초광대역특성을 가지는 Ferrite 전파흡수체의 설계방법

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Design Method of Electromagnetic Wave Absorber with Ultra Wide-Band Frequency Characteristics.

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Abstract

A wide band design method of an electromagnetic wave absorber using exponentially tapered ferrite, which has very wide band frequency characteristics, is proposed and discussed. The wide band electromagnetic wave absorber can be designed by the proposed equivalent material constants method for the regions varying spatially in the shape of ferrite.

Furthermore, the wide band ferrite electromagnetic wave absorbers with taper, which have not only excellent reflectivity frequency characteristics but also the band width of 30MHz to 2150 or 2450MHz under the tolerance limits of -20dB reflectivity, were designed.

I. Introduction

Recently, Eletromagnetic Interference(EMI) becomes very serious problem according to the office auto- mation, the factory automation, etc. Thus, for a countermeasure of EMI or EMC, the various electromagnetic wave absorbers are applicable according to their uses, which are needed to broaden the useful frequency bandwidth, reduce the thickness, and decrease the weight.

At present, an single-layered ferrite absorber which is composed with sintered ferrite tiles backed to a conducting metal, the bandwidth of which covers from nearly

30MHz to 400Mhz as lower and upper frequency limits, respectively, under the tolerance limits of -20dB in reflectivity1),2). In addition, the band- width of a grid ferrite electromagnetic wave absorber has been broadened to 700MHz in the above tolerance limit, which has been designed by the authors1).

Nowadays, one of the main purposes of the elecromagnetic wave absorber is to make an anechoic chamber for checking or measuring the leakage of electromagnetic wave electronic wave from electronic equipments or the immunity3), which is used for preventing TV ghost as well. However, 30MHz to 1000MHz or 3GHz upper in the bandwidth of the electromagnetic wave absorber used for anechoic chamber is required by the regulation, e.g., ANSI C63.4-1991, CISPR A SEC.109, or IEC 801-3. In this paper, for the above purpose, super wide-band Electromagnetic Wave Absorber is designed and developed tapered ferrite matrial, where the equivalent material constants method has been proposed and adopted. Thus, the bandwidth from 30MHz up to 2150 MHz or 2430 MHz has been obtained, and hence, the developed electromagnetic wave absorber is to be applicable to various uses.

II. Equivalent Material Constants Method

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.1, where the width is of w in the y-direction, the gap between the plates is g, and the currunt flows in the z-direction. Then the capacitance per unit length is given by4)

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

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

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

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.2 which is used later for designing the super wide-band electromagnetic wave absorber proposed in this paper.

Using Fig.2, we can make a synthesized capacitance model as shown in Fig.3. The total synthesized capacitance C is calulated by extending eq.(1). Then,

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

where ε_r is the relative permittivity of the ferrite material filled in Fig. 2 and ε_o is the permittivity of vacuum. Thus the equivalent permittivity ε_{eq} for the structure with thickness Δz as shown in Fig.2 is given by

$$\varepsilon_{eq} = bC/(\varepsilon_o\, a\, \Delta z) \qquad (4)$$

Substituting eq.(3) into eq.(4), the equivalent permittivity ε_{eq} for the structure as shown in Fig.2 is to given by

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

where

$$K_H = \frac{a_1}{a_1 + a_2}$$

$$K_E = \frac{b_1}{b_1 + b_2} \qquad (6)$$

Let L be the self-inductance of the area in Fig.1.
Then, the magnetic flux across the area of g a is given by

$$\Phi = B_y\, g\, a \qquad (7)$$

and the magnetic flux density B_y is given by

$$w\, B_y = \mu\, I \qquad (8)$$

The self-inductance L is given by

$$LI = \Phi \qquad (9)$$

since the self-inductance L is defined by

$$L\frac{dI}{dt} = \frac{d\Phi}{dt}\ .$$

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

$$\frac{L}{a} = \frac{g\mu}{w} \qquad (10)$$

Using Fig.2, as the same manner as the above, we can make a synthesized inductance model as shown in Fig.4. The total synthesized inductance L is calculated by extending eq.(10). Then,

$$L = \frac{\mu_o \mu_r \{ab_2 + b_1(a_1 + a_2\mu_r)\}\Delta z}{a(a_1 + a_2\mu_r)} \qquad (11)$$

where μ_r is the relative permittivity of the ferrite material filled in Fig.2, and μ_o is the permeability of vacuum. Thus, the equivalent permeability μ_{eq} for the structure with thickness as shown in Fig.2 is given by

$$\mu_{eq} = \frac{a\, L}{\mu_o\, b\, \Delta z} \qquad (12)$$

Substituting eq.(11) into eq.(12), the equivalent permeability μ_{eq} for the structure as shown in Fig.2 is given by

$$\mu_{eq} = K_E \mu_r + \frac{(1 - K_E)\mu_r}{K_H + (1 - K_H)\mu_r} \qquad (13)$$

The above method is referred to as the equivalent material constants method.

Ⅱ. Design of Wide-Band Electromagnetic Absorbers

Fig.5 shows a wide-band ferrite electromagnetic wave absorber proposed in this paper. The proposed electro- magnetic wave absorber is composed of ferrite matrial only, the shape typical of which is the same as Fig.5 and the cross section of which is the same as Fig.6

Suppose that the tapered region with height h_t varies exponentially as shown in Fig.7 and the cross section of the tapered resion 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.2 are given by

$$\left.\begin{aligned} x_1 &= \frac{t_{m1}}{2} \\ y_1 &= \frac{t_{m1}}{2} \\ z_1 &= \frac{h_1}{2} \end{aligned}\right]\quad \text{for } i = 1$$

$$\left.\begin{aligned} x_2 &= \frac{t_{m2}}{2} \\ y_2 &= \frac{t_{m2}}{2} \\ z_2 &= h_1 + \frac{h_2}{2} \end{aligned}\right]\quad \text{for } i = 2 \qquad (14)$$

$$\left.\begin{aligned} x_i &= \frac{1}{2}(t_m - Q)e^{-k(z_i-h_1-h_2)} + \frac{Q}{2} \\ y_i &= \frac{1}{2}(t_m - Q)e^{-k(z_i-h_1-h_2)} + \frac{Q}{2} \\ z_i &= h_1 + h_2 + \frac{h_t}{n-2}\left\{ (i-3) + \frac{1}{2} \right\} \end{aligned}\right] \quad \text{for } i \geq 3 \qquad (15)$$

since x_i is corresponding to $b_i/2$, y_i to $a_i/2$ and z_i is the center position of the i-th layer respectively. In the eq.(15), n dipicts the numbers of total layers, Q dipicts the minimum width of the end tip of the tapered resion, and

$$k = P/h_t \qquad (16)$$

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

Next, we can the equivalent material constants for each layer using the equivalent constants for each layer using the equivalent constant mathod. The frequency dispersion of ferrite permeability can be formulated by5)

$$\mu_r = 1 + K/(1 + jf/f_m)$$

where K is relative permeability in DC, f is used fre- quency, and f_m is relaxation frequency.

Fig.8 shows a multi-layed electromagnetic wave absorber model using the each layers equivalent materi- al constants.

Then we can design a wide-band ferrite electro- magnetic wave absorber6),7), since we can control the permeability and permittivity at the same time by use of the spatial shape varying technique of electro- magnetic wave absorber.

Ⅳ. Results

The material constants,i.e., the complex permit- tivity and the complex permeability of a high permea- bility Ni-Zn ferrite with low frequency permeability of 2500, are measured in the frequency band from 30MHz to 4000MHz according to frequencies. Then, we have design- ed wide-band electromagnetic wave absorbers based upon the above sections.

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

Fig.9(a) shows the reflectivity characteristics with frequencies of the designed wide -band ferrite electro- magnetic wave absorber of the design #-1 in log scale which is depicted by TAPERED, while the characteristics of the conventional ferrite tile and the GRID type fer- rite absorber are compared simultaneously on the graph. The wave incident angle is 0 degree.

Fig.9(b) shows the normalized input impedance for those of Fig.9(a) on the Smith chart. Figs.10(a) and (b) show the same ones as Figs.9(a) and (b) for the design #-2.

It has been shown from Fig.9 and Fig.10 that the ferrite electromagnetic wave absorbers tapered with the design #-1 and #-2 have very wide band frequency characteristics even if the tolerance limits are given by -20dB reflectivity.

These absorbers could be used for construction of the anechoic chamber, GTEM-cell, etc, for EMC.

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

Nos.	Measured material constants parameters	Absorber Dimension (mm)	Band width with the tolerance limits of -20dB	Remark
Design #-1	ε_r = 14.0 K = 2500 f_m = 2.5	t_{m1} = 12.8 t_{m2} = 7.4 S = 20.0 h_1 = 5.8 h_2 = 0 h_t = 48.0 P = 20 Q = 0.8	30-2150 MHz	T A P E R E D
Design #-2	ε_r = 14.0 K = 2500 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 Q = 0.6	30-2430 MHz	T A P E R E D

V. Conclusion

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

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 2150 or 2430MHz under the tolerance limits of -20dB reflectivity, while the conventional ferrite tile or the grid type ferrite absorbers has the band with of 30MHz to 370MHz or 870MHz , respectively.

References

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[5] Y. Naito, "Formulation of Frequency Dispersion of Ferrite Permeability," IECE of Japan, Vol. J59-C, No.5, pp.297-304, May 1976.

[6] Y. Naito, Electomagnetic Wave Absorber, OHM Publishing Co., Japan, 1987.

[7] P. A. Chatterton and M. A. Houlden, EMC - Electromagnetic Theory to Practical Design, Chapter 3, John Wiley & Sons Ltd, 1992.

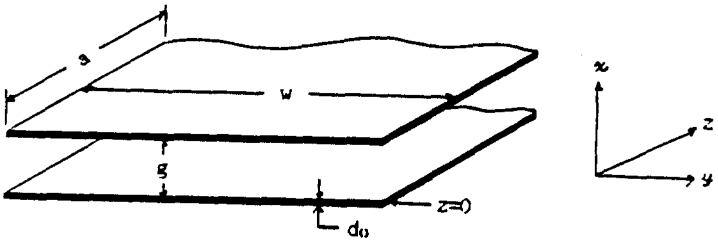


Fig.1 A Parallel Plate Transmission Line

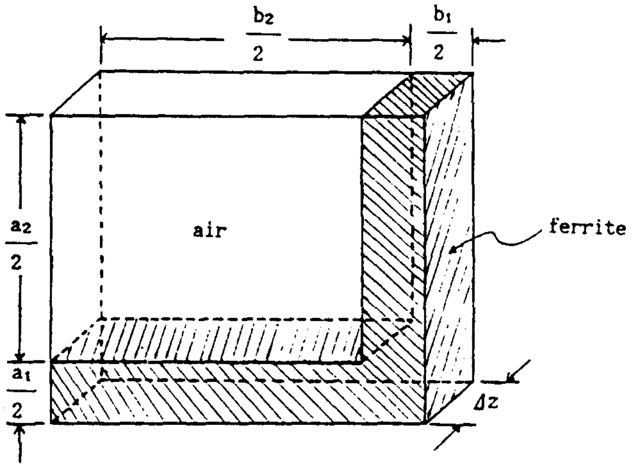


Fig.2 A Model for Calculation of Equivalent Material Constants

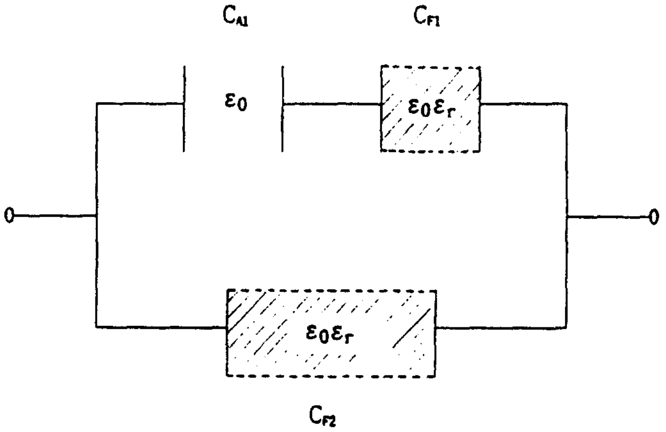


Fig.3 A Synthesized Capacitance Model

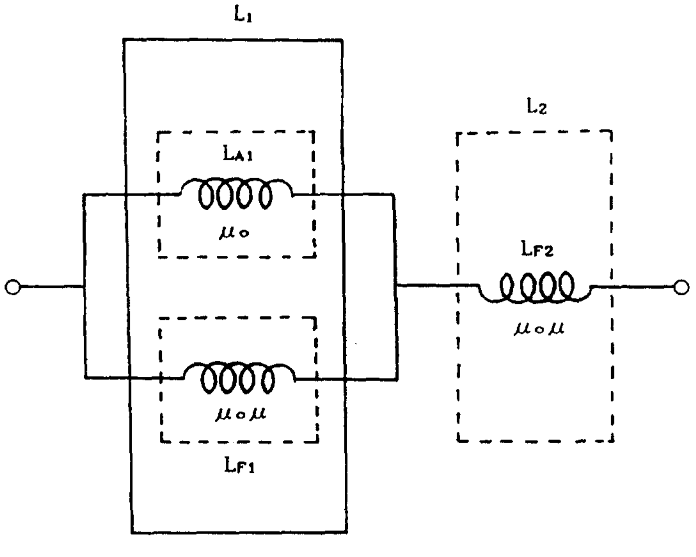


Fig.4 A Synthesized Inductance Model.

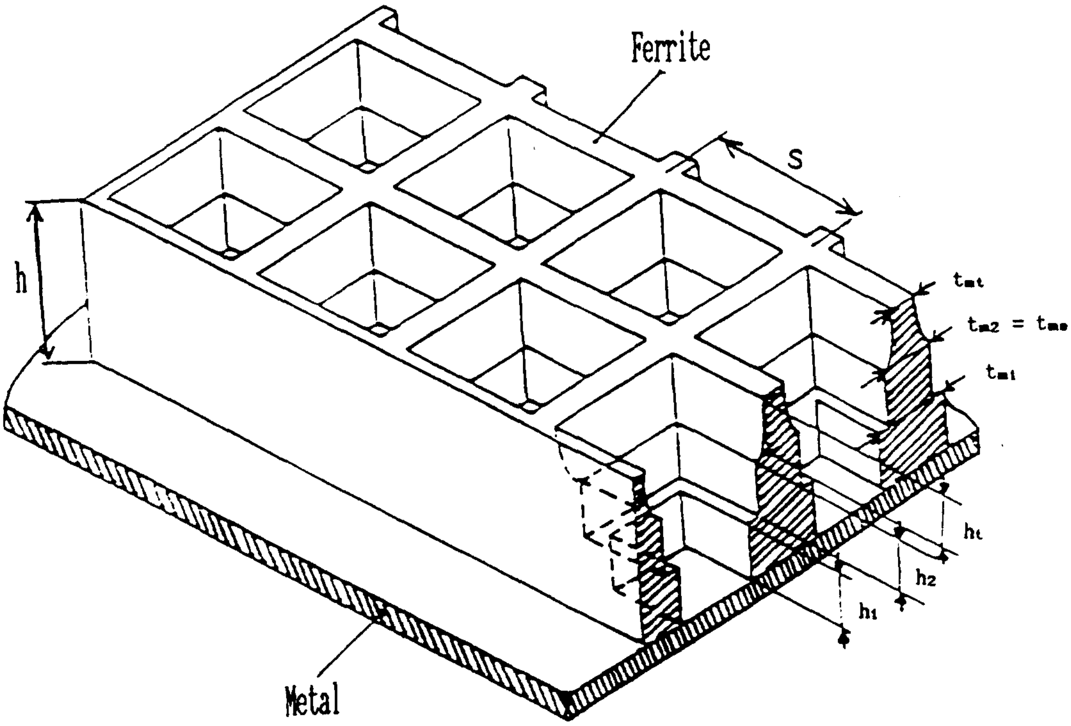


Fig.5 The Typical Shape of a Wide-Band Ferrite Electromagnetic Wave Absorber Proposed in this Paper.

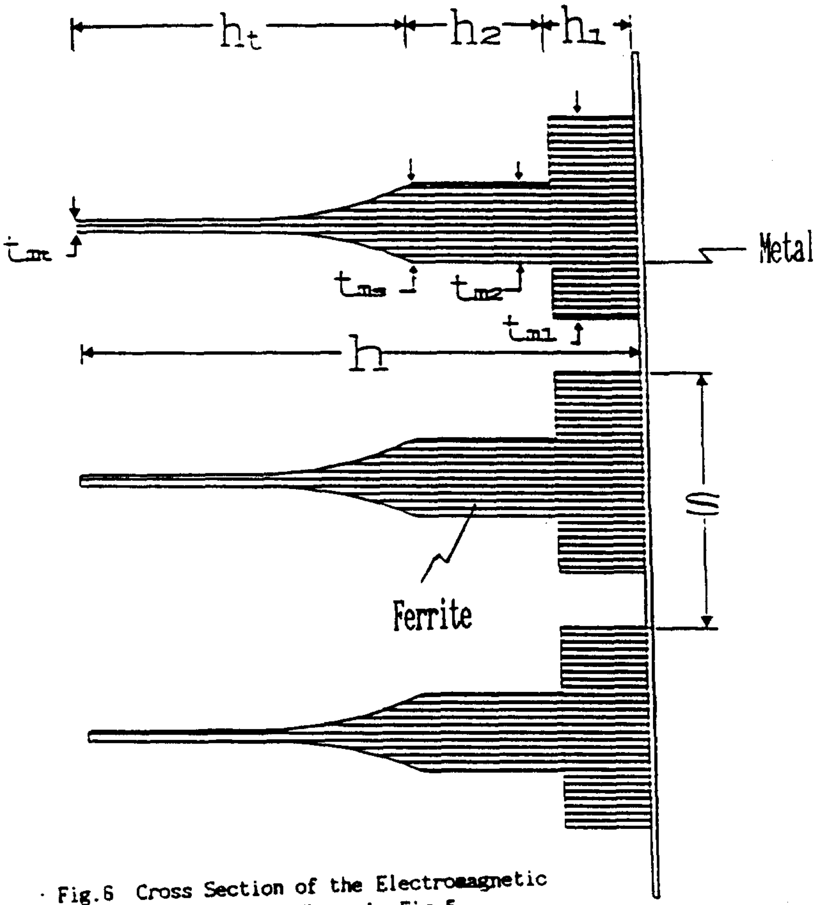
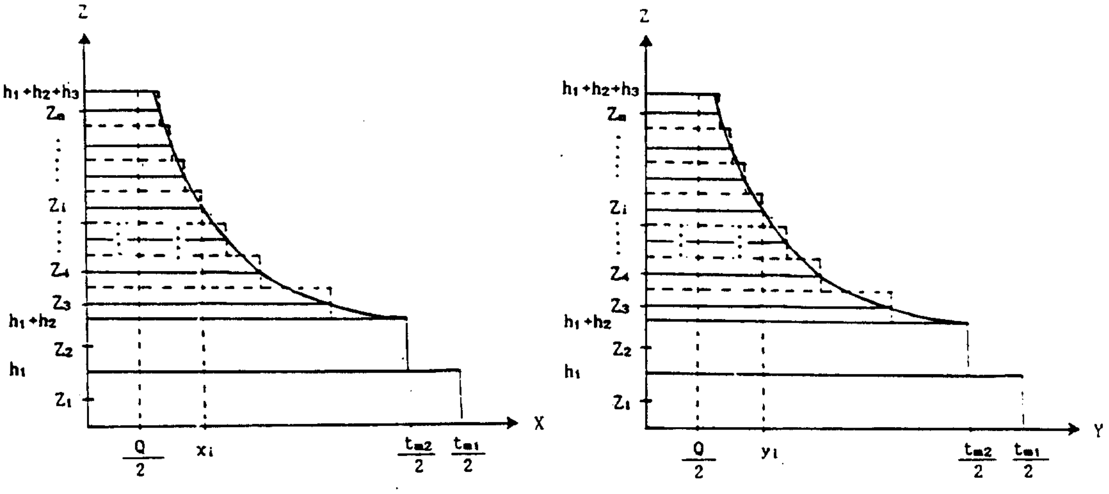


Fig.6 Cross Section of the Electromagnetic Wave Absorber Shown in Fig.5.



(a) for x-axis

(b) for y-axis

Fig.7 Divided Cross Sections in z-Direction.

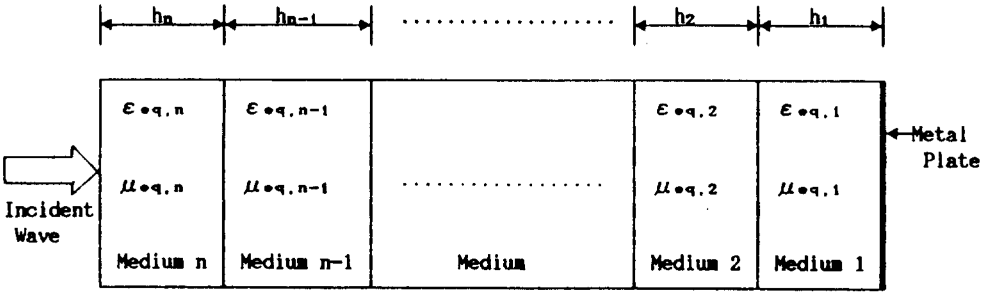


Fig.8 Multi-layered Electromagnetic Wave Absorber Model.

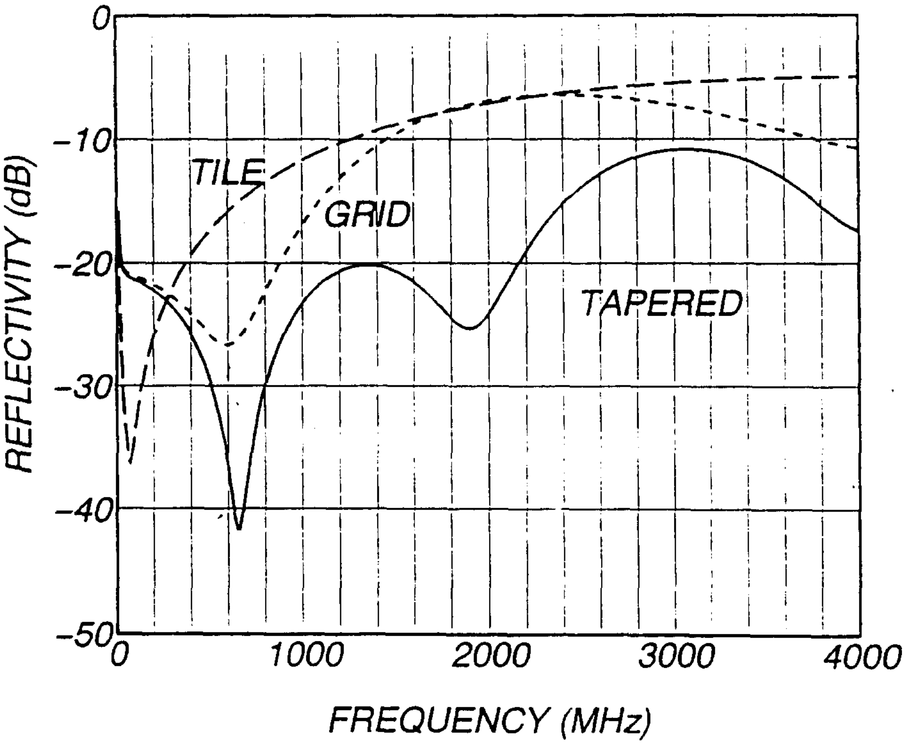


Fig.9 (a) Reflectivity Frequency Characteristics of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-1 in Table 1.

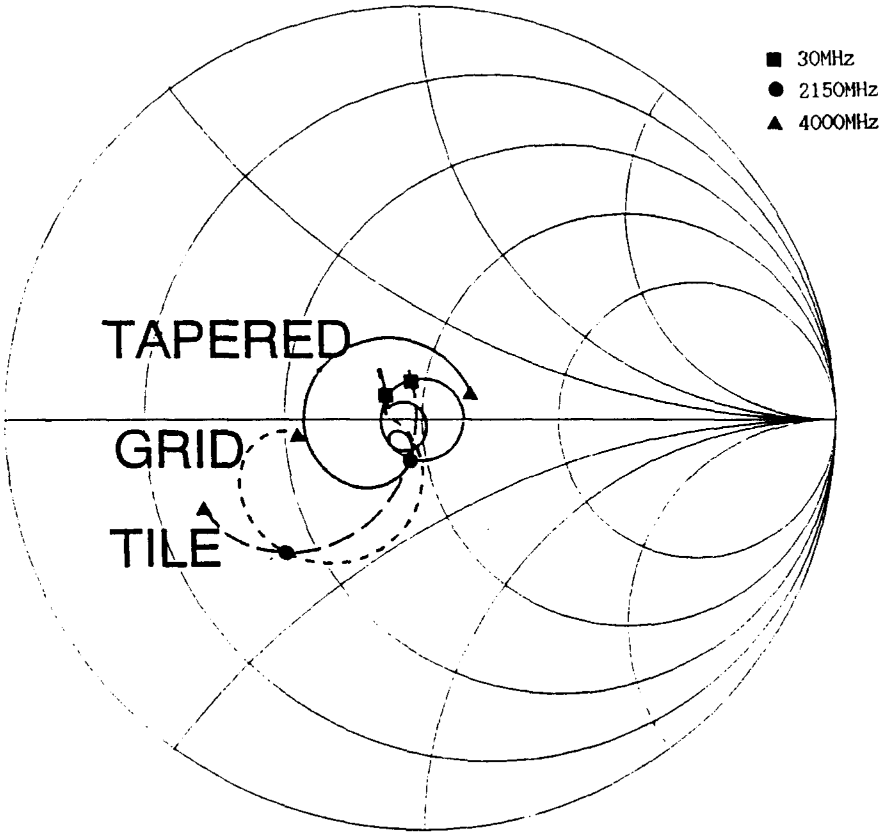


Fig.9 (b) Normalized Input Impedance of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-1 in Table 1.

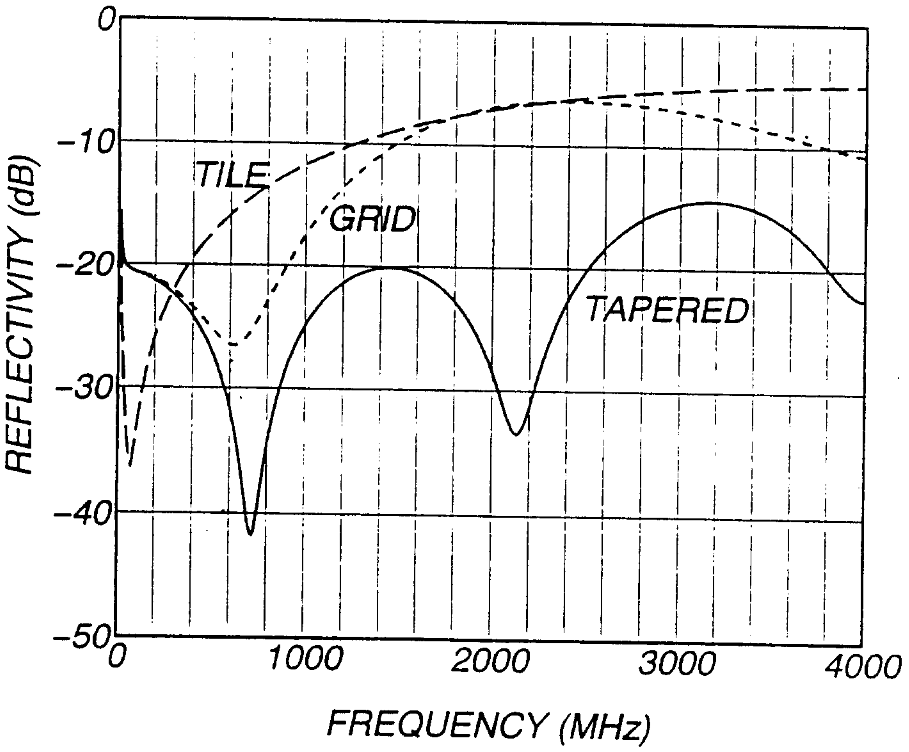


Fig.10(a) Reflectivity Frequency Characteristics of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-2 in Table 1.

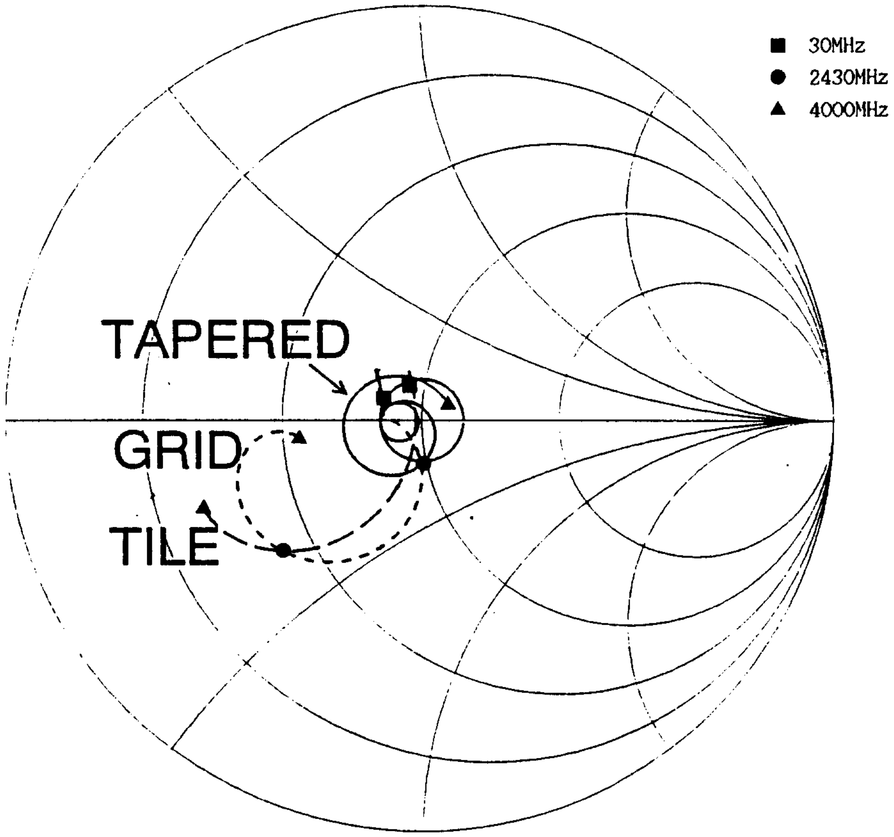


Fig.10(b) Normalized Input Impedance of the Designed Wide-Band Electromagnetic Wave Absorber of Design #-2 in Table 1.