United States Patent [19]

Suetake et al.

[11] **3,737,903**

[45] **June 5, 1973**

[54] **EXTREMELY THIN, WAVE ABSORPTIVE WALL**

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[52] **U.S. Cl.** .....**343/18 A**

[51] **Int. Cl.** **H01q 17/00**

[58] **Field of Search** .....343/18 A

[56] **References Cited**

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Primary Examiner—Benjamin A. Borchelt
Assistant Examiner—G. E. Montone
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[57] **ABSTRACT**

An electromagnetic wave absorbing wall employing ferromagnetic ferrite and ferroelectric material. Much thinner walls of this construction are effective shields in contrast to the thick walls of lossy materials required to achieve equivalent shielding.

2 Claims, 11 Drawing Figures

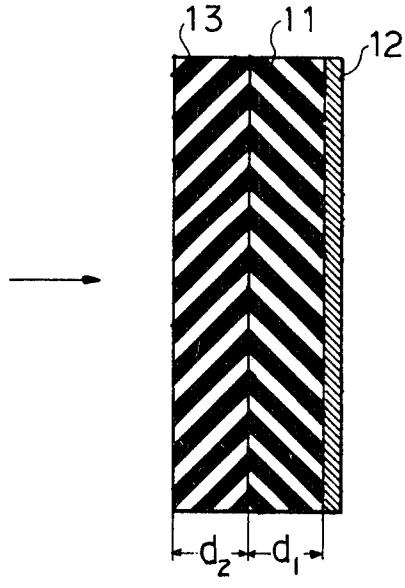


Fig. 1

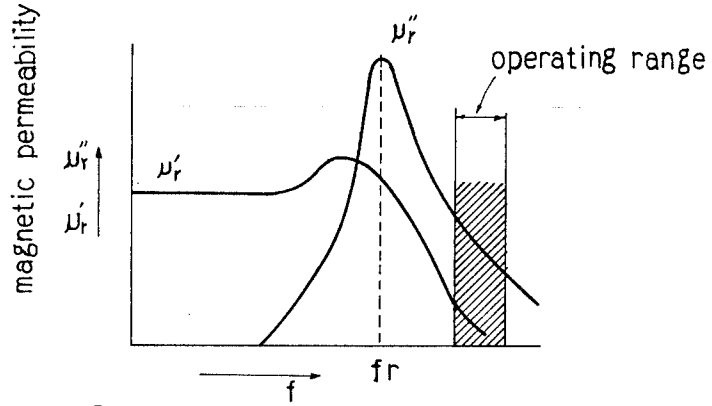


Fig. 2

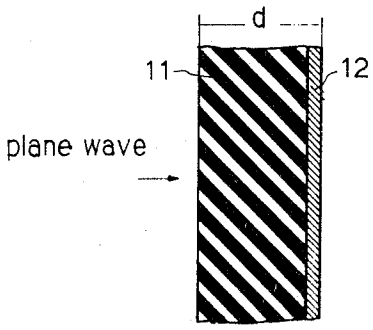


Fig. 2A

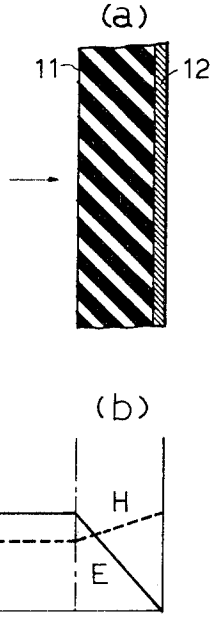
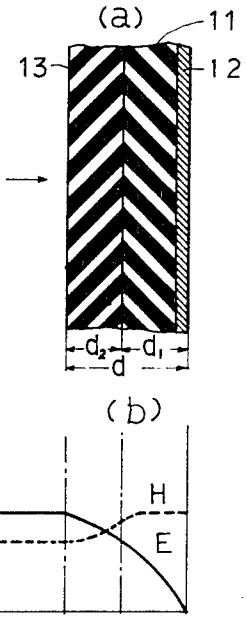


Fig. 2B



E: electric field

H: magnetic field

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Fig. 5

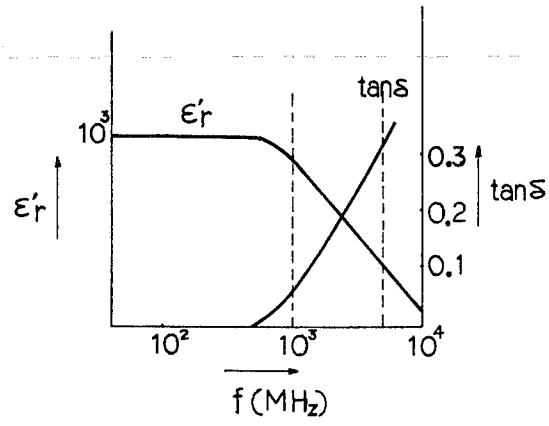


Fig. 6

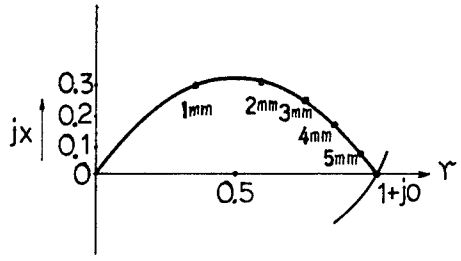
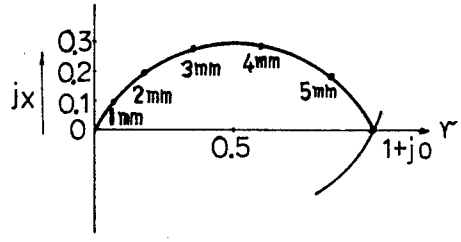


Fig. 7



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Fig. 8

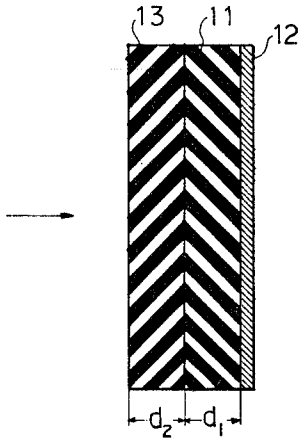
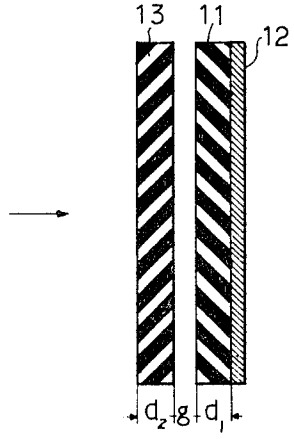


Fig. 9



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Fig. 3

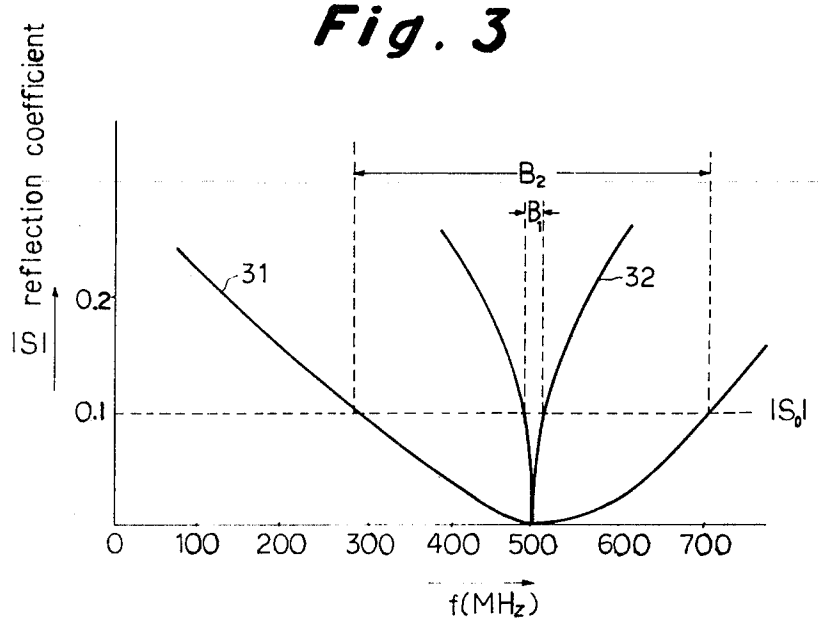
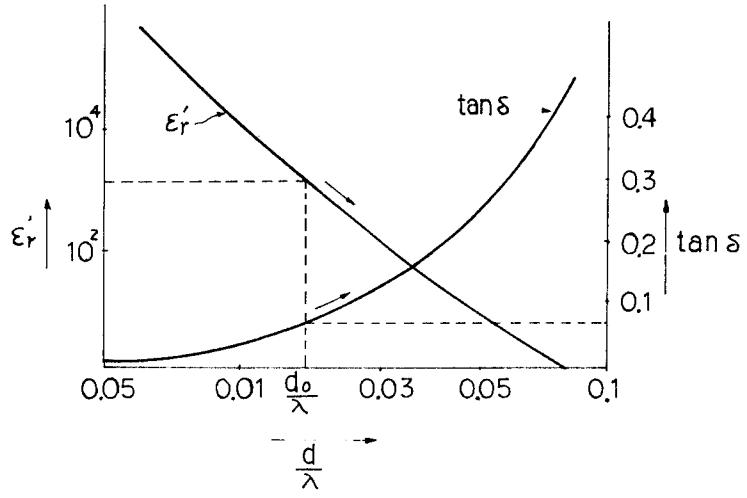


Fig. 4



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EXTREMELY THIN, WAVE ABSORPTIVE WALL

The aforementioned abstract is neither intended to define the invention of the application which, of course, is measured by the claims, nor is it intended to be limiting as to the scope of the invention in any way.

This invention relates to a thin, wave absorbing wall particularly to a wave absorber made of ferromagnetic ferrite and ferroelectric material.

Two kinds of materials are conventionally used for a wave absorbing wall. One is dielectric materials having a substantial dielectric loss, such as foamed polystyrene including graphite powder or fibers coated by graphite powder. Another material is ferrite, the loss in which is due to the interaction between the spin and the crystal lattice.

Recently, various kinds of thin, wave absorbing walls for VHF and UHF band have been proposed. These walls are used to form a shielded chamber for researching antenna for space communication or color television and for preventing the formation of ghost images of television waves resulting from reflections of high steel frame buildings or metal guard rails of highways.

The theoretical thickness of wave absorbing walls made of conventional dielectric materials is 100cm, and hence dielectric walls are not practical.

It is known that a ferrite plate of 3 to 5 mm thickness is a good wave absorber, but it is desired that the thickness be further reduced for reasons of cost.

The object of the present invention is to provide an extremely thin, wave absorbing wall. This is accomplished by utilizing the frequency dispersion characteristics of both ferromagnetic materials and ferroelectric materials. In the present invention, the dielectric loss of the absorber is derived from the frequency dispersion characteristics of the dielectric constant of the ferroelectrics, and hence the first advantage is that said ferroelectrics need not contain absorptive materials such as graphite powder. The second advantage is that if the both materials (ferroelectrics and ferromagnetics) are used, the wave absorbing wall is much thinner than the wall made of single material.

BRIFF DESCRIPTION OF THE DRAWING

A more detailed description of the present invention is given below with reference to the accompanying drawings wherein:

FIG. 1 shows the frequency characteristics of complex magnetic permeability of ferromagnetic ferrites;

FIG. 2 shows the single layer wave absorbing wall of the prior art;

FIG. 2 A (*a*) shows a single layer wave absorber utilizing a ferromagnetic ferrite plate;

FIG. 2 A (*b*) shows the profile of electric and magnetic fields in the absorber depicted in FIG. 2 A(*a*);

FIG. 2 B (*a*) shows a wave absorber utilizing the combination of ferroelectrics and ferromagnetic ferrite;

FIG. 2 B (*b*) shows the profile of electric and magnetic fields in the absorber depicted in FIG. 2 B (*b*);

FIG. 3 shows the frequency characteristics of the reflection coefficient $|S|$ of the ferromagnetic ferrite and dielectrics;

FIG. 4 shows the characteristics of ϵ_r and δ of dielectric materials being drawn for the purpose of explaining the principle of the present invention;

FIG. 5 shows the frequency characteristics of ϵ_r and tan δ of ferroelectric materials such as $BaTiO_3$ or $PbTiO_3$;

FIG. 6 and 7 show the variations of input impedance of the wave absorbing walls made of ferromagnetic ferrites and ferroelectric materials VS. variations of the thickness of the walls;

FIG. 8 and 9 show the cross sectional view of the extremely thin, wave absorbing walls according to the present invention which is made of ferromagnetic ferrites and ferroelectrical materials.

The frequency characteristics of the real and imaginary parts of the complex, specific magnetic permeability of ferrites ($\dot{\mu}_r = \mu'_r - j\mu''_r$) are shown in FIG. 1. In FIG. 1 fr is a resonant frequency and the actual working range of the ferrites is the hatched right part.

FIG. 2 is a cross sectional view of a part of the single layer wave absorbing wall made of ferrite or dielectric material, which is composed of dielectrics or ferrite **11** and a metal plate **12**, and the thickness of this wall is *d*.

The frequency characteristics of reflection coefficient $|S|$ is shown in FIG. 3, the wave being incident upon the front surface of the wall. In FIG. 3, curves **31** and **32** show the characteristics of ferrite and dielectric material, respectively, and the areas enclosed by dotted lines are the range where the reflection coefficient is within the allowable reflection coefficient $|So|$, that is $|S|$ is below 0.1.

The frequency band width B1, where the reflection coefficient $|S|$ of the dielectrics is less than the allowable reflection coefficient $|So|$, is too narrow to be put in practical use, as shown in the curve **32**.

On the other hand, the frequency band width B2, where the reflection coefficient $|S|$ of the ferrite is less than the allowable reflection coefficient $|So|$, is rather wide as shown in the curve **31**. While this seems to indicate that ferrite is suited for practical use the Applicants have found that the thickness *d* necessary for the wave absorbing wall made of ferrite is 3 to 5 mm if the wall is to absorb all of the wave regardless of the wave length, and that the thickness cannot be reduced. Accordingly, the wave absorbing wall made of ferrite has the limitation in its thickness and a thin wall cannot be obtained.

Next, the wave absorbing phenomena of ferromagnetic ferrite and dielectrics will be explained.

The wave absorption of electric field is different from that of magnetic field.

1. Wave absorption is represented by the form gE^2 in the place where electric field E is present. Its reason will be well understood from the following consideration. Energy loss per unit volume is JE, where J is current density, and current density J due to electric field E is identical to gE. Therefore, absorbed or consumed electric energy JE is $gE \times E$ ($=gE^2$).

2. Wave absorption is represented by the form $\gamma m H^2$ in the place where magnetic field H is present. γm is magnetic resistance and it is equal to $\omega\mu_0\mu''_r$ if the complex, specific magnetic permeability μ_r is ($\mu'_r - j\mu''_r$). The reason is as follows:

Energy loss per unit volume is $J \times E$, J is identical H, and electric field is $\gamma m \times H$, hence absorbed or consumed electric energy $J \times E$ is $H \cdot \gamma\, mH$ ($=\gamma m H^2$).

3. The wave absorbing wall of ferrite positively utilizes magnetic resistance γm (see U.S. Pat. No. 3,460,142), its principle is based on the wave absorption of the form $\gamma m H^2$.

In the case of using ferrite as wave absorber, in order to increase magnetic field H in the neighborhood of the

back surface of said ferrite absorber, a conductive plate (its impedance is substantially zero) is fixed to said back surface and a huge short circuit current is produced in said conductive plate. As a result, magnetic field H is increased in the vicinity of said back surface, while electric field E is apparently zero in the same vicinity. Accordingly, wave absorption of the type $\gamma m H^2$ is predominant and the properties of electric and magnetic fields are as shown in FIGS. 2 A (*a*) and (*b*). That is, in the wave absorber made of a conductive plate **12** and a ferrite plate **11**, magnetic field H is large and electric field E is nearly zero in the neighborhood of the conductive plate **12**, and electric field is gradually increased as the distance from the conductive plate is increased but magnetic field is generally constant (see FIG. 2 A (*b*)).

On the other hand, the change of impedance is as follows:

Impedance is zero in the close vicinity of the front surface of the conductive plate, and it is one in the front surface of the absorbing wall, where impedance Z is a normalized value.

Positions in the absorbing wall	Front surface	Central parts	Vicinity of the conductive plate
E	E	←	0
H	H	←	Hmax
Z = E/H	1	←	0

Next, an explanation will be described with respect to an absorber composed of dielectrics and ferromagnetics such as ferrite. In FIGS. 2 B (*a*) and (*b*), wave absorber is consisted of a conductive plate **12**, a thin ferromagnetic ferrite plate **11** and a thin dielectric plate **13**. As is above-mentioned in (3) and as shown in FIG. 2 B (*b*), magnetic field H is decreased while electric field E is increased with the distance from the conductive plate **12**, and hence electric field is predominant in the dielectric plate **13** in the vicinity of the ferromagnetic plate **11**. Therefore, energy loss due to electric field E is larger than due to magnetic field. And hence, the wave absorber shown in FIG. 2 B (*a*) is possible to absorb wave energy both in magnetic field (type of $\gamma m H^2$) and in electric field (type of gE^2), and it is efficient in wave energy consumption. Consequently, the total thickness d ($= d_1 + d_2$, where d_1 and d_2 are the thickness of the ferromagnetic ferrite plate and dielectric plate, respectively) can be reduced more than in case of using single material.

Next, the present invention will be better described with reference to the drawing of characteristics.

In FIG. 2, the complex, specific dielectric constant and the complex, specific magnetic permeability of the material are $\dot{\epsilon}_r$ and $\dot{\mu}_r$, respectively, and $\dot{\mu}_r$ may be 1 if the material is ferroelectrics. When the wave length of incident plane wave is λ, normalized input impedance is (normalization is carried out under the assumption that the wave impedance for the plane wave in vacuum is regarded as 120 λ ($= 377\Omega$))

$$Z = 1/\sqrt{\dot{\epsilon}_r} \tanh [j(2\pi/\lambda)\sqrt{\dot{\epsilon}_r} d] \quad (1)$$

The condition wherein matching is obtained in a wide range is that Z of the equation (1) is always 1 independently of λ. By solving the equation (1) under the above condition, the relation between d/λ and $\dot{\epsilon}_r$ shown in FIG. 4 is obtained. Accordingly, if the thickness d is do, $\dot{\epsilon}_r$ and tan δ VS. do/λ should change as shown in FIG. 4 in order that the absorbing wall of the type shown in FIG. 2 is a wide band absorber.

The frequency characteristics of ferroelectric materials such as $BaTiO_3$ and $PbTiO_3$ are shown in FIG. 5, where the above mentioned condition is satisfied in the range between broken lines and hence a wide band width absorber is obtained by utilizing ferroelectric materials, and if $\dot{\epsilon}_r$ is large, do/λ is small. Therefore, the desired properties can be obtained by a thin wall.

Next, the variation of the input impedance of the absorbing (see FIGS. 2 A and 2 B) wall made of ferromagnetic and ferroelectric materials VS. thickness d will be explained, when plane waves are incident upon said wall. FIGS. 6 and 7 show the variation of impedance in the case of using ferromagnetic ferrite and ferroelectrics, respectively.

FIG. 6 shows the characteristics of ferromagnetic ferrite. The measured values are shown in the below table.

Thickness (mm)	1	2	3	4	5
γ	0.36	0.60	0.75	0.85	0.95
χ	0.31	0.32	0.25	0.16	0.06

The thickness is 1, 2, 3, 4 or 5 mm in each point on the curve. The change of impedance is large in the range of 0 to 2 mm thickness. In other words, impedance can be largely changed by only 1 mm change of thickness. But in the part where impedance is nearly 1, the change of impedance is small.

FIG. 7 shows the characteristics of ferroelectric material. The measured values are shown in the below table.

Thickness (mm)	1	2	3	4	5
γ	0.06	0.18	0.35	0.60	0.85
χ	0.10	0.2	0.30	0.31	0.19

The thickness of the wall is 1, 2, 3, 4 or 5 mm in each point on the curve. The property of ferroelectric material reverses to that of ferromagnetic ferrite, the change is small in the range of 0 to 4 mm thickness and large in the range where impedance is nearly 1.

The physical meaning of this phenomena is explained as follows:

The effect of ferrite is large in the presence of a strong magnetic field and hence a 1 mm increase in thickness is effective in the neighborhood of impedance being 0, where the magnetic field is strong. On the other hand, the effect of ferroelectric material is large in the presence of a strong electric field, and hence a 1 mm increase in thickness is effective in the neighborhood of impedance being 1, where the electric field is strong.

One of the embodiments of the present invention is derived due to the properties shown in FIGS. 6 and 7. In this embodiment ferromagnetic ferrite is used in the range where impedance is nearly 0 (see FIG. 6) and ferroelectric material is used in the range where impedance is nearly 1 (see FIG. 7). Thus the thickness of the absorbing wall may be thinner than that of the wall made of single material. Such an embodiment is shown in FIG. 8, wherein the wall is composed of ferroelectric material **13**, a metal plate **12** and ferromagnetic material **11**.

FIG. 9 shows still another embodiment of the present invention. In this embodiment there is a gap (g) between ferroelectrics **13** and ferromagnetic ferrite **11**.

The gap (g) may be filled by air or another dielectric material. The electric field in the place where the ferroelectrics is to be arranged is so increased by the gap (g) that the total thickness d can be thinner than in the case of former embodiments.

What we claim:

1. A thin wide band-width electromagnetic wave absorbing wall comprising, in sequence, a layer of ferroelectric material disposed facing the incident wave, a layer of ferromagnetic ferrite material and a metal plate, said absorbing wall characterized by the absence of absorptive material dispersed therein, wherein the dielectric loss is inherently due to the frequency dispersion characteristics of the materials.

2. An absorbing wall as in claim **1** further including a gap between said two layers, said gap containing dielectric material.

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