論文97-34D-4-2

테이퍼부를 가지는 초광대역 페라이트 전파흡수체

(Electromagnetic Wave Absorber with Wide-Band Frequency Characteristics Using Exponentially Tapered Ferrite)

金東一*, 全相燁**

(Dong Il Kim and Sang Yup Jun)

요약

공간적으로 형상이 변화하는 테이퍼구조의 초광대역 페라이트 전파흡수체의 설계법을 제안하고 설명하였다. 한편, 공간적으로 페라이트의 형상이 변화하는 부분의 특성은 등가재료정수법을 이용하는 해석모델을 개발하여 근사적인 방법으로 해석하였다. 개발한 이론해석모델을 이용하여 30MHz에서 2,150MHz 혹은 2,430MHz의 주파수범위에서 -20dB미만의 반사감쇠량을 가지는 전파흡수특성이 뛰어난 페라이트 전파흡수체를 설계하였다.

Abstract

A wide band design method of an electromagnetic wave absorber with using exponentially tapered ferrite is proposed and discussed. A theoretical model using the equivalent material constants method is also proposed to analyze the regions varying spatially in the shape of ferrite. Based on the developed model, wide band electromagnetic wave absorbers with excellent reflectivity frequency characteristics in the frequency range of 30MHz to 2,150MHz or 2,430MHz were designed.

I. Introduction

Electromagnetic Interference(EMI) becomes very serious problem to the office automation, the factory automation, etc.. Thus, for a counter-measure of EMI or EMC, various electromagnetic wave absorbers are applicable to their uses.

Nowadays, one of the main purpose of the electromagnetic wave absorber is to make an anechoic chamber for checking or measuring the leakage of electromagnetic wave radiated by electronic equipments.

To satisfy the regulation, e.g., ANSI C63.4-1991, CISPR A SEC.109, or IEC 801-3 the performance of an anechoic chamber should be available to measure EMI over the frequency range 30-1000MHz or 3GHz upper.

The anechoic chambers have been frequently lined with arrays of pyramid cone dielectric materials.

In recent years, ferrite lined compact anechoic chamber has been developed by improved ferrite characteristics. Despite the small test site size, it was found that the data measured in this chamber were in good agreement with those in open field test site.

---

* 正會員, 韓國海洋大學校 電波工學科

(Department of Radio Sciences and Engineering, Korea Maritime University)

** 正會員, 韓國海技硏修院

(Korea Marine Training and Research Institute)

接受日字:1995年7月21日, 수정완료일:1997年3月20日

Up to now, single-layer ferrite absorber has been used for suppressing various kinds of electromagnetic interference. However, the applications have been restricted by the narrow band characteristics. It covers only frequency band from 30MHz to 400MHz[1],[2].

On the other hand, the useful frequency bandwidth of a grid type ferrite absorber has been broadened from 30MHz to 780MHz[1].

However, these absorbers are still limited to satisfy the adequate performance for the anechoic chamber.

For the above purpose, super wide-band electromagnetic wave absorber is designed with tapered ferrite material. In analyzing the exponentially tapered ferrite arrays, the equivalent material constants method has been proposed and adopted. Thus, the bandwidth from 30MHz up to 2,150MHz or 2,430MHz has been obtained, and it has been found that the developed electromagnetic wave absorber is to be applicable to various uses.

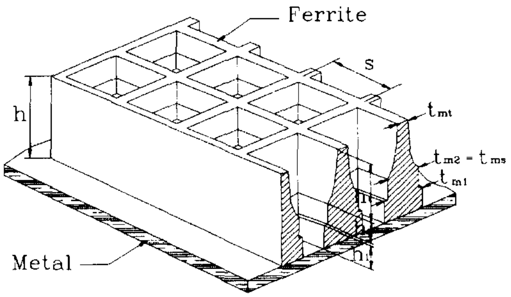


그림 1. 제안안 초광대역 전파흡수체의 외형

Fig. 1. The Typical Shape of a Wide band Ferrite Electromagnetic Wave Absorber Proposed in this Paper.

II. Equivalent material constants method

Fig.1 shows a wide-band ferrite electromagnetic wave absorber which is composed of periodic arrays of exponentially tapered ferrite. When the period of an absorber array is small compared to a wavelength, then the periodic structure can be replaced by an effective medium as indicated by homogenization[3]-[7].

The direct numerical approaches to the problem of computing the electromagnetic field in the vicinity of an array of absorbing medium using finite-difference time-domain method and spatial network method are capable of high accuracy at arbitrary frequencies, but are computationally very intensive and do not lend themselves readily to the design of the absorber[5],[8].

Thus, asymptotic methods are used to analyze the mechanism of electromagnetic wave interaction with an absorber array.

The proposed ferrite electromagnetic wave absorber is to be approximated as multilayered structure as shown in Fig.2.

The shape of the unit layer is the same as grid type absorber shown in Fig.3.

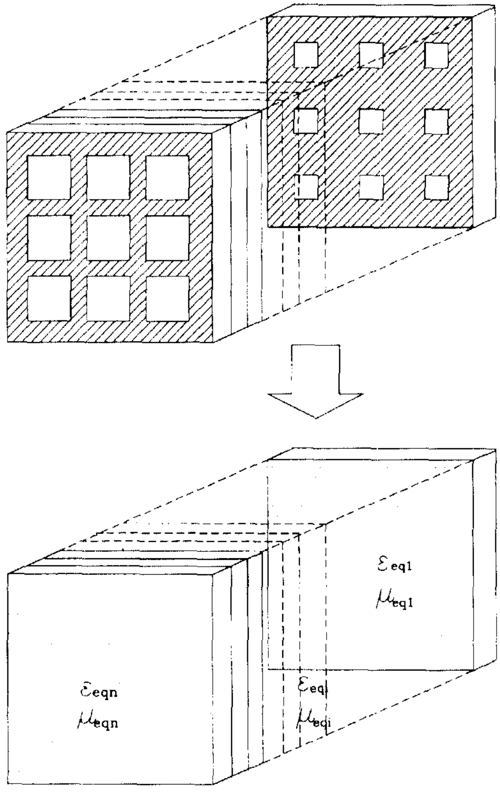


그림 2. 테이퍼형 전파흡수체의 다층근사 구조

Fig. 2. Multi-layered asymptotic structure for the tapered ferrite electromagnetic wave absorber.

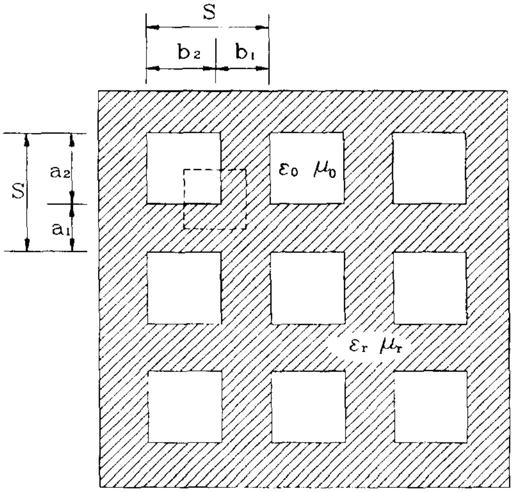


그림 3. 테이퍼형 전파흡수체의 횡단면도
Fig. 3. The unit structure of the tapered ferrite electromagnetic wave absorber(Cross Section of XY Plane).

The properties and frequency characteristics of the grid ferrite absorber are shown in[8]. In Fig.3, S is the period in the X,Y direction, a_1, b_1 and a_2, b_2 are the widths of area occupied by the ferrite and air respectively, ε_r and μ_r are the relative complex parameters of the bulk ferrite, and ε_0 and μ_0 are those of free space.

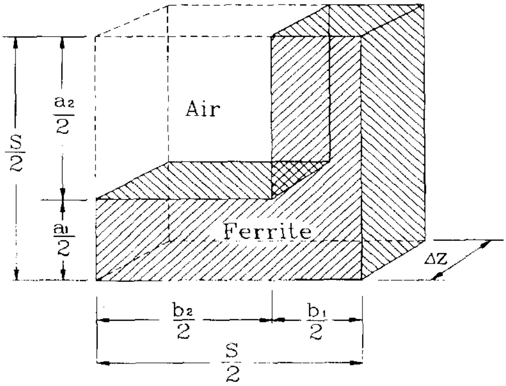


그림 4. 등가재료정수 모델
Fig. 4. A Model for Calculation of Equivalent Material Constants.

To study the properties of the absorber we have only to consider the area closed a dashed line shown in Fig.3 because the arrays are symmetrical in the X,Y directions.

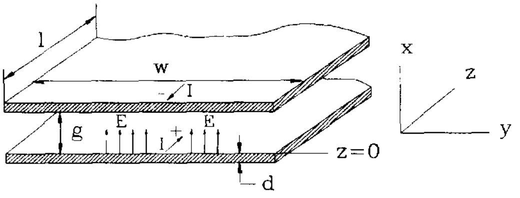


그림 5. 평행판 전송선로
Fig. 5. A Parallel Plate Transmission Line.

The properties of the unit layer are to be analyzed using synthesized capacitance and inductance model shown in Fig.4.

First, let us calculate the capacitance and the inductance per unit length in the z-direction in a parallel plate transmission line as shown in Fig. 5, where the width is w in the y-direction, the length is l in the z-direction, the gap between the plates is g and the current flows in the z-direction. Then the capacitance per unit length is given by[9]

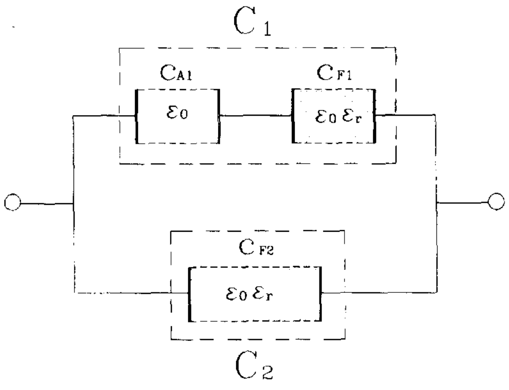


그림 6. 합성용량 모델
Fig. 6. A Synthesized Capacitance Model.

$$\frac{C}{l} = \frac{\varepsilon w}{g} \tag{1}$$

where C is the total capacitance between the parallel plates and ε is the permittivity of the material filled in the transmission line. On the other hand, the inductance per unit length is given by

$$\frac{L}{l} = \frac{g\mu}{w} \tag{2}$$

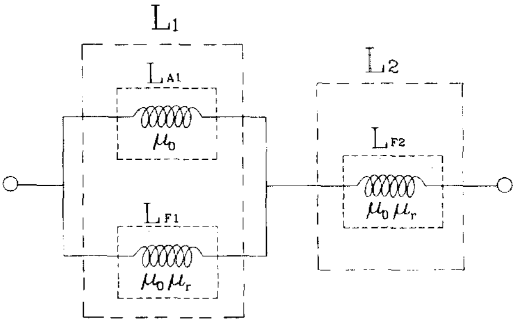


그림 7. 합성인덕턴스 모델
Fig. 7. A Synthesized Inductance Model.

where L is the total inductance between the parallel plates and μ is the permeability of the material filled in the transmission line.

Now, the calculation method can be extended to the model as shown in Fig.4 which is used later for designing the wide band electromagnetic wave absorber proposed in this paper.

If the metal plates were placed left and right in Fig.4 we can make a synthesized capacitance model as shown in Fig.6. The total synthesized capacitance C is then found as follows by subdividing the cell into areas of homogeneous material, computing the capacitance of these subcells, and then combining these in series and parallel.

$$C = \frac{C_{A1}\,C_{F1}}{C_{A1} + C_{F1}} + C_{F2}$$

$$= \frac{\varepsilon_o \varepsilon_r \Delta z\{b a_2 + a_1(b_1 + b_2\varepsilon_r)\}}{b(b_1 + b_2\varepsilon_r)} \tag{3}$$

where, $C_{A1} = \frac{\varepsilon_o a_2 \Delta z}{b_2}$

$$C_{F1} = \frac{\varepsilon_o \varepsilon_r a_2 \Delta z}{b_1}$$

$$C_{F2} = \frac{\varepsilon_o \varepsilon_r a_1 \Delta z}{b}$$

$$b = b_1 + b_2$$

Thus, the equivalent permittivity ε_{eq} for the structure with thickness Δz as shown in Fig.4 is given by

$$\varepsilon_{eq} = \frac{bC}{\varepsilon_o a \Delta z} \tag{4}$$

Substituting eq.(3) into eq.(4), the equivalent permittivity ε_{eq} for the structure is given by

$$\varepsilon_{eq} = K_H\varepsilon_r + \frac{(1-K_H)\varepsilon_r}{K_E + (1-K_E)\varepsilon_r} \tag{5}$$

where, $K_H = \frac{a_1}{a_1 + a_2}$ $K_E = \frac{b_1}{b_1 + b_2}$ (6)

Next, let L be the self-inductance of the area in Fig.5.

Then, the magnetic flux across the area of gl is given by

$$\Phi = B_y g l \tag{7}$$

and the magnetic flux density B_y is given by

$$w B_y = \mu I \tag{8}$$

The self-inductance L is given by

$$L I = \Phi \tag{9}$$

Since the self-inductance L is defined by

$$L\frac{dI}{dt} = \frac{d\Phi}{dt} \tag{10}$$

From eqs.(7),(8) and (9), the inductance per unit length L/l is given by

$$\frac{L}{l} = \frac{g\mu}{w} \tag{11}$$

Assuming that all field fringing is neglected, in the same manner as the above, we can make a synthesized inductance model as shown in Fig.7. The total synthesized inductance L is calculated by extending eq.(11). Then,

$$L = \frac{L_{A1}\,L_{F1}}{L_{A1} + L_{F1}} + L_{F2}$$

$$= \frac{\mu_o \mu_r \Delta z\{a b_2 + b_1(a_1 + a_2\mu_r)\}}{a(a_1 + a_2\mu_r)} \tag{12}$$

where, $L_{A1} = \frac{\mu_o b_2 \Delta z}{a_2}$

$$L_{F1} = \frac{\mu_o \mu_r b_2 \Delta z}{a_1}$$

$$L_{F2} = \frac{\mu_o \mu_r b_1 \Delta z}{a}$$

$$a = a_1 + a_2$$

Thus, the equivalent permeability μ_{eq} for the structure with thickness Δz shown in Fig.4 is given by

$$\mu_{eq} = \frac{aL}{\mu_0 b \Delta z} \tag{13}$$

Substituting eq.(12) into eq.(13), the equivalent permeability μ_{eq} for the structure is given by

$$\mu_{eq} = K_E \mu_r + \frac{(1-K_E)\mu_r}{K_H + (1-K_H)\mu_r} \tag{14}$$

The above method is also described in the references[3] [7],[9]-[13] and referred to as the equivalent material constants method.

The frequency characteristics of the grid type ferrite absorber by the prescribed method agree well with the measured ones[1] as shown in Fig.8.

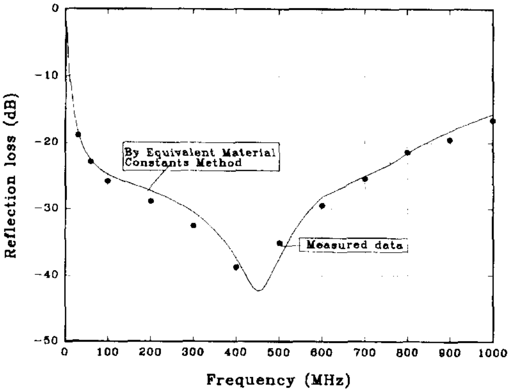


그림 8. 격자형 전파흡수체의 반사주파수 특성

Fig. 8. Reflectivity Frequency Characteristics of the Grid Type Absorber.
(Period(S) = 19.8mm, Ferrite part(a_2) = 4.4mm, Thickness = 27.5mm)

Using these methods, therefore, we are able to predict the effective properties of artificial medium from a knowledge of their geometry and material properties of their constituents.

Ⅲ. Design of wide-band electromagnetic wave absorbers

As discussed in the previous section, we are able to try out different absorber design in an attempt to vary the geometry and bulk material parameter of the absorber.

The proposed electromagnetic wave absorber is composed of ferrite material only, the typical shape of which is the same as Fig.1 and the cross section of which is the same as Fig.9.

Suppose that the tapered region with height h_t varies exponentially as shown in Fig.9 and the cross section of the tapered region is divided equally into n-2 layers, then, in the i-th layer the dimensions corresponding to the model for calculation of equivalent material constants shown in Fig.4 are given by

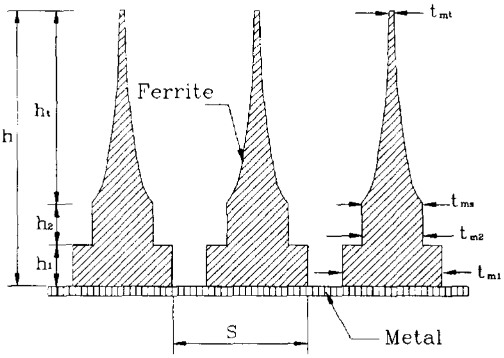


그림. 9. 테이퍼형 전파흡수체의 종단면도

Fig. 9. Cross Section of the Electromagnetic Wave Absorber shown in Fig.1.

when i is 1,

$$x_1 = \frac{t_{m1}}{2} \quad y_1 = \frac{t_{m1}}{2} \tag{15}$$

$$z_1 = \frac{h_1}{2}$$

and when i is 2,

$$x_2 = \frac{t_{m2}}{2}$$

$$y_2 = \frac{t_{m2}}{2} \tag{16}$$

$$z_2 = h_1 + \frac{h_2}{2}$$

and when i is equal or greater than 3,

$$\begin{aligned} x_i &= \frac{1}{2}(t_{ms}-Q)e^{-k(z_i-h_1-h_2)}+\frac{Q}{2} \\ y_i &= \frac{1}{2}(t_{ms}-Q)e^{-k(z_i-h_1-h_2)}+\frac{Q}{2} \qquad (17) \\ z_i &= h_1+h_2+\frac{h_t}{N-2}\left\{(i-3)+\frac{1}{2}\right\} \end{aligned}$$

since x_i is corresponding to $b_i/2$, y_i is to $a_i/2$ and z_i is the center position of the i-th layer respectively. In the eq.(17), N depicts the number of total layers, Q depicts the minimum width of the end tip of the tapered region, and

$$k = \frac{P}{h_t} \qquad (18)$$

where P is an arbitrary number to determine the shape of the tapered region.

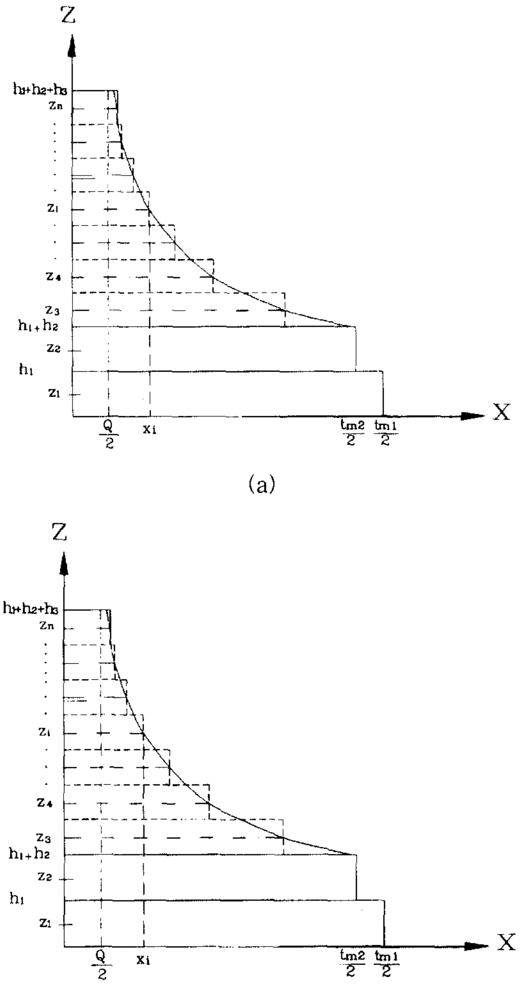


그림 10. z축 방향의 단면 등분할
(a) x-축 (b) y-축
Fig. 10. Divided Cross Sections in z-Direction.
(a) For x-axis (b) For y-axis

The relative permeability of the ferrite is assumed to be described by the following dispersion equation in the frequency range under consideration[14]

$$\mu_r = 1 + \frac{K}{(1+j\frac{f}{f_m})} \qquad (19)$$

where, f is an operating frequency, K is relative permeability in DC and f_m is relaxation frequency. Its permittivity ε_r is considered constant. The sintered ferrite used here is characterized by the parameters K=2500, f_m=2.5MHz, and ε_r=14.0

Now, we can design a wide-band ferrite electromagnetic wave absorber[15],[16], since we can control the permittivity and permeability at the same time by use of the spatial shape varying technique of electromagnetic wave absorber.

Ⅳ. Results

By changing the geometric dimensions of tapered ferrite region as well as thickness of layers, we found the optimum structure which provides the highest frequency limit for the return loss of less than -20dB with the lower limit of 30MHz. The tapered section of the absorber was approximated by multiple layers, the computed results were converged at 27 to 30 in the number of the layers.

The designed results with excellent absorbent characteristics are listed in the Table 1.

Fig.11(a) shows the reflectivity character- istics with frequencies of the designed wide-band ferrite electromagnetic wave absorber of the design #-1 which is depicted by TAPERED, while the characteristics of the conventional ferrite TILE and the GRID type ferrite absorber are compared simultane-ously on the graph. Fig.11(b) shows the normalized input impedance for those of Fig.11(a) on the Smith chart.

Figs.12(a) and (b) show the same ones as Figs.11(a) and (b) for the design #-2.

As shown in Fig.11 & 12, the reflectivity with the tolerance limits -20dB is available in the frequency range 30 to 2,150MHz or 2,430MHz.

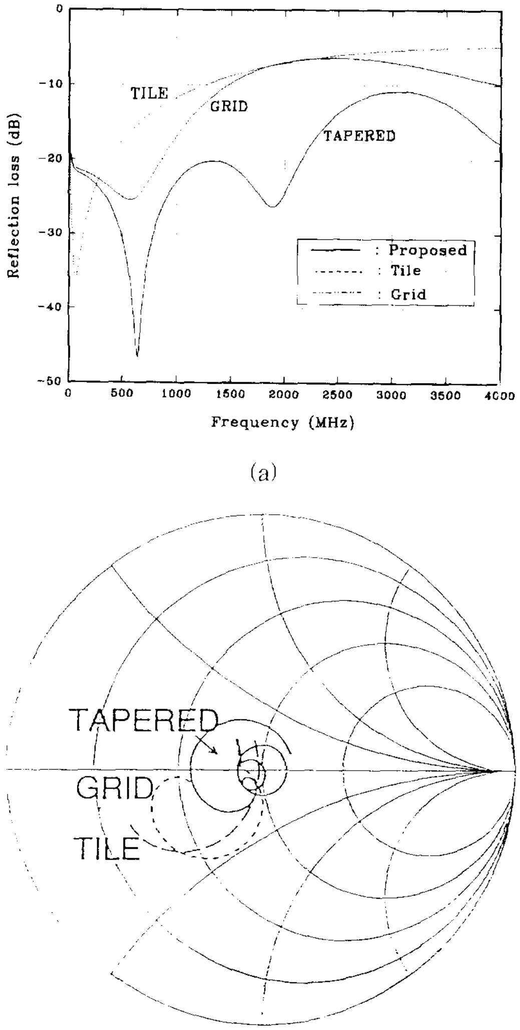
Even though the frequency limitations were not considered in the above design, it is possible to apply the proposed design method for high frequency application by controlling the dimensions into smaller cell size relative to the wavelength maintaining the ratios of S, t_{m1}, t_{m2}, t_{mt}, etc.

As pointed out in[10], the equivalent material parameters depend on the materials and direction, resulting tensor expression for the permittivity and permeability. However, only normal incidence was considered here and the performance of such tapered absorbers at off angles is studied in the near future.

표 1. 고투자율을 가지는 Ni-Zn계 페라이트로 구성한 광대역 전파흡수체의 특성 결과

Table 1. Designed Wide-band Electromagnetic Wave Absorbers with Excellent Characteristics Using High Permeability Ni Zn Ferrite.

Nos.	Measured material constants parameters	Dimensions (mm)	Band width with the tolerance limits of -20dB	Remark
Design #-1	ε_r = 14.0 K= 2,500 f_m = 2.5	t_{m1} = 12.8 t_{m2} = 7.4 S = 20.0 h_1 = 5.8 h_2 = 0.0 h_t = 48.0 P = 20.0 Q = 0.8 N = 30	30-2,150 MHz	TAPERED
Design #-2	ε_r = 14.0 K= 2,500 f_m = 2.5	t_{m1} = 12.8 t_{m2} = 1.6 S = 20.0 h_1 = 6.6 h_2 = 15.0 h_t = 30.0 P = 15.0 Q = 0.6 N = 30	30-2,430 MHz	TAPERED

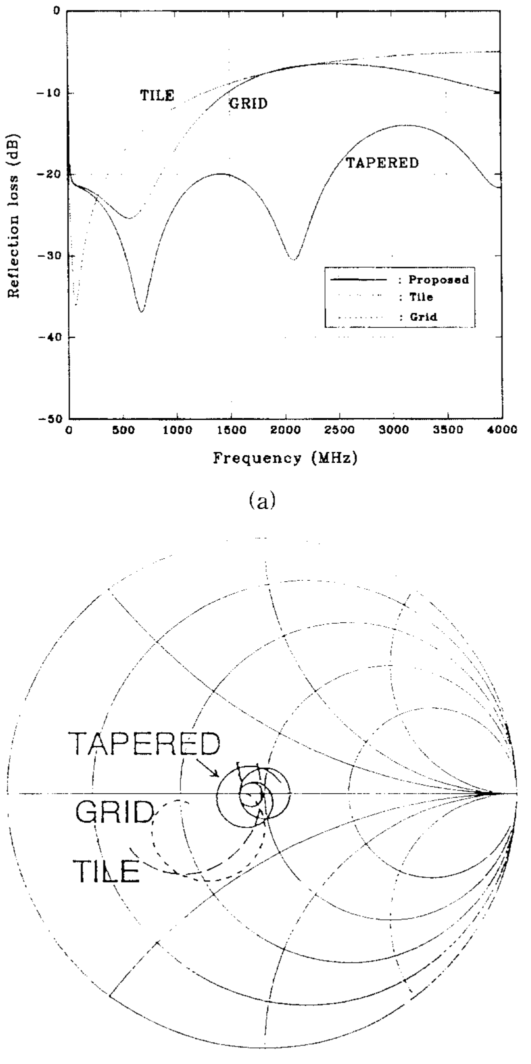


(a)

(b)

그림 11. (a) Design #-1 전파흡수체의 반사주파수 특성, (b) Design #-1 전파흡수체의 입력 임피던스

Fig. 11. (a) Reflectivity Frequency Characteristics of the Designed Wide band Electromagnetic Wave Absorber, (b) Normalized Input Impedance of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-1 in Table 1.



(a)

(b)

그림 12. (a) Design #-2 전파흡수체의 반사주파수 특성, (b) Design #-1 전파흡수체의 입력 임피던스

Fig. 12. (a) Reflectivity Frequency Characteristics of the Designed Wide band Electromagnetic Wave Absorber, (b) Normalized Input Impedance of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-1 in Table 1.

V. Conclusion

A wide band design method of the electromagnetic wave absorber using exponentially tapered ferrite was described, where the equivalent material constants, i.e, the equivalent complex permittivity and permeability for the regions of spatially varying ferrite shape were calculated by the synthesized capacitance method and the synthesized inductance method under some approximations.

Then, the wide band ferrite electromagnetic wave absorbers with taper were designed, which are with excellent reflectivity frequency characteristics and with the band width of 30MHz to 2,150MHz or 2,430MHz under the tolerance limits of -20dB reflectivity, while the conventional ferrite tile or the grid type ferrite absorbers has the band width of 30MHz to 370MHz or 870MHz. These absorbers could be used for the construction of an anechoic chamber, GTEM-cell, etc. for EMC.

In the near future, the exact material constants model for the tapered absorber will be derived and the experiments will be carried out.

References

[1] Y.Naito et al., “Design of the grid type ferrite electromagnetic wave absorber,” EMCJ 91-81, IEICE of Japan, pp. 21-28, Jan. 1992.

[2] Y. Shimizu et al., Absorption and shield of electromagnetic wave, Nikkei Publishing Co., Japan, 1989.

[3] E. Bensoussan, J. L. Lions and G. Pananicolaou, Asymptotic Analysis for Periodic Structures. Amsterdam: North-Holland, 1978.

[4] N. S. Bakhvalov and G. Panasenko, Homogenization: Averaging Processes in Periodic Media: Mathematical Problems in the Mechanics of Composite Materials. Kluwer Academic Publishers, 1989.

[5] E. F. Kuester and C. L. Holloway, “A low-frequency model for wedge or pyramid absorber arrays-I: Theory,” EEE Trans. on Electromagnetic Compatibility, vol. 36, no. 4, Nov. 1994.

[6] C. L. Holloway and E. F. Kuester, “A

low-frequency model for wedge or pyramid absorber arrays-II: Computed and measured results," IEEE Trans. on Electromagnetic Compatibility, vol. 36, no. 4, Nov. 1994.

[7] E. F. Kuester and C. L. Holloway, "Improved low-frequency performance of pyramid cone absorbers for application in semi-anechoic chambers," IEEE National Symposium on Electromagnetic Compatibility, Denver, CO, May 23-25, pp. 394-399, 1989.

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

[9] H. Takahashi, Waves I, Maruzen Publishing Co., Tokyo, Japan, 1973.

[10] E. F. Kuester and C. L. Holloway, "Comparison of approximations for effectiv parameters of artificial dielectrics," IEEE Trans. Microwave Theory and Tech., vol. 38, no. 11, pp. 1752-1755, Nov. 1990.

[11] J. l. Jackson and S. R. Coriell, "Transport coefficients of composit materials," J. Appl. Phys., vol. 39, pp. 2349-2354, 1968.

[12] S. R. coriell and J. l. Jackson, "Bounds on transport coefficients of two-phase materials," J. Appl. Phys., vol. 39, pp. 4733-4736, 1968.

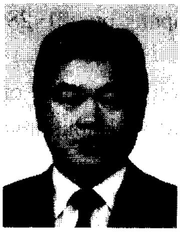
[13] G. N. Dulner, "Thermal conductivity of mixtures with interpenetrating components," J. Engr. Phys., vol. 19, no. 3, pp. 1195-1206, Sept. 1970.

[14] Y. Natio, "Formulation of frequency dispersion of ferrite permeability," IEICE of Japan, vol. J59-C, no. 5, pp. 297-304, May 1976.

[15] Y. Natio, Electromagnetic wave absorber, OHM Publishing Co., Japan, 1987.

[16] P. A. Chatterton and M. A. Houlden, EMC-Electromagnetic theory to practical design, Chapter 3, John Wiley & Sons Ltd, 1992.

저자소개



金 東 一(正會員)

1952년 2월 26일생. 1975년 2월 한국해양대학교 항해학과 졸업(공학사). 1977년 2월 한국해양대학교 대학원 전파공학 전공(공학석사). 1984년 3월 일본 동경공업대학 대학원 전기전자공학과 공학박사 학위취득. 1975년 3월 ~ 1993년 9월 한국대양대학교 전자통신공학과 조교~부교수. 1993년 10월 현재 한국해양대학교 전파공학과 교수. 1990년 3월 20일 산학협조상 대상 수상. 1993년 12월 11일 본학회 학술상 수상. 1995년 4월 21일 과학기술진흥 대통령 표창 수상. 주관심분야는 마이크로파 및 밀리미터와 회로의 설계, CATV 전송회로의 설계, 고성능 전파 흡수체의 개발, EMI/EMC 대책 등.

全 相 燁(正會員)

1957년 10월 16일생. 1982년 2월 한국해양대학교 항해학과 졸업(공학사). 1992년 2월 한국해양대학교 대학원 선박운항학 전공(공학석사). 1993년 3월 ~ 현재 한국해양대학교 대학원 박사과정 수료. 1989년 4월 ~ 현재 한국해기연수원 항해학과 부교수. 주관심분야는 고성능 전파흡수체의 개발, EMI/EMC 대책, 전자파문제의 수치해석 등.