, Korea, in 1993 and 1999, respectively. He is currently pursuing the Ph.D. degree under the supervision of Prof. D. I. Kim at Korea Maritime University, Pusan, Korea. He has been a Technical Operations Dept. Director at the KBS Changwon Headquarters. His research interests include the EMI/EMS, and Broadcasting technology.

June Young Son

was born in Pusan, Korea in 1969. He received the B.S. and M.S. degree in Dongeui University, Pusan, Korea, in 1995 and 1997, respectively. He is currently pursuing the Ph.D. degree under the supervision of Prof. D. I. Kim at Korea Maritime University, Pusan, Korea. His research interests include the design of Electromagnetic Wave Absorber, and EMI/EMC analysis, and mathematical analysis.

Dong Han Choi



was born in Uiseong, Korea in 1969. He received the B.S degree in KyungSung University, Pusan, Korea, in 1998 and the M.S degree in Pukyong National University, Pusan, Korea, in 2000. He is currently pursuing the Ph.D. degree under the supervision of Prof. D. I. Kim at Korea Maritime University, Pusan, Korea. His research interests include the design of Electromagnetic Wave Absorber, and EMI/EMC analysis.