International Journal of Navigation and Port Research
Vol.30, No.2 pp. 161~166, 2006 (ISSN-1598-5725)

A Study on Design and Fabrication of Complex Type EM Wave Absorber with Super Wide-band Characteristics

Dae-Hun Kim · Dong-Il Kim* · Chang-Mook Choi* · Jun-Young Son**

**Department of Radio Science & Engineering, Korea Maritime University, Pusan 606-791, Korea*

Abstract : *In order to construct an Anechoic Chamber satisfying international standards for EMI testing, it has been recognized that the absorption characteristics of the EM wave absorber must be higher than 20 dB over the frequency band from 30 MHz to 18 GHz. In this paper, an EM wave absorber with super wide-band frequency characteristics was proposed and designed in order to satisfy the above requirements by using the Equivalent Material Constant Method(EMCM) and Finite Difference Time Domain(FDTD). The proposed absorber is to attach a pyramidal absorber onto a hemisphere-type absorber on a cutting cone-shaped ferrite. As a result, the proposed absorber has absorption characteristics higher than 20 dB over the frequency band from 30 MHz to more than 20 GHz.*

Key words : *Anechoic chamber, EM wave absorber, Absorption characteristics, Hemisphere type, Complex type*

1. Introduction

With the progress of the electronics industry and radio communication technology, humans enjoy greater freedom in communication. On the other hand, certain problems, such as electromagnetic interference (EMI) and electromagnetic susceptibility (EMS), have arisen due to the increased use of electromagnetic waves. Therefore, finding a countermeasure against unwanted electromagnetic waves has become very important, along with finding the measurements of EMI and EMS. International organizations such as CISPR, FCC, ANSI, etc. have provided the standard for the electromagnetic (EM) wave environment and the countermeasure of electromagnetic compatibility (EMC).

An important application of absorbers is for the construction of an Anechoic Chamber. EM wave absorbers for Anechoic Chambers need broad-band absorption characteristics. In order to satisfy the international standards of Anechoic Chambers for EMI and EMS measurement[1], the absorption characteristics of absorbers must be higher than 20 dB over the frequency band from 30 MHz to 1 GHz. Since November 1998, however, the CISPR11[2] has required that the frequency bandwidth be extended from 1 GHz to 18 GHz. Since the tile ferrite EM wave absorber has an absorption frequency band from 30 MHz to 400 MHz, and the grid ferrite has an absorption frequency band from 30 MHz to 870 MHz[3], and a hemisphere-type absorber on a cutting cone-shaped ferrite, which was developed recently in our laboratory has an absorption frequency band from 30 MHz to 6 GHz, a new EM wave absorber with more wide-band characteristics is needed. Therefore, in this paper, an EM wave absorber with super wide-band frequency characteristics was proposed in order to satisfy the above requirements by using the EMCM[4] and FDTD[5].

2. General guidelines of an EM wave absorber for an Anechoic Chamber

In general, an Anechoic Chamber is used to measure EMI, EMS, and antenna characteristics. The frequency band of the EM wave absorber used in the Anechoic Chamber must have broad-band characteristics in order to satisfy the CISPR11. While tile ferrite and grid ferrite absorbers are insufficient in bandwidth, a carbon urethane foam pyramidal absorber is too large in size and heavy. On the other hand, a hemisphere-type absorber on a cutting cone-shaped ferrite, which was developed recently in our laboratory[6], has an absorption frequency band from 30 MHz to 6 GHz. Therefore, in this paper, the complex-type EM wave absorber is proposed to increase EM wave absorption band.

The proposed EM wave absorber is to attach a pyramidal absorber onto a hemisphere-type absorber on a cutting cone-shaped ferrite in order to improve absorption characteristics.

---

* Corresponding Author : Dae Hun Kim, daehunee@nate.com, 016-9466-5065
** dikim@mail.hhu.ac.kr 051)410-4314
*** navsun@naver.com 055)543-6642
**** daehunee@nate.com 011-863-5418

3. Design

3.1 Hemisphere-type absorber on a cutting cone-shaped ferrite

The Hemisphere-type absorber on a cutting cone-shaped ferrite is shown in Fig. 1 and Fig. 2. To analyze the hemisphere-type absorber on a cutting cone-shaped ferrite, the absorber was divided into multiple thin layers. Then, the equivalent permittivity and the equivalent permeability were calculated by applying the multi-layered model analysis method[6]. Table 1 presents the dimensions of the hemisphere-type absorber on a cutting cone-shaped ferrite. these dimensions were applied to fabricate the Hemisphere-type absorber on a cutting cone-shaped ferrite. Table 1 shows the total height of Hemisphere-type absorber on a cutting cone-shaped ferrite. the total height is 28.3 mm.

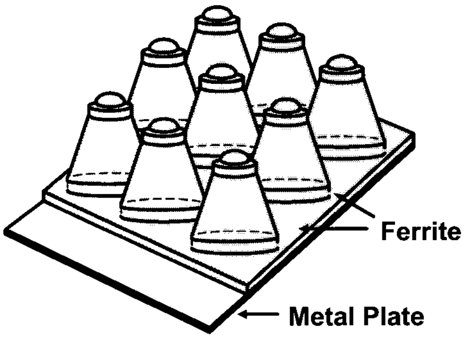


Fig. 1 Bird's eye view of the hemisphere-type absorber on a cutting cone-shaped ferrite.

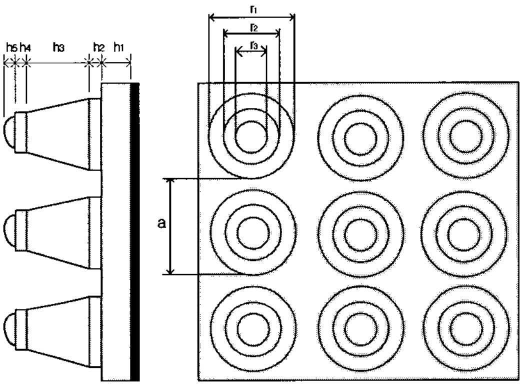


Fig. 2 Side view and floor plan of the EM wave absorber.

Table 1 The dimensions of the hemisphere-type absorber on a cutting cone-shaped ferrite.

	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

When the multi-layered model is applied to this absorber, the normalized input impedance of the first layer, $\hat{z}_1$, is calculated by eq. (1), where ε_{r1}, μ_{r1} and d_1 are the equivalent permittivity of the first layer, the equivalent permeability, and the thickness, respectively.

$$\hat{z}_1=\sqrt{\frac{\mu_{r1}}{\varepsilon_{r1}}}\ tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{r1}\varepsilon_{r1}}d_1) \tag{1}$$

After calculating the input impedance repeatedly, the normalized impedance from the i-th layer, $\hat{z}_i$, is calculated by eq. (2).

$$\hat{z}_i=\sqrt{\frac{\mu_{ri}}{\epsilon_{ri}}}\ \frac{\hat{z}_{i-1}+\sqrt{\frac{\mu_{ri}}{\epsilon_{ri}}}\ tanh(j\frac{2\pi}{\sqrt{\mu_{ri}}}\epsilon_{ri}d_i)}{\sqrt{\frac{\mu_{ri}}{\epsilon_{ri}}}+\hat{z}_{i-1}tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{ri}\epsilon_{ri}}\,d_i)} \tag{2}$$

In the same method, the normalized input impedance from the last layer is calculated by eq. (3), which is the input impedance from the top of the hemisphere type absorber.

$$\hat{z}_n=\sqrt{\frac{\mu_{rn}}{\epsilon_{rn}}}\ \frac{\hat{z}_{n-1}+\sqrt{\frac{\mu_{rn}}{\epsilon_{rn}}}\ tanh(j\frac{2\pi}{\sqrt{\mu_{rn}}}\epsilon_{rn}d_n)}{\sqrt{\frac{\mu_{rn}}{\epsilon_{rn}}}+\hat{z}_{n-1}tanh(j\frac{2\pi}{\lambda}\sqrt{\mu_{rn}\epsilon_{rn}}\,d_n)} \tag{3}$$

2. Complex type EM wave absorber

2.1 design method using EMCM

The complex type EM wave absorber is shown in Fig. 2. This absorber has a pyramidal-type absorber[7] attached on top of a hemisphere type absorber on a cutting cone-shaped ferrite. Fig. 3 shows a side view and a floor plan of the complex-type EM wave absorber.

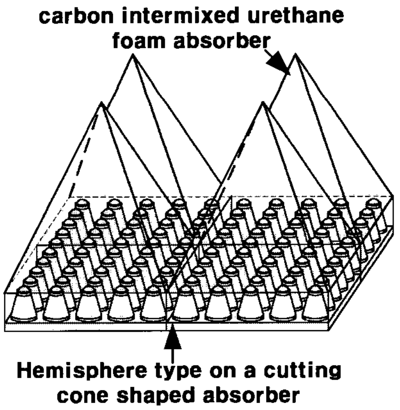
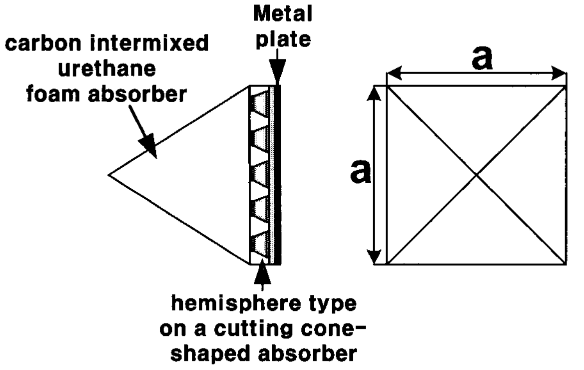


Fig. 3 Bird's eye view of the complex type EM wave absorber.



(a) side view (b) top view

Fig. 4 Side view and top view of the complex type absorber

A carbon urethane absorber can be analyzed by the synthesized capacitance model[1] for the calculation of the equivalent permittivity, such as in Fig. 4.

To analyze the absorber, we have only to consider the area denoted by the dashed line in Fig. 4(b), because the array is symmetrical in the x and y directions.

The synthesized capacitance model is shown in Fig. 5. By using Fig. 5, each capacitance is calculated by eqs. (4)~(6) and the total capacitance C is calculated by eq. (7).

$$C_1 = \epsilon_o \epsilon_r \frac{d/2 \cdot \Delta z}{d/2} = \epsilon_o \epsilon_r \Delta z \tag{4}$$

$$C_2 = \frac{d/2 \epsilon_o \Delta z}{(1/2)(a-d)} = \frac{d \epsilon_o \Delta z}{(a-d)} \tag{5}$$

$$C_3 = \frac{(1/2)(a-d)\, \epsilon_o \Delta z}{a/2} = \frac{(a-d)\, \epsilon_o \Delta z}{a} \tag{6}$$

$$C = \left\{ \frac{(a-d)}{a} + \frac{\epsilon_r d}{(a-d)\epsilon_r + d} \right\} \epsilon_o \Delta z \tag{7}$$

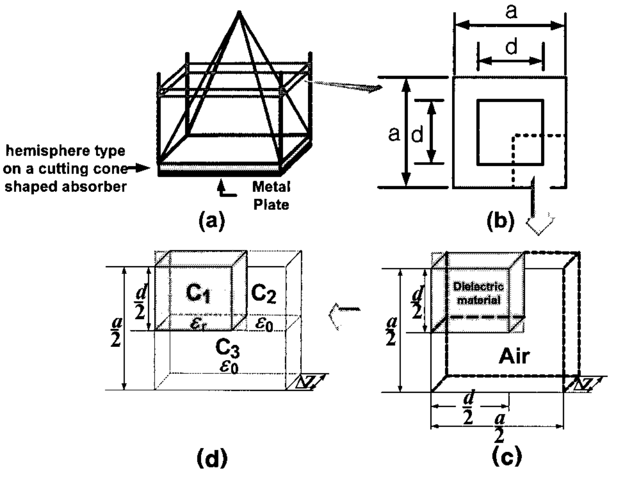


Fig. 5 Capacitance model of carbon uretane absorber for calculation of the equivalent permittivity.

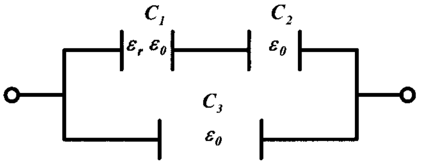


Fig. 6 Synthesized capacitance model.

The equivalent permittivity with thickness is calculated using eq. (9) by substituting eq. (7) into eq. (8).

$$\epsilon_{eq} = \frac{C}{\epsilon_o \Delta z} \tag{8}$$

$$\epsilon_{eq} = \frac{(a-d)}{a} + \frac{\epsilon_r d}{(a-d)\epsilon_r + d} \tag{9}$$

Then, the complex-type EM wave absorber can be analyzed with the multi-layered model. The multi-layered model of the complex type EM wave absorber is illustrated in Fig. 6, where ε_r, μ_r' and d are the equivalent permittivity of each layer, the equivalent permeability, and the thickness, respectively.

The normalized input impedance from the last layer of a hemisphere type absorber on a cutting cone-shaped ferrite is $\hat{z}_f$ in Fig. 6. The normalized input impedance of the first layer of the pyramidal absorber is calculated by eq. (10).

$$\hat{z}_{p1} = \sqrt{\frac{1}{\epsilon_{r1}}}\, \frac{\hat{z}_f + \sqrt{\frac{1}{\epsilon_{r1}}}\, tanh(j\frac{2\pi}{\lambda}\sqrt{\epsilon_{r1}}\, d_1)}{\sqrt{\frac{1}{\epsilon_{r1}}} + \hat{z}_f\, tanh(j\frac{2\pi}{\lambda}\sqrt{\epsilon_{r1}}\, d_1)} \tag{10}$$

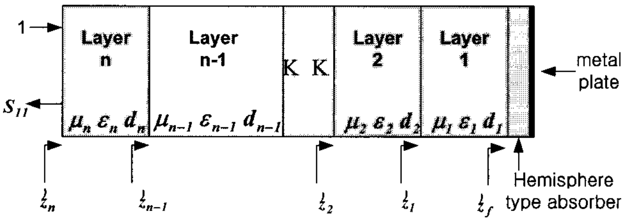


Fig. 7 Multi-layered Model of the complex type EM wave absorber.

By calculating repeatedly, the normalized input impedance from the last layer of the pyramidal absorber is calculated by eq. (11).

$$\hat{z}_{pn} = \sqrt{\frac{1}{\epsilon_{rn}}}\, \frac{\hat{z}_n + \sqrt{\frac{1}{\epsilon_{rn}}}\, tanh(j\frac{2\pi}{\lambda}\sqrt{\epsilon_{rn}}\, d_n)}{\sqrt{\frac{1}{\epsilon_{rn}}} + \hat{z}_n tanh(j\frac{2\pi}{\lambda}\sqrt{\epsilon_{rn}}\, d_n)} \tag{11}$$

The final Reflection coefficient is obtained by eq. (12)

using the normalized impedance $\hat{z}_n$.

$$S_{11} = \frac{\hat{z}_{pn} - 1}{\hat{z}_{pn} + 1} \tag{12}$$

2.2 design method using FDTD

The reflection coefficient is simulated by calculating of the reflection from a Gaussian derivative pulse normally on the EM wave absorber. The Gaussian derivative pulse is incident from the right on the proposed EM wave absorber.

The time dependent general form of Maxwell's curl Equations are

$$\nabla \times H = \frac{\partial D}{\partial t} \tag{13}$$

$$D(\omega) = \varepsilon_0 \cdot \epsilon_r(\omega) \cdot E(\omega) \tag{14}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{15}$$

$$B(\omega) = \mu_0 \cdot \mu_r(\omega) \cdot H(\omega) \tag{16}$$

where D is the electric flux density, E is the electric field, B is the magnetic flux density, and H is the magnetic field. We are dealing with a lossy dielectric and magnetic medium of the form

$$\varepsilon_r = \epsilon_r + \frac{\sigma}{j\omega\epsilon_0} \tag{17}$$

$$\mu_r = 1 + \frac{K_r}{1 + j\dfrac{\omega}{\omega_r}} \tag{18}$$

where ϵ_r is the constant permittivity, σ is the conductivity, μ_r is the constant permeability, ω is the driving frequency, ω_r is the relaxation frequency, and K_r is the initial relative permeability. The actual frequency dispersion characteristics for the relative permittivity or complex permittivity of the lossy dielectric medium has been reported to correspond to that of the formula proposed by Debye formulation. Eq. (17) shows Debye's frequency dispersion formula for the permittivity. The actual frequency dispersion characteristics for the relative permeability or complex permeability of the ferrite has been reported to correspond to that of the formula proposed by Naito. Eq. (18) shows Naito's frequency dispersion formula for the permeability.

The normalized Maxwell's Equation, Eqs. (13)~(16) can be written as

$$\nabla \times \tilde{H} = \sqrt{\epsilon_0\mu_0}\,\frac{\partial \tilde{D}}{\partial t} \tag{19}$$

$$\tilde{D}(\omega) = \epsilon_r(\omega) \cdot \tilde{E}(\omega) \tag{20}$$

$$\nabla \times \tilde{E} = -\sqrt{\epsilon_0\mu_0}\,\frac{\partial \tilde{B}}{\partial t} \tag{21}$$

$$\tilde{B}(\omega) = \mu_r(\omega) \cdot \tilde{H}(\omega) \tag{22}$$

These normalized Equations are used with the normalization parameters

$$\tilde{E} = \sqrt{\epsilon_0}\,E \tag{23}$$

$$\tilde{D} = \frac{1}{\sqrt{\epsilon_0}}\,D \tag{24}$$

$$\tilde{H} = \sqrt{\mu_0}\,H \tag{25}$$

$$\tilde{B} = \frac{1}{\sqrt{\mu_0}}\,B \tag{26}$$

In a three dimensional simulation, we deal with six different fields $\tilde{E}_x$, $\tilde{E}_y$, $\tilde{E}_z$, $\tilde{H}_x$, $\tilde{H}_y$ and $\tilde{H}_z$. In a one dimensional simulation, we choose the transverse magnetic (TM) mode which is composed of $\tilde{E}_x$ and $\tilde{H}_y$. We will write the vector components of the curl operator in Eqs. (19)~(22) to yield the following system of three coupled scalar equation in a one dimensional rectangular coordinate system.

$$\frac{\partial \tilde{D}}{\partial t} = \frac{1}{\sqrt{\epsilon_0\mu_0}}\,\nabla \times \tilde{H} \tag{27}$$

$$\tilde{D}(\omega) = \epsilon_r(\omega) \cdot \tilde{E}(\omega) \tag{28}$$

$$\frac{\partial \tilde{H}}{\partial t} = -\frac{1}{\sqrt{\epsilon_0\mu_0}}\,\nabla \times \tilde{E} \tag{29}$$

$$\tilde{B}(\omega) = \mu_r(\omega) \cdot \tilde{H}(\omega) \tag{30}$$

We assume that the FDTD modeling space is partially filled with a lossy dielectric material and with a ferrite as an absorber. Then the finite difference scheme results for the TM mode are given by the following difference equations.

$$\frac{\tilde{E}_x^{n+1/2}(k)-\tilde{E}_x^{n-1/2}(k)}{\Delta t} = \frac{1}{\epsilon_r\sqrt{\epsilon_0\mu_0}}\cdot\frac{\widetilde{H}_y^{n}(k-1/2)-\widetilde{H}_y^{n}(k+1/2)}{\Delta x} \tag{31}$$

$$\frac{\widetilde{H}_y^{n+1}(k+1/2)-\widetilde{H}_y^{n}(k+1/2)}{\Delta t} = -\frac{1}{\mu_0}\frac{\tilde{E}_x^{n+1/2}(k+1)-\tilde{E}_x^{n+1/2}(k)}{\Delta x} \tag{32}$$

The propagation of a distance of one cell requires a minimum time of $\Delta t=\frac{\Delta x}{\sqrt{2}C_0}$ by the Courant Condition in a one dimensional simulation. where Δt is the time step, Δx is the distance and C_0 is the velocity of light.

The electric parameters of each medium are the relative permittivity ϵ_r and the relative permeability μ_r. When the ferrite absorber is used in the microwave-band, the relative permittivity of the ferrite is almost constant. Similarly, the relative permeability of the lossy dielectric medium is almost constant.

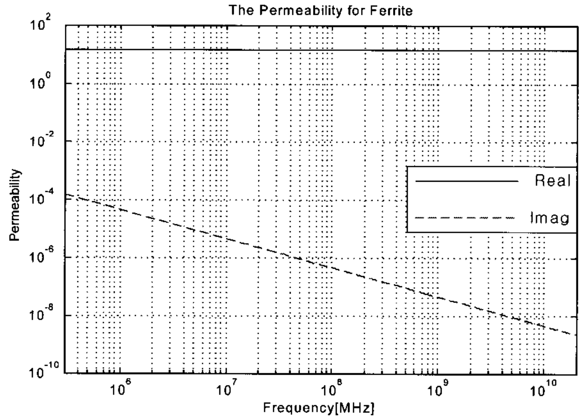


Fig. 8 The complex permitivitty of Ferrite material

Fig. 8 shows the complex permitivitty of Ferrite material. In Fig. 8, we know the real permitivitty is about 14. and the imaginary permitivitty is about 0. So, in this paper, we put ϵ_r=14 in the ferrite region and μ_r=1 in the lossy dielectric medium. However, the relative permeability μ_r of ferrite region and the relative permittivity ϵ_r of lossy medium region depend strongly on the frequency. We also calculated the effective permeability and permittivity by using the EMCM and FDTD simulation.

4. Simulated and measured results

The absorption characteristics of the proposed EM wave absorber were measured by a network analyzer and a rectangular coaxial waveguide in the time domain. Fig. 7 presents the rectangular coaxial waveguide system for measuring the absorber.

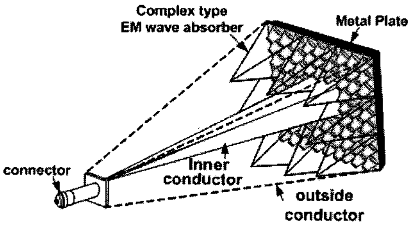


Fig. 9 Rectangular coaxial waveguide system for measuring the absorption ability of absorber.

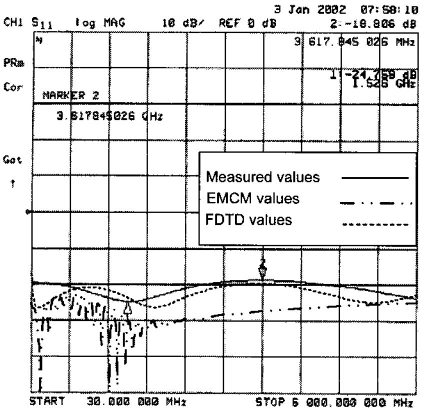


Fig. 10 Comparison of EMCM simulation and measurement of the hemisphere type absorber on a cutting cone-shaped ferrite.

The simulated and measured results of the hemisphere type absorber on a cutting cone-shaped ferrite are shown in Fig. 8, where the solid line represents the measured results and the dotted line represents the simulated ones. From Fig. 8 we can see that the hemisphere type absorber on a cutting cone-shaped ferrite has absorption characteristics higher than 20 dB over the frequency band from 30 MHz to 6 GHz.

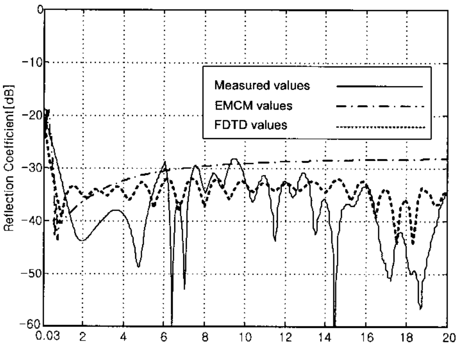


Fig. 11 Comparison of EMCM simulation and measurement of the complex type EM wave absorber.

The simulated and measured results of frequency responses for the proposed super wide-band complex-type EM wave absorber are shown in Fig. 9, where the solid line represents the measured results and the dotted line represents the simulated ones. The optimum height of the carbon urethane foam pyramidal absorber is 150 mm with 34% carbon loading.

Compared with the absorption characteristics of the hemisphere-type absorber on a cutting cone-shaped ferrite, the complex-type EM wave absorber has absorption characteristics higher than 20 dB over the frequency band from 30 MHz to more than 20 GHz.

5. Conclusion

In this paper, the super wide-band complex-type EM wave absorber for an Anechoic Chamber was proposed. The complex-type EM wave absorber is composed of a pyramidal type absorber attached onto a hemisphere type absorber on a cutting cone-shaped ferrite. The optimum height of a pyramidal absorber is 150 mm with 34% carbon loading and the height of a hemisphere type on a cutting cone-shaped ferrite absorber is 28.3 mm. The complex-type EM wave absorber has absorption characteristics higher than 20 dB over the frequency band from 30 MHz to more than 20 GHz.

Acknowledgments

This research was supported by the MIC, Korea, under the ITRC support program supervised by the IITA (IITA-2005-(C1090-0502-0014))

References

[1] CISPR11. (1997), "ISM radio frequency equipment electromagnetic disturbance characteristics limits & methods of measurement", IEC, pp.12-15.

[2] Christoper L. Holloway, Ronald R. Delyser, Robert F. German, Paul Mckenna, and Motohisa Kanda. (1997), "Comparison of Electromagnetic Absorber Used in Anechoic and Semi-Anechoic Chamber for Emissions and Immunity Testing of Digital Device", IEEE Trans. on Electromagnetic Compatibility, vol. 39, no. 1, pp. 33-47.

[3] Dennis M. Sullivan. (2000) "Electromagnetic Simulation Using the FDTD method", IEEE Press series on RF and Microwave Technology.

[4] Kim, D. I. Kim, S. T., Park, J. Y. and Chung, S. M., (1995), "A comparative study on measuring methods of absorption characteristics for electromagnetic wave absorber using Time Domain Method", Proceedings of Korea EMC/EMI Society, vol. 6, pp. 11-18.

[5] Kim, D. I., Michiharu Takahashi, Hiroki Anzai, Sang Y. J..(1996), "Electromagnetic wave absorber with wide-band frequency characteristics using exponentially tapered ferrite", IEEE Trans. On electromagnetic compatibility, vol. 38, no. 2, pp. 173-177.

[6] Naito, Y. et al. (1993), "Characteristics of grid ferrite electromagnetic wave absorber", IEICE of Japan, vol. J76-B-II, No. 11, pp. 898-905.

[7] Son, J. Y., Kim, D. I.,(2003), "A study on absorption characteristics of Hemisphere type on cutting cone shaped absorber for obliquely incident EM waves", 2003 Asia-Pacific Microwave Conference, Sheraton Walkerhill Hotel, Seoul, Korea, Vol. 01, pp. 53-56.

Received 28 February 2006
Accepted 28 March 2006