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Broad-Band Design of Ferrite Absorber in Cross-Shaped Projection Type

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SUMMARY With the progress of the electronics industry and radio communication technology, humans enjoy greater freedom in communicating. On the other hand, certain problems, such as electromagnetic interference (EMI), have arisen due to the increased use of electromagnetic (EM) waves. EM wave absorbers are used for constructing an anechoic chamber to test and measure EMI and electromagnetic susceptibility (EMS). Prior to 1998, international standards for anechoic chambers required that EM wave absorbers should absorb more 20 dB in the bandwidth from 30 MHz to 1,000 MHz. Since November 1998, however, the Comit International Special des Perturbations Radioelectrigne (CISPR) has required that the frequency bandwidth be extended from 1 GHz to 18 GHz for EMI measurement by the CISPR11 [1]. In this work, wide-band EM wave absorbers were designed by a theoretical model using the equivalent material constants method (EMCM) [2]. We designed a cross-shaped absorber which has a bandwidth from 30 MHz to above 2 GHz under the tolerance limit of −20 dB in reflection, the results of which were compared with the results analyzed using the finite-difference time-domain method (FDTD) [3]. The tapered cross-shaped absorber was also designed, which has a bandwidth from 30 MHz to 26 GHz under the same tolerance limit.
key words: *ferrite absorber, EMI/EMS, CISPR11, EMCM*

1. Introduction

With the development of electronics and radio communication technology, the electromagnetic wave environment has become complicated and more difficult to control. Organizations such as the International Electrotechnical Commission (IEC), the CISPR, the Federal Communications Commission (FCC), and the American National Standard Institution (ANSI) have provided the standards for the EM wave environment and for the countermeasure of the EMC.

In the past, these organizations required EM wave absorbers to be able to absorb more than 20 dB in a bandwidth from 30 MHz to 1 GHz (IEC 61000-4-3 [4], CISPR A SEC.109 [5], and/or ANSI C63.4-1991 [6]) for EMI/EMS measurements. Since November 1998, however, the CISPR11 has required that the frequency bandwidth be extended from 1 GHz to 18 GHz for EMI measurement [1].

At present, a single-layered absorber composed of sintered ferrite tiles covers only 30 MHz to 400 MHz under the tolerance limit of −20 dB in reflection, and a grid-type absorber covers the bandwidth from 30 MHz to 780 MHz within the same tolerance limit [7] and [8]. This does not satisfy the standard of CISPR11; therefore, the development of a new EM wave absorber is needed to satisfy international standards.

In this research, the EMCM was used to design cross-shaped absorbers [2], [9] and [10], which have a bandwidth from 30 MHz to 3 GHz under the tolerance limit of −20 dB in reflection. The results tend to agree with the results analyzed using the FDTD method. In addition, we designed a tapered cross-shaped absorber with a height of 28.6 mm, which expanded the bandwidth from 30 MHz to 26 GHz under the tolerance limit of −20 dB. The proposed absorbers could be fabricated without difficulty by creating a one-body molding without assembling each layer.

2. Equivalent Material Constants of Cross-Shaped Wave Absorber

2.1 Equivalent Permittivity and Permeability

We propose a cross-shaped EM wave absorber to enable absorption across a wider frequency band. The proposed wave absorber is composed of two layers on a metal plate as shown in Fig. 1.

When the period of an absorbing structure is small compared to the wavelength, the periodic structure can

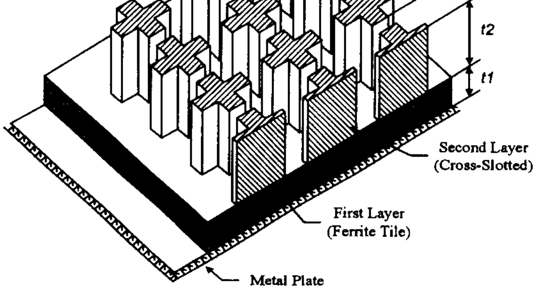

Fig. 1 Cross-shaped electromagnetic wave absorber.

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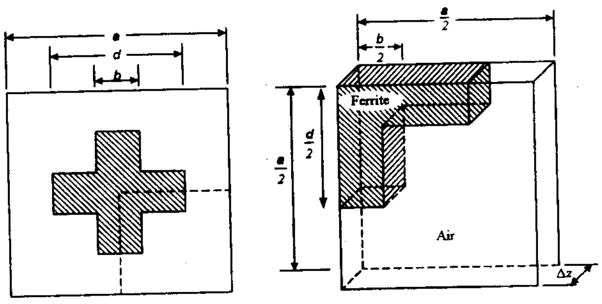
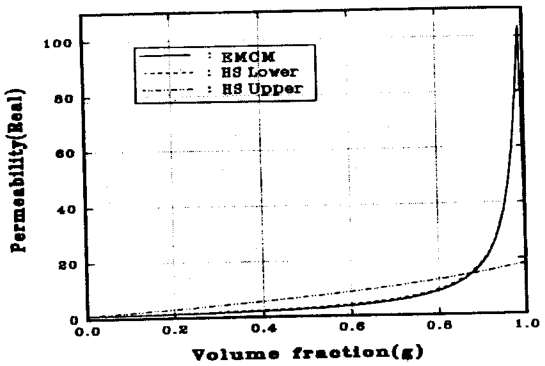
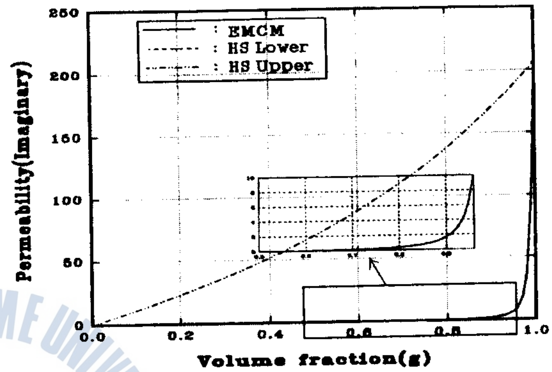


(a) One-cell (b) A quarter cell

Fig. 2 A model for calculation of equivalent material constants.



(a)



(b)

Fig. 3 (a) A comparison of equivalent permeability with HS values for $K = 2500$, $f_m = 2.5$ MHz (Real part at 30 MHz). (b) A comparison of equivalent permeability with HS values for $K = 2500$, $f_m = 2.5$ MHz (Imaginary part at 30 MHz).

be replaced by an effective medium as indicated by homogenization [11]–[14].

It is possible to apply the FDTD method (at arbitrary frequencies and in close proximity to an array of absorbing media) to the computation of the EM field with a high degree of accuracy. However, it is computationally very intensive and does not lend itself readily to the design of the absorber [12], [13]. Thus, asymptotic methods are used to analyze the mechanism of EM wave interaction with an array of absorbers.

Figure 2 shows a model for the calculation of equivalent material constants in which the periodic structure is replaced by an effective medium by homogenization. By virtue of the symmetry of each cell and array as shown in Fig. 2(a), we can find the equivalent permittivity by analyzing just the quarter cell shown in Fig. 2(b) [2] and [9]–[13]. Thus, the equivalent relative permittivity ε_{eq} for the second layer with the thickness t_2 is expressed as

$$\varepsilon_{eq} = \varepsilon_r \left\{ \frac{b}{\varepsilon_r(a-d)+d} + \frac{\varepsilon_r(d-b)}{\varepsilon_r(a-b)+b} + \frac{a-d}{\varepsilon_r a} \right\} \tag{1}$$

where ε_r is the relative permittivity of the ferrite.

The equivalent relative permeability μ_{eq} for the second layer can be represented by the reference of 2, 9, and 10.

$$\mu_{eq} = \mu_r \left\{ \frac{b}{\varepsilon_r(a-d)+d} + \frac{\mu_r(d-b)}{\mu_r(a-b)+b} + \frac{a-d}{\mu_r a} \right\} \tag{2}$$

where μ_r is the relative permeability of the ferrite.

2.2 Comparison with the Hashin-Shtrikman Bounds

To confirm the validity of the EMCM, we compared the equivalent permeability with the Hashin-Shtrikman (HS) bounds [15] and [16], the results of which are shown in Fig. 3. Figure 3(a) and (b) show comparisons between the equivalent permeability of the EMCM and the HS bounds for the sample where the initial permeability $K = 2500$ and the relaxation frequency $f_m = 2.5$ MHz. These figures indicate that the equivalent permittivity of the EMCM agree very well with that of the HS lower bound.

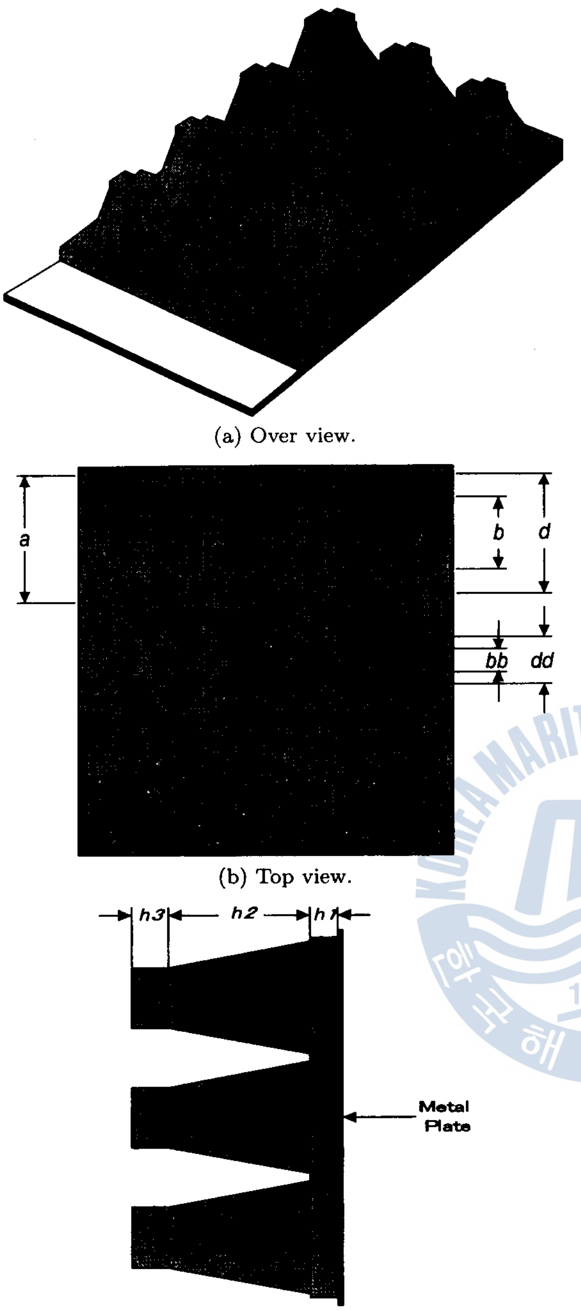
Figure 3 clearly shows that the Hashin-Shtrikman gives the correct effect to material property at the lower bound since the air is surrounded with a high-density material in the second layer.

3. Design of the Tapered EM Wave Absorber in Cross-Shaped Type

The design and analysis of a tapered EM wave absorber is very similar to that of a cross-shaped one. Figure 4 shows the shape of the proposed wave absorber, which has three different sections. The top section has a height of h_3, the middle tapered section has a height of h_2, and the bottom section, which rests on a metal plate, has a height of h_1.

To calculate the equivalent material constant for the tapered layer, we apply the multi-layer analysis method [1], [9], [10], and [17]. When we assume that the tapered layer is divided into n layers with thickness Δz as shown in Fig. 5, we can obtain the equivalent material constants for the i-th layer in the same way as for a cross-shaped type.

The equivalent permittivity ε_{eq}^{i} for the i-th layer



(a) Over view.

(b) Top view.

(c) Front view.

Fig. 4 Tapered cross-shaped electromagnetic wave absorber.

in the tapered layer is expressed as Eq. (3).

$$\varepsilon_{eq}^{i}=\varepsilon_r\left\{\begin{array}{l}\dfrac{d-ip}{\varepsilon_r(a-d+ip)+(d-ip)}\\+\dfrac{d-b}{(a-b+ip)\varepsilon_r+(b-ip)}+\dfrac{a-(d-ip)}{\varepsilon_r a}\end{array}\right\} \tag{3}$$

where $p=(b-bb)/2n$.

On the other hand, the equivalent relative permeability μ_{eq}^{i} for the i-th layer in the tapered layer is expressed as Eq. (4).

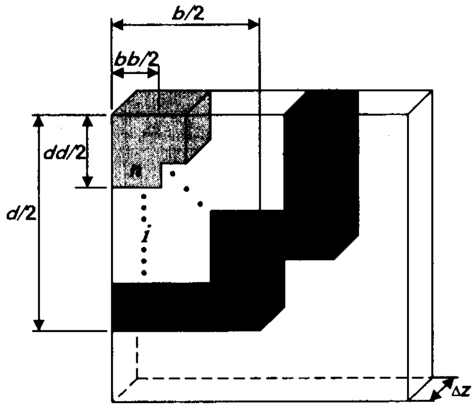


Fig. 5 A model for calculation of equivalent material constants.

$$\mu_{eq}^{i}=\mu_r\left\{\begin{array}{l}\dfrac{d-ip}{\mu_r(a-d+ip)+(d-ip)}\\+\dfrac{d-b}{(a-b+ip)\mu_r+(b-ip)}+\dfrac{a-(d-ip)}{\mu_r a}\end{array}\right\} \tag{4}$$

In the same manner, the equivalent relative permittivity ε_{eq} for the top layer with the thickness h_3 is given by Eq. (5).

$$\varepsilon_{eq}=\varepsilon_r\left\{\begin{array}{l}\dfrac{bb}{\varepsilon_r(a-dd)+dd}\\+\dfrac{\varepsilon_r(dd-bb)}{\varepsilon_r(a-bb)+bb}+\dfrac{a-dd}{\varepsilon_r a}\end{array}\right\} \tag{5}$$

The equivalent relative permeability μ_{eq} for the top layer with the thickness h_3 is given by Eq. (6).

$$\mu_{eq}=\mu_r\left\{\begin{array}{l}\dfrac{bb}{\mu_r(a-dd)+dd}\\+\dfrac{\mu_r(dd-bb)}{\mu_r(a-bb)+bb}+\dfrac{a-dd}{\mu_r a}\end{array}\right\} \tag{6}$$

4. Results and Discussions

4.1 Characteristics of the Cross-Shaped Wave Absorber

The characteristics of the cross-shaped wave absorber were calculated using the multi-layer analysis method [1], [9], [10] and Eq. (7). Equation (7) is the formula of frequency dispersion of the complex permeability [18].

$$\mu_r=1+\frac{K}{1+j(f/f_m)} \tag{7}$$

where ε_r, K, and f_m are the relative permittivity, the initial permeability, and the relaxation frequency of the ferrite, respectively.

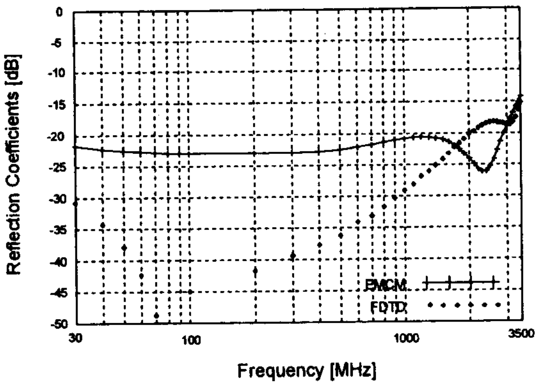
Table 1 shows the material constants of ε_r, K, and f_m, the dimensions of the designed cross-shaped wave

Table 1 Design parameters and absorption ability of cross-shaped electromagnetic wave absorber.

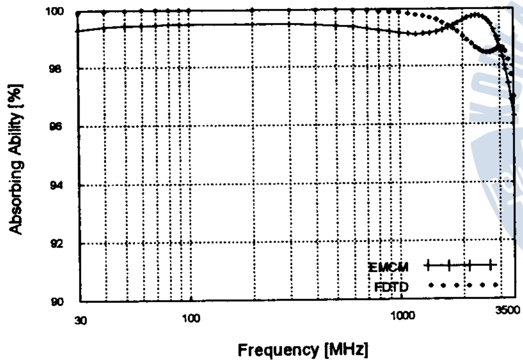
Material constant	Dimensions (mm)					20 dB frequency range
	t_1	t_2	a	b	d	
ε_r=14.0 K=2,500 f_m= 2.5 MHz	6.6	17	20	16.2	6	30 MHz~3 GHz

Table 2 Design parameters of a tapered cross-shaped EM wave absorber.

Material Constant	Dimensions (mm)							
	a	dd	d	b	bb	h1	h2	h3
ε_r=14.0 K=2,000 f_m= 3.1 MHz	20	19	8.3	12.4	5.3	6.4	18	4.2



(a) Reflection coefficients in dB.



(b) Absorbing ability of EM wave energy in %.

Fig. 6 The characteristics of the cross-shaped electromagnetic wave absorber.

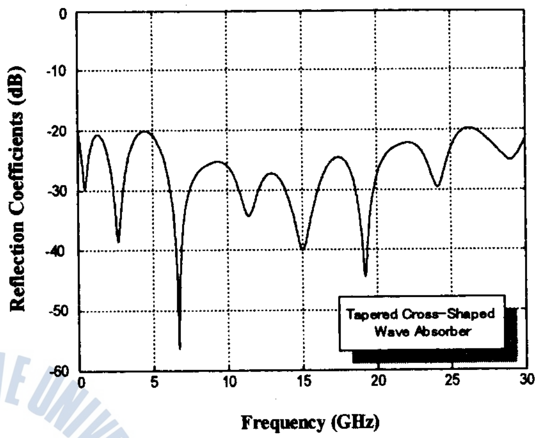


Fig. 7 The characteristics of the tapered cross-shaped EM wave absorber calculated by the EMCM.

absorber, and the frequency range above 20 dB absorption.

The periodic structure can be replaced by an effective medium as indicated by homogenization. At that time, the EMCM [2], [5], and [6] is available only when the period of an absorbing structure is small compared to the wavelength. In high frequency, however, the period of the absorbing structure is relatively large compared to the wavelength. Thus, we compared the results of the EMCM with those of the FDTD [11] analysis to verify the accuracy of the EMCM.

Figure 6(a) shows the reflection coefficients in dB, and Fig. 6(b) shows the absorbing ability of EM wave energy in % for the designed wave absorber. As shown in Fig. 6(a), the results of the EMCM and the FDTD analyses are very different in the dB scale. In Fig. 6(b), however, we can see that the difference between the absorbing energies calculated by the EMCM and the FDTD analyses is less than 1% over the frequency range. Since, however, the goal is to obtain an absorption ability above 99%, the difference of absorption ability within 1% is not a problem. Thus, we can say that the experimental results between the EMCM and the FDTD analyses for an EM wave absorber tend to agree [19]. Therefore, the design of an EM wave absorber using the EMCM is recommended.

As shown in Fig. 6, the absorber designed by the EMCM has excellent characteristics across the frequency band from 30 MHz to 3 GHz under the tolerance limit of −20 dB in reflection. The results of the FDTD analysis show that the bandwidth from 30 MHz to above 2 GHz is under the tolerance limit of −20 dB in reflection.

4.2 Characteristics of the Tapered Cross-Shaped Wave Absorber

We also proposed a tapered cross-shaped EM wave absorber and designed it with the dimension shown in Table 2. Figure 7 shows the reflection coefficients versus frequency for the designed wave absorber by the EMCM.

The results obtained by using the EMCM show that the bandwidth from 30 MHz to 26 GHz is under the tolerance limits of −20 dB in reflection. In addition, the total height is only 28.6 mm. However, when frequencies higher than 3 GHz are reached, it must be confirmed whether or not the EMCM is exact. This will require further experiment.

5. Conclusion

In this paper, we proposed and designed a cross-shaped wave absorber which has a height of only 28.6 mm and has a bandwidth from 30 MHz to 3 GHz under the tolerance limit of −20 dB in reflection. The results of its absorption abilities were compared with those using the FDTD analysis and showed that, under the same tolerance limit, the designed absorber has a bandwidth from 30 MHz to 3 GHz using the EMCM analysis and from 30 MHz to above 2 GHz using the FDTD analysis.

Moreover, a tapered cross-shaped EM wave absorber was also proposed and designed by the EMCM, which has a bandwidth from 30 MHz to 26 GHz under the tolerance limits of −20 dB in reflection. It is expected that the designed wave absorber will be used for the construction of an anechoic chamber or GTEM Cell and for the test EMI/EMS, and EMC/EMI countermeasure products among other things.

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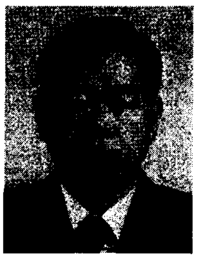

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