

[54] **WIDE BAND FLEXIBLE WAVE ABSORBER**

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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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[57] **ABSTRACT**

This invention relates to a flexible super-wide band wave absorber composed of a mixture of ferromagnetic and dielectric materials. One form of the wave absorber is composed of a plurality of ferrites having different magnetic resonant frequencies. A further embodiment uses a dielectric material having a high dielectric constant. The wave absorber can be semispherically shaped to form a non-directional wave absorber.

13 Claims, 18 Drawing Figures

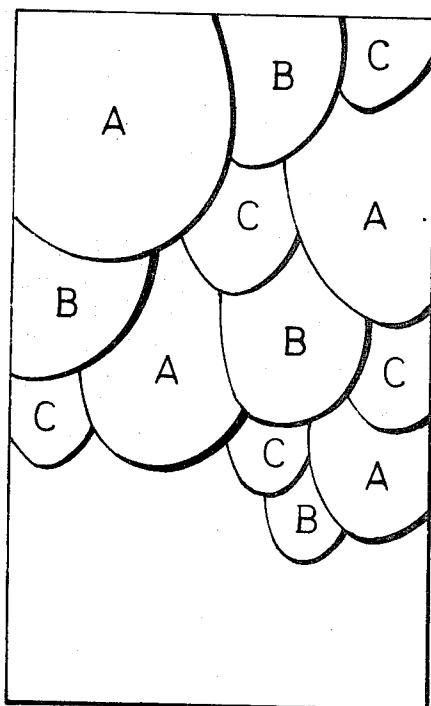


FIG. 1

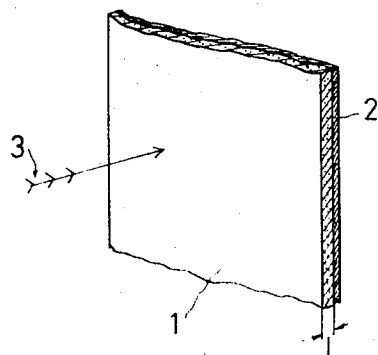


FIG. 2a

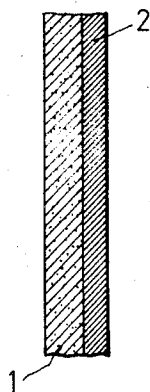


FIG. 2b

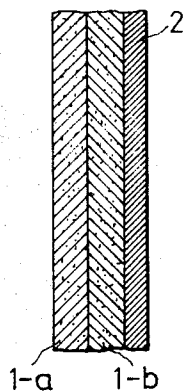
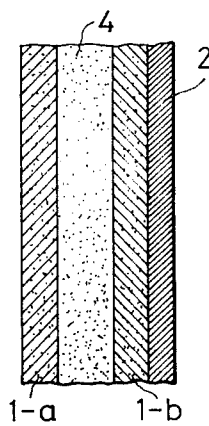


FIG. 2c



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FIG. 3

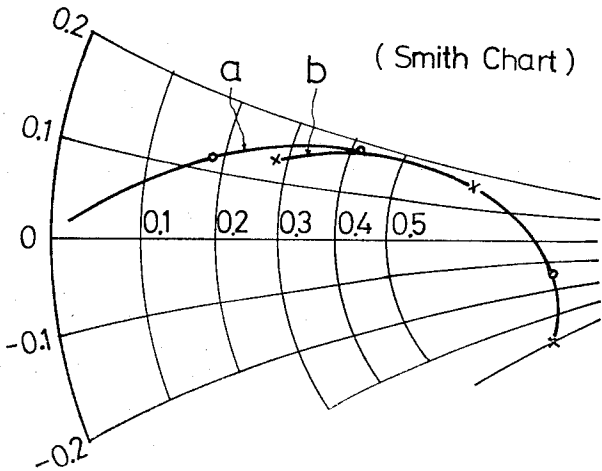


FIG.4a FIG.4b FIG.4c FIG.4d

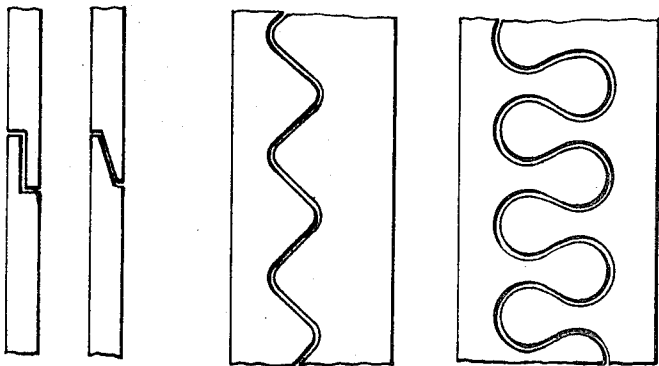


FIG. 5a

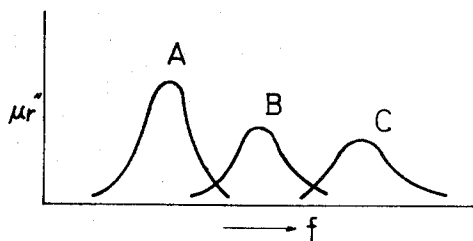


FIG. 5b

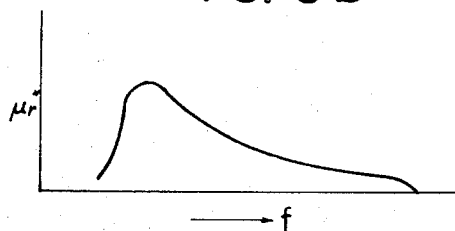


FIG. 6

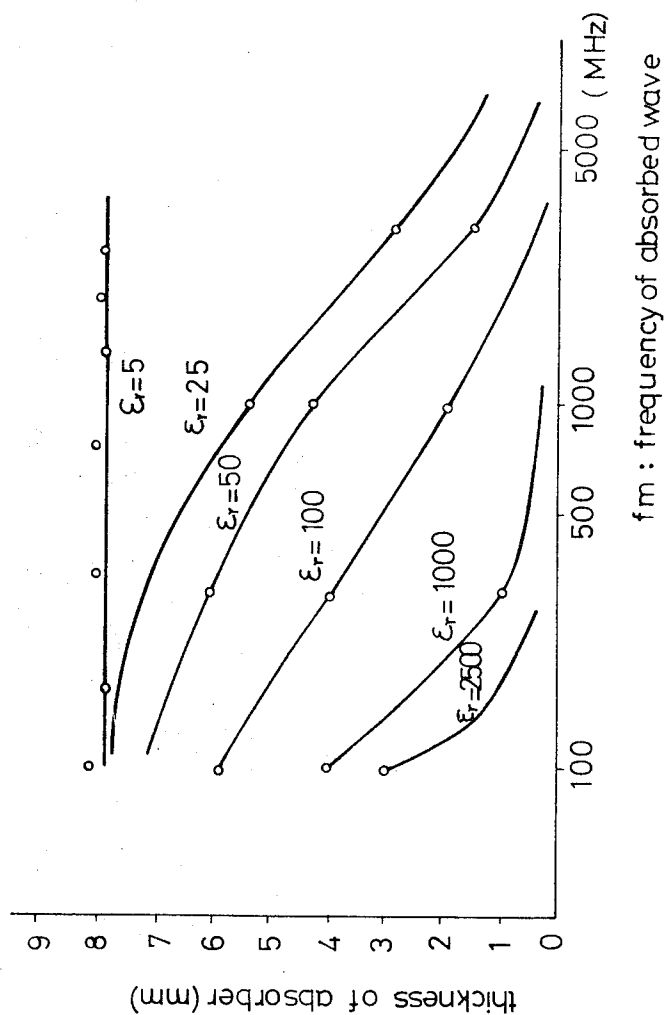


FIG. 7

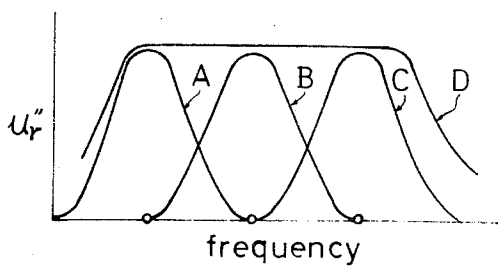


FIG. 8

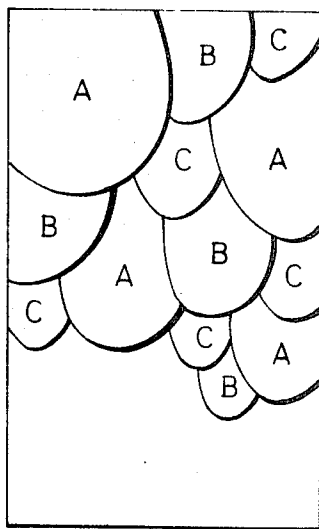


FIG. 9a

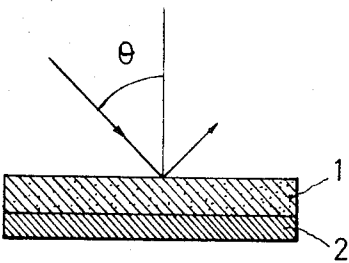


FIG. 9b

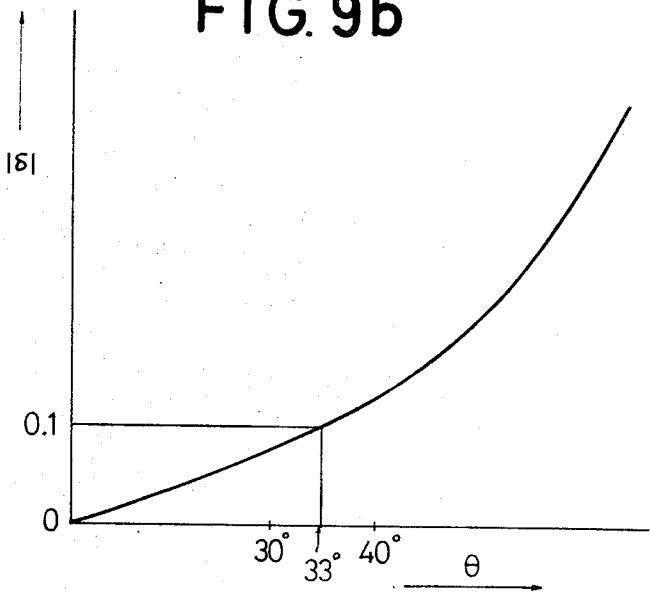


FIG. 10a

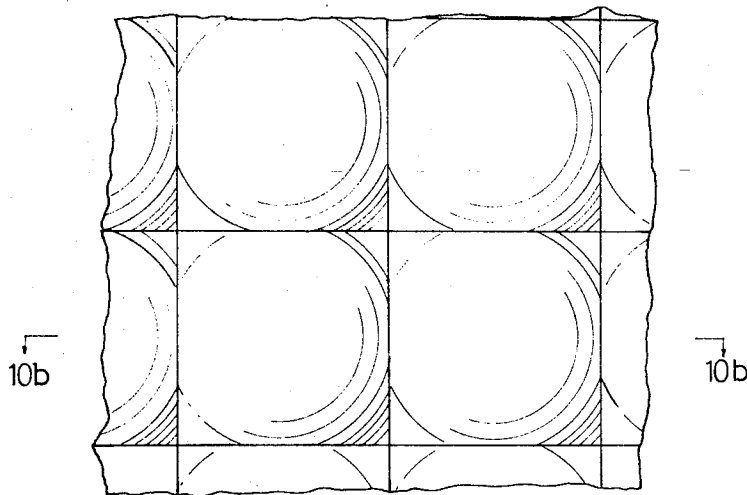
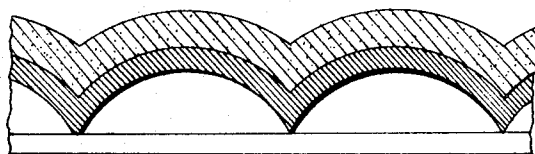


FIG. 10b



WIDE BAND FLEXIBLE WAVE ABSORBER

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 super-wide band wave absorber, and particularly to a super-wide band absorber composed of a mixture of ferromagnetic ferrite powder and dielectric materials.

BACKGROUND OF THE INVENTION

Wave absorbers are an important tool for research involving radio waves. They are widely used in many kinds of applications of radio engineering. One of the most important needs of users of wave absorbers is a thin wave absorber. This problem is universal to all kinds of waves from short to long wave lengths. It is generally known that the thickness of the absorbing wall has to be at least a half of the length of the wave to be absorbed. Accordingly, in order to absorb waves of lower frequency, which have longer wave lengths, conventional wave absorbers made of only dielectric material must be rather thick. For instance, a thickness of 150 cm. is necessary for absorbing a 100 MHz wave. It has been found that by using ferromagnetic ferrites, the thickness of the absorbing wall can be much reduced. Using ferrites, the thickness of the absorbing wall can be about 8 mm for almost all kinds of wave lengths, which represents a great reduction compared with the dielectric wall of the prior art. However, for some applications even this is too thick. Distorted television images resulting from the interference of reflections from water tanks, towers and high buildings, is a current problem which can be solved by coating the outer surface of the buildings with a wave absorber. However, the above mentioned 8 mm absorber is too thick for this purpose. Accordingly, thinner absorbers are demanded.

An object of this invention is to provide a thin wave absorber for the wide band of electromagnetic waves.

Another object of this invention is to provide a wide-band wave absorber composed of a mixture of one or more kinds of ferrite powders which have different magnetic resonant frequencies and a dielectric binder such as rubber or resin.

A further object of this invention is to provide a wave absorbant coating for a structure.

These and other objects, features and advantages of the invention will, in part, be pointed out with particularity and will, in part, become obvious from the following more detailed description of the invention, taken in conjunction with the accompanying drawings, which form an integral part thereof.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of a wave absorber;

FIGS. 2 a, b and c are cross-sectional views of various wave absorbers;

FIG. 3 is a Smith chart showing the characteristics of the wave absorber;

FIGS. 4 a, b, c and d are plane views of wave absorbers made to fit particular shapes;

FIGS. 5 a and b show the relation between the imaginary part of the complex specific magnetic permeability of absorbers having different types of ferrite compositions;

FIG. 6 shows the relation between the thickness of the absorber and the frequency of the wave to be absorbed;

FIG. 7 shows the resultant characteristics of a wave absorber composed of a mixture of various ferrites;

FIG. 8 is a plan view of an absorber composed of various kinds of ferrites;

FIG. 9 a shows the relation between the incident angle and the absorber, and FIG. 9 b shows the reflection ratio for the absorber of FIG. 9 a; and

FIGS. 10 a and b are plan and sectional views, respectively, of non-directional absorbers.

BRIEF DESCRIPTION OF PREFERRED EMBODIMENTS

The principles on which this invention is based relate to the use of the electromagnetic wave absorbing member described in U. S. Pat. No. 3,460,142.

This most important feature of this invention is the utilization of the properties of ferrites wherein specific magnetic permeability is represented by $\mu_r = \mu' - j\mu''$. The effective part, μ' , is greatly decreased and the loss part, μ'' , is greatly increased in the neighborhood of the resonant frequency, and μ'' , then decreases as the frequency increases above the resonant one.

As shown in FIG. 1, a ferrite plate 1, whose thickness is $\mu_1 2 \pi \mu''$, where λ is the wave length, is prepared and a metal plate 2 made from conductive material is fixed to one surface of the plate 1 by means of an adhesive of synthetic resin or the like. The electromagnetic wave 3 coming from the other surface is absorbed throughout a wide band of frequency. For example, if μ'' is 20 and the ratio of l/λ is 1/120, then l is less than 2.5 cm for a wave length of 3 m which corresponds to a frequency of 100 MHz. This represents a significant improvement over the conventional dielectric wall which would need a thickness of 1.5 to 2 m to absorb the same wave.

As shown in FIG. 2, two or more plates 1a, 1b made of various ferrites can be placed in contact with each other or spaced by gap 4. The thickness of the ferrite plates is chosen as described hereinafter. In this case, even if the individual characteristics of each ferrite plate does not satisfy the required conditions, a wide band wave can still be absorbed by a combination of the various ferrite plates.

There are, however, some problems in using these ferrite absorbers, namely:

1. A large plate cannot be easily produced because a thin ferrite plate made by a sintering process is often curved.

2. Ferrite plates cannot be placed directly on a curved surface without gaps resulting because the plates are like rigid tiles and cannot be shaped to conform to the surface. The gaps between the plates interfere with the absorption properties of the absorbing wall.

Thus, it would be desired to have a ferrite absorber capable of absorbing a wide band of electromagnetic waves whose thickness is less than 8 mm and being flexible. According to this invention, it is possible to achieve such a ferrite absorber.

In accordance with this invention, ferrite powder is mixed with dielectric material such as rubber and flexible plates are made of this mixture. If the mix ratio is properly chosen, flexible plates having the same magnetic properties as rigid plates can be obtained.

When the powder of Mg-Cu-Zn ferrite is mixed with rubber in the ratio of $w : 1$ (w parts of the ferrite to one part of rubber), the frequency of the wave to be absorbed is determined by w . The magnetic permeability of Mg-Cu-Zn ferrite is about 200 and it absorbs a wave of 500 MHz. But if rubber is added to this ferrite in a ratio wherein w is 3, 4.5 or 10, the frequency of the wave absorbed is 4,000, 2,200 or 1,500 MHz, respectively. When Mn-Zn ferrite whose magnetic permeability is about 5,000 is added to rubber wherein the ratio of w to rubber is 10:1, the frequency is 500 MHz. As is clear from the above example, if a ferrite of higher permeability is mixed with rubber, the same property as pure ferrite of lower permeability can be obtained.

Curves a and b of FIG. 3, respectively, show the properties of a flexible wave absorbing wall of this invention and those of a pure ferrite plate of the prior art. From the standard Smith chart of FIG. 3 the relation between the input impedance and the thickness of the sample can be seen.

In the above examples, thermoplastic resins such as butyl-rubber, neoprene or pyraprene can also be used as the dielectric material. The product is flexible, its thickness can be easily changed as the mix passes through a calender and a continuous long plate can be produced. The plate can be cut in any desired shape so that the wave absorbing wall can be fixed onto the surface of any configuration without any gap therebetween.

FIG. 4 shows the cross-sectional view of examples of the many shapes of wave absorbers according to this invention. FIGS. 4 a, b, c and d show respectively a stepped connection, a tapered connection, a wave-form connection and an insert connection. It is understood that in adapting the absorber of this invention to any surface without a gap, if the absorber is to be used as an absorbing wall, a metal plate is fixed on the back surface of the absorber.

In addition to the single ferrite mixture hereinbefore described, two or more kinds of ferrites whose magnetic resonant frequency are different from each other can be mixed so that any desired wide band characteristics and desired central working frequency can be obtained. The ferrites could be mixed with the dielectric material.

FIGS. 5a and b show the characteristic curves of the imaginary part of the complex specific permeability μ''_r as a function of the frequency f . FIG. 5 a shows these characteristics for absorbing plates made of the mixture of rubber and an individual one of the ferrites herein referred to as A, B and C. FIG. 5 b shows the characteristic of a single absorbing plate made of the mixture of rubber and a combination of the ferrites A, B and C. It can be seen that the imaginary part μ''_r of the permeability varies inversely to the frequency in a wide band.

For example, H_{3A} ferrite composed of 26.01 percent $MnCO_3$, 2.06 percent CuO , 17.39 percent ZnO and 54.53 percent Fe_2O_3 ; A_3 ferrite composed of 16 percent NiO , 34 percent ZnO and 50 percent Fe_2O_3 ; and M_3 ferrite composed of 25.2 percent MgO , 8.1 percent CuO , 18.6 percent ZnO and 47.3 percent Fe_2O_3 were prepared. H_{3A} , A_3 and M_3 are trade marks of the TDK Electronics Company LTD. The specific band is defined by the ratio B/f_0 where B is the band width and f_0 is the central frequency. When the value of the spe-

cific band B/f_0 is large, the characteristic of the ferrite is good.

The specific bands of ferrites H_{3A} , A_3 and M_3 are 14.3 percent, 22.6 percent and 22.4 percent, respectively. But the mixtures of A_3 and M_3 in the ratio of 1 : 1; M_3 and H_{3A} in the ratio of 1 : 1; A_3 and M_3 in the ratio of 2 : 1; and A_3 and M_3 in the ratio of 1.5 : 1 will have specific bands of 62 percent, 68.1 percent, 31 percent and 34.6 percent, respectively.

Thus, a flexible wave absorber can be made composed of the mixture of a plurality of ferrites whose magnetic resonant frequencies are different from each other and which exhibits wide band characteristics.

A further variation of this invention is to make a wave absorber by sintering the mixture of a dielectric powder having a high dielectric constant with the ferrite powder. An example of such material consists of

Ba Ti O ₃	74 mol %
Ba Zr O ₃	14 mol %
Ca Ti O ₃	9 mol %
Mg Ti O ₃	3 mol %

to which is added 0.2 percent by weight of $Mn CO_3$. The material is mixed and shaped. The product obtained from this process is presintered at 1,180° C for 2 hours, crushed and again shaped and sintered at 1,350° C for 2 hours. The resultant sintered material is again crushed and the powdered dielectric material thus obtained is mixed with ferrite. This process is most preferable. However, presintered dielectric material may be used and mixed with the ferrite without the additional sintered process.

FIG. 6 shows the characteristics of this type of absorber wherein the thickness is plotted as a function of frequency for various dielectric constants. It can be seen that the thickness necessary for absorbing a wave at a particular frequency is dependent upon the specific dielectric constant ϵ_r . As is clear from FIG. 6, by using dielectric material whose dielectric constant is more than 5, the thickness can be remarkably decreased. By using a dielectric substance having a high dielectric constant an absorbing wall can be had with very small thickness to the extent that it can be made into a paint. "Ghost" images can then be avoided by painting the outer surfaces of buildings with the wall absorber and thereby eliminate interference.

In addition to combining various ferrites into a mixture, the ferrites can be combined in other ways. For example, three kinds of ferrites, herein referred to as A, B and C, were prepared. The characteristic of the imaginary part of the complex specific permeability μ''_r as a function of the frequency for each of the ferrites A, B and C are shown respectively in FIG. 7. These ferrites were disposed in a random arrangement as shown in FIG. 8. In FIG. 8 the areas S_A , S_B and S_C occupied by the materials A, B and C can be determined by the following equations:

$$S_A = \lambda_A/80 A + \lambda_B + \lambda_C$$

$$S_B = \lambda_B/\lambda_A + \lambda_B + \lambda_C$$

$$S_C = \lambda_C/\lambda_A + \lambda_B + \lambda_C$$

Where λ_A , λ_B and λ_C are the matching frequencies of ferrites A, B and C, respectively.

The resultant characteristic of the absorber comprising ferrites A, B and C disposed as shown in FIG. 8 is shown by curve D in FIG. 7. As is clear from curve D,

the resultant absorber is effective over a wide range of frequencies.

In this example, the thickness of the various ferrites was uniform and the surface of the absorber of FIG. 8 was flat.

An application of the flexible wave absorber of this invention will now be described.

In general, a wave absorber is made of a ferrite plate 1 and a metal plate 2 as shown in FIG. 9a, and a good absorbing property can be obtained for waves arriving perpendicularly to the face of the absorber, but not for waves arriving obliquely to it.

As shown in FIG. 9a wherein the angle θ represents the incident angle of the electromagnetic waves onto the absorber, FIG. 9b shows the relation between the absolute value of the reflection ratio δ and the incident angle θ . As can be seen the reflection ratio δ is 10 percent when the incident angle is 33° though it is zero when the wave comes perpendicularly to the face of the absorber and θ is zero.

The wave absorber shown in FIG. 10 has a semi-spherical surface, and therefore, whatever direction the wave comes from, a part of the absorber is perpendicular to the incident wave. The absorber of FIG. 10 is composed of a metal plate 11, a semispherical, flexible absorbing ferrite 13, a semispherical metal plate adapted to the back surface of the ferrite 14.

The absorber shown in FIGS. 10a and 10b is practically produced by affixing the ferrite to the semispherical metal plate 14, and good absorbing property is obtained for the incident wave in all directions so that a non-directional absorber is provided.

Ferrites, the mixture of ferrite and rubber, and the mixture of ferrite and dielectrics can be used as the absorbing material of the absorber of FIGS. 10a and 10b.

There has been disclosed heretofore the best embodiment of the invention presently contemplated. However, it is to be understood that various changes and modifications may be made by those skilled in the art without departing from the spirit of the invention.

We claim:

1. An electromagnetic wave absorber comprising, a contiguous thin ferrite plate composed of a plurality of ferrite materials whose specific magnetic permeability is represented by the formula $\hat{\mu}_r = \mu'_r - j\mu''_r$, where μ'_r

is the effective part and μ''_r is the loss part, and wherein the μ''_r of each of the ferrite materials differs from the others, each of said ferrite materials forming a unique transverse section of said ferrite plate, said section being randomly arranged, and a metallic plate fixed to one surface of said ferrite plate.

2. A wave absorber as in claim 1 wherein each of said ferrite materials is composed of a mixture of ferrite and dielectric material.

3. A wave absorber as in claim 1 wherein the sections have a surface area determined by the formula

$$S = \frac{\lambda_1}{\sum_{n=1}^n \lambda}$$

where S , is the surface area of one of the sections λ , λ_1 , is the matching frequency of the ferrite material of that section and n is the total number of ferrite materials comprising the ferrite plate.

4. A wave absorber as in claim 2 wherein said dielectric material has a high specific dielectric constant.

5. A wave absorber as in claim 1 wherein each of said ferrite materials is further comprised of a mixture of at least two ferrites having different magnetic resonant frequencies.

6. A wave absorber as in claim 4 wherein said specific dielectric constant is more than five.

7. A wave absorber as in claim 2 wherein said dielectric material is further comprised of a ferroelectric material and a dielectric binder.

8. A wave absorber as in claim 1 wherein each of said ferrite materials is of uniform thickness and said ferrite plate is flat.

9. A wave absorber as in claim 2 wherein said dielectric material is rubber.

10. A wave absorber as in claim 2 wherein said dielectric material is a synthetic resin.

11. A wave absorber as in claim 2 wherein said mixture is in a predetermined ratio said ratio dependent upon the frequency of the wave to be absorbed.

12. A wave absorber as in claim 1 wherein said absorber has a semispherical shape.

13. The wave absorber as in claim 1 wherein said absorber is in the form of a plurality of semispheres.

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