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APPARATUS FOR ABSORPTION OF ELECTROMAGNETIC ENERGY REFLECTED FROM A DENSE PLASMA

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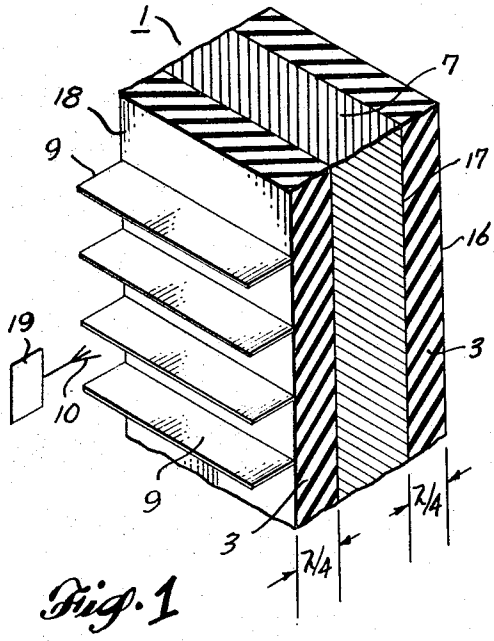


Fig. 1

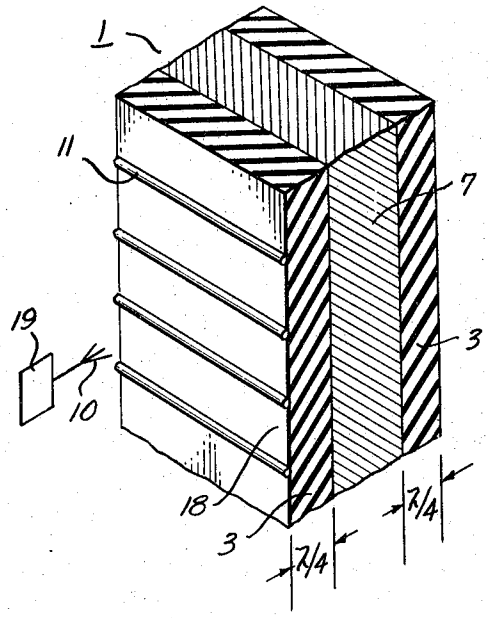


Fig. 2

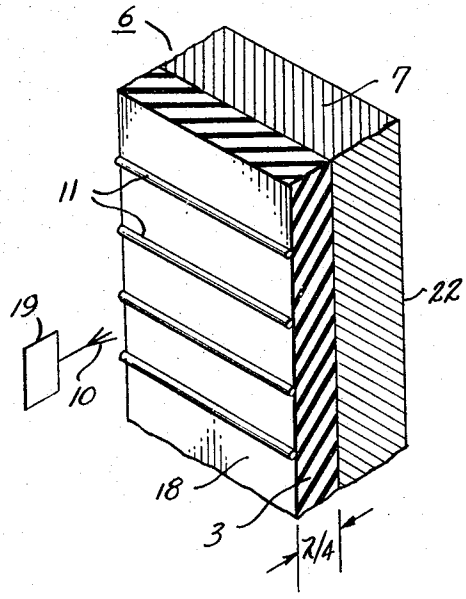


Fig. 3

INVENTOR.

GUILFORD L. HOLLINGSWORTH

BY

K. H. Thomas

ATTY.

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APPARATUS FOR ABSORPTION OF ELECTROMAGNETIC ENERGY REFLECTED FROM A DENSE PLASMA

Guilford L. Hollingsworth, Seattle, Wash., assignor to The Boeing Company, Seattle, Wash., a corporation of Delaware

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This invention relates to the transmission of electromagnetic energy through a dense plasma medium and more particularly to the removal of electromagnetic energy reflections caused by a dense plasma medium so as to prevent physical damage to a transmitter of said electromagnetic energy by said electromagnetic energy reflections.

The teachings of this invention involve subject matter related to a copending application Serial No. 346,792, filed February 24, 1964, and entitled Apparatus for Effecting the Transmission of Electromagnetic Energy Through a Dense Plasma; invented by Melvin J. Kofoid. In particular, an antenna window wall is used to achieve transmission of electromagnetic energy through a dense plasma medium in a manner described in the above-mentioned copending application. However, the teachings herein refer particularly to an antenna wall construction which presents a constant impedance when viewed from one side, i.e., the transmitter of electromagnetic energy side of the antenna window wall.

A typical situation in which the instant invention derives utility can be visualized by considering radio transmission from a high speed vehicle to a distant receiver. A layer of ionized gas commonly present about such a vehicle can cause essentially total reflection of transmitted radio signals, i.e., minimal transmission. As taught in the cited copending application, a window through such a dense plasma can be opened so as to effect almost total transmission of radio waves. However, additional reflection of transmitted energy may occur from reflecting media at some distance from the high speed vehicle; such reflected energy can cause damage to a transmitter where it is permitted to impinge thereon. It is therefore a feature of the instant invention to remove these last mentioned energy reflections before they impinge upon the transmitter.

The problem of removing reflected electromagnetic energy before damage to a transmitter results has met with varied solutions. For example, the use of the well-known "gyrator" which effectively "swallows," so to speak, reflected electromagnetic energy before such reflections can damage a transmitter.

As taught in the above-cited copending application an antenna cover wall will provide a strong magnetic field in proximity to a juxtapositioned dense plasma medium so as to effect almost total transmission, through the dense plasma, of electromagnetic energy. The antenna cover wall effectively eliminates reflections of electromagnetic energy on passage through the wall itself. However, the problem of reflection from a reflective medium located at a distance from the antenna cover wall must be controlled in order to prevent damage to the transmitter. The teachings of this invention provide a solution to this problem in a manner that is superior to others in the art from both an economy of weight and space concept, while maintaining high efficiency.

As set forth in the above-mentioned copending application, an antenna cover wall which incorporates a ceramic magnetic material sandwiched between and bonded to two dielectric sheets $\lambda/4+k(\lambda/2)$ in electric thickness, where k is zero or any whole number, will effectuate transmission of electromagnetic energy through the antenna cover wall with minimal attenuation and subsequently, with the same result, through a juxtapositioned dense plasma medium. As mentioned in the referred to copending application, once dielectric sheets of prescribed electric thickness are placed against a ceramic magnetic material and all materials are chosen to have a certain permeability constant and dielectric constant relationship, energy reflections are minimized regardless of the effect the ceramic magnetic material may have in causing angular rotation of the electric field vector of the electromagnetic energy. However, should this transmitted electromagnetic energy encounter additional dense plasma media at some distance outside the effect of the ceramic magnetic material's field, reflections of electromagnetic energy from the latter mentioned dense plasma media will occur and result in a net energy reflection arriving back at the transmitter.

Consider, therefore, an antenna cover wall of the type mentioned above but having a ceramic magnetic material of a type that will effect a one-way angular rotation of the electric field vector of electromagnetic energy equal to 45 degrees. That is, instead of a wall which causes an angular rotation of some arbitrary amount, we choose a ceramic magnetic material that will rotate, angularly, the electric field vector of electromagnetic energy 45 degrees as the electromagnetic energy passes one way through the antenna cover wall. Therefore, any energy which is reflected back towards the transmitter will pass again through the antenna cover wall and have experienced a total angular rotation of its electric field vector of 90 degrees. This reflected energy is effectively removed before it damages the transmiter by providing for a matched constant impedance on the transmitter side of the antenna cover wall. Therefore, in connection with the above antenna cover wall consider energy absorbing means such as several sheets of dielectric coated resistive material, having their surface planes parallel to one another and disposed between the transmitter of electromagnetic energy and the antenna cover wall. By transmitting electromagnetic energy so that the electric field vector is normal and non-coplanar to the above absorbing means, any reflection of the electromagnetic energy after passing through the antenna cover wall and again encountering the absorbing means will have had the electric field vector rotated 90 angular degrees, as discussed above, so as to now lie co-planar to the absorbing means. Absorption of the reflected energy is thereby effected, preventing reflected energy from impinging upon the transmitter. The invention as taught by this embodiment can be practiced by an antenna cover wall which rotates the electric field vector of electromagnetic energy 45 or $45+k(90)$ angular degrees as the electromagnetic energy passes one way through the antenna cover wall, where k is any whole number. With any of the above angular rotations, however, transmitted electromagnetic energy must impinge upon the absorbing means with the electric field vector normal and non-coplanar thereto.

The teachings of this invention are not restricted, however, to the use of a ceramic magnetic material which effectuates angular rotation of an electric field vector of $45+k(90)$ angular degrees, where k is zero or any whole number. Considering the above absorbing means which comprise sheets of resistive material, in order that reflected energy be effectively absorbed by said means the electric field vector of the reflected energy must be coplanar with the surface plane of the sheet of resistive material. In the above embodiment then, where the transmitted energy impinges upon the absorbing means with the electric field vector at some angle other than the angle representing an electric field vector normal to the absorb-

ing means, the electric field vector of reflected energy passing back through the antenna cover wall will have been rotated so that the electric field vector is now non-coplanar with the absorbing means and net energy reflection will reach the transmitter. Therefore, where energy is transmitted with the electric field vector at any angle other than that which is normal to the absorbing means, it is a feature of this invention to adapt the ceramic magnetic material of the antenna cover wall so as to again rotate the electric field vector of reflected energy into coplanar relation to the absorbing means.

Consider, for example, transmitted electromagnetic energy which impinges upon absorbing means such as sheets of resistive material with the electric field vector 30 angular degrees from the normal, i.e., making an angle of 60 degrees to the surface plane of the resistive sheets. In order that any possible reflections of this electromagnetic energy be prevented from impinging back on the transmitter after passing through an antenna cover wall, ceramic magnetic material of a type capable of rotating the electric field vector $30+k(180)$ angular degrees in a one way passage through said antenna cover wall is used where k is zero or any whole number. For example, where k is zero, total rotation of the electric field vector of reflected energy will be 60 degrees, again placing the electric field vector co-planar to the absorbing sheets. Thus, the combination of absorbing elements and ceramic magnetic material in precise relationship is used so that any net reflection of electromagnetic energy arrives at the absorbing means with the electric field vector coplanar with the absorbing means so as to eliminate said reflections.

It will be recognized from the above examples that many varied combinations of absorbing means and antenna cover walls are possible through this invention, to achieve a minimizing of absorption of transmitted electromagnetic energy and a maximizing of absorption of reflected electromagnetic energy.

Other embodiments of the invention provide different absorbing means. For example, several parallel metal wires placed at the transmitter side of the antenna cover wall. Electromagnetic energy with the electric field vector normal to the longitudinal axis of the parallel metal wires and passing through an antenna cover wall effecting a 45-degree angular rotation of the electric field vector will be prevented from reflecting back upon the transmitter by the combination of the 90-degree total angular rotation in traveling a round trip through the antenna cover wall and the absorbing wires.

Again, where transmited energy impinges upon the last mentioned absorbing means with the electric field vector normal thereto and subsequently passes through an antenna cover wall which effects angular rotation of the electric field vector of $45+k(90)$ degrees in a one way passage through the antenna cover wall, where k is zero or any whole number, any reflection of the electromagnetic energy passing back through the antenna cover wall will be absorbed by the combination of electric field vector rotation and said absorbing means. And, where transmitted electromagnetic energy impinges on the last mentioned absorbing means with the electric field vector at varied angles to the longitudinal axis of said absorbing means, absorption of reflected energy is accomplished within the scope of the teachings set forth above.

Therefore, it is an object of this invention to effectively eliminate reflections of electromagnetic energy occurring on transmission through a reflective medium before said reflections can interfere with a transmitter of said electromagnetic energy.

Another object of this invention is to effectively eliminate reflections of electromagnetic energy occurring on transmission through a reflective medium before said reflections can interfere with a transmitter of said electromagnetic energy by the use of a constant impedance provided by resistive material.

Other objects of this invention will be apparent from the following description in which:

FIG. 1 is an illustration of one embodiment of the teachings of this invention wherein the absorbing elements comprise parallel sheets of resistive material affixed perpendicularly to an antenna cover wall which includes: (1) a ceramic magnetic material, chosen to effect a predetermined angular rotation of the space electric vector of electromagnetic energy passing therethrough and sandwiched between; (2) two dielectric sheets;

FIG. 2 is an illustration of a second embodiment of the teachings of this invention wherein like components of FIGS. 1 and 2 have the same reference characters and wherein the absorbing elements comprise parallel wires of resistive material affixed to an antenna cover wall which includes: (1) a ceramic magnetic material, chosen to effect a predetermined angular rotation of the space electric vector of electromagnetic energy passing therethrough and sandwiched between; (2) two dielectric sheets; and,

FIG. 3 is an illustration of a third embodiment of the teachings of this invention wherein like components of FIGS. 1, 2 and 3 have the same reference characters and wherein the absorbing elements comprise parallel wires of resistive material affixed to an antenna cover wall which includes: (1) a ceramic magnetic material, chosen to effect a predetermined angular rotation of the space electric vector of electromagnetic energy passing therethrough and bonded to; (2) a single sheet of dielectric.

Although it is taught in the embodiments of FIGS. 1, 2 and 3 that the absorbing elements are affixed to the antenna cover wall, it is to be understood that operativeness of this invention is not dependent thereon. The embodiments of FIGS. 1, 2 and 3 work equally well when the absorbing elements are simply disposed between the transmitter of electromagnetic energy and the antenna cover wall.

Referring to FIG. 1, a composite antenna cover wall **1** is illustrated comprising a magnetized ferrite sheet **7** of a type ferrite in which the degree of angular rotation of the space electric vector of electromagnetic energy effected in a one-way passage through said magnetized ferrite sheet **7** is 45 degrees. The magnetized ferrite sheet **7** has arbitrary electrical thickness and is sandwiched between and bonded to two dielectric sheets **3** which are each $\lambda/4$ in electrical thickness. Hereinafter, whenever $\lambda/4$ is designated as proper electric thickness, it is to be understood that $\lambda/4$ plus any number of half-wave lengths in electrical thickness is appropriate. The dielectric constant ϵ_7 of the magnetized ferrite sheet **7** is equal to the dielectric constant ϵ_3 of the dielectric sheets **3** raised to the second power, i.e. $\epsilon_3^2=\epsilon_7$.

In combination with the antenna cover wall **1** of FIG. 1 is a radiator of electromagnetic energy **10** and parallel absorbing elements **9** affixed perpendicularly to the plane of the dielectric sheet **3**. The dielectric sheet **3** to which the absorbing elements **9** are affixed is the dielectric sheet **3** which is situated most proximate to the electromagnetic energy radiator **10**. The absorbing elements **9** may physically be of any of several forms known to the electrical art; thin sheets of resistive material having a dielectric coating for example.

In operation, upon transmitting electromagnetic energy through the antenna cover wall **1** from left to right as shown, there will be no absorption of electromagnetic energy by the absorbing elements **9** since the electric field vector of the electromagnetic energy is transmitted normal to the absorbing elements **9**. After the electromagnetic energy has left the antenna cover wall **1** and passed through a juxtapositioned dense plasma medium with essentially zero reflection, i.e., minimal attenuation, any reflection of the electromagnetic energy which occurs from a reflecting medium outside of the influence of the antenna cover wall's magnetic field will pass back through the antenna cover wall **1** from right to left as shown and will arrive at the front of the antenna cover wall **1**, i.e.,

interface **18**, with the electric field vector lying coplanar with the surface plane of the absorbing elements **9**. Thus, electromagnetic energy transmitted with the electric field vector in a plane normal to the antenna absorbing elements **9** and passing through the antenna cover wall **1** of FIG. 1 from left to right as shown will be prevented from traveling from right to left as shown, i.e., from the interface **18** to a transmitter **19**, by the combination of 90-degree angular rotation of the electric field vector in traveling a round trip through magnetized ferrite sheet **7** of the antenna cover wall **1** and encountering the absorbing elements **9** at interface **18**. Hereinafter, whenever a magnetized ferrite sheet **7** effecting a 45-degree angular rotation of the electric field vector is specified, it is to be understood that $45+k(90)$ degrees is appropriate where k is zero or any whole number.

In the embodiment of FIG. 2 the antenna cover wall **1** is exactly the same as in the embodiment of FIG. 1. As shown in FIG. 2, however, the absorbing elements **11** comprise parallel metal wires affixed to the surface of the dielectric sheet **3** most proximate to the electromagnetic energy radiator **10**. Reflected electromagnetic energy will be absorbed and thus prevented from impinging upon the transmitter **19** in the manner described in FIG. 1; i.e., by the combination of 90-degree angular rotation of the electric field vector in traveling a round trip in magnetized ferrite sheet **7** of the antenna cover wall **1** and encountering the absorbing elements **11** at interface **18**.

The embodiment of FIG. 3 discloses an antenna cover wall **6** which differs from the embodiment of FIG. 2 only in that a $\lambda/4$ dielectric sheet **3** on the side of antenna cover wall **6** farthest from the radiator **10** of electromagnetic energy has been removed. While the antenna cover wall **1** of FIGS. 1 and 2; (1) effects transmission of electromagnetic energy through the antenna cover wall and a juxtapositioned plasma with minimal reflection of electromagnetic energy; and (2) provides for constant impedance as seen from the radiator **10** of electromagnetic energy side of said antenna cover wall **1**, the antenna cover wall **6** of FIG. 3 will not provide transmission of high frequency electromagnetic energy with substantially zero reflection of transmitted electromagnetic energy but will offer a constant impedance load as seen from the transmitting side. However, the antenna cover wall **6** of FIG. 3 has the advantage that if a medium at interface **22** of the antenna cover wall **6** has a dielectric constant with any value between unity and the square of the dielectric constant of the magnetized ferrite **7**, the worst reflection of electromagnetic energy encountered will be simply that which would be with air associated with a single interface reflection of the magnetized ferrite **7**, i.e., that occurring at interface **17** illustrated in FIG. 1. This feature provided by antenna cover wall **6** is of considerable advantage when the media at interface **22** is ionized gas existing either as the plasma sheath about a high-speed vehicle or produced by breakdown of the air outside of the window when high power electromagnetic energy is transmitted. As pointed out above, the embodiment of FIG. 3 presents a constant impedance when viewed from the transmitter **19** side of antenna cover wall **6**. Reflections are thus absorbed at interface **18** by absorbing elements **11** in the same manner as in FIG. 2.

Since numerous changes may be made in the above apparatus and different embodiments may be made without departing from the spirit and scope thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. A composite mechanical structure disposed to cooperate with a radiator of electromagnetic energy and to effect electromagnetic energy transmission through the composite mechanical structure and subsequently through a juxtapositioned dense plasma medium with a minimum of attenuation of electromagnetic energy and to absorb electromagnetic energy reflected from a reflecting medium at a distance from the composite mechanical structure comprising:

(a) at least one sheet of ceramic magnetic material;

(b) at least one sheet of a dielectric material affixed to said sheet of ceramic magnetic material; and,

(c) energy absorbing elements disposed at said at least one sheet of dielectric material said at least one sheet of a dielectric material being interposed between said ceramic magnetic material and said energy absorbing elements in sandwich fashion.

2. Apparatus for elimination of electromagnetic energy reflected from a reflecting medium comprising:

(a) a sheet of arbitrarily thick but uniformly thick ceramic magnetic material bonded to and sandwiched between;

(b) two dielectric sheets, at least one of said dielectric sheets having disposed at its surface a plurality of energy absorbing elements, said last mentioned dielectric sheet being most proximate to a radiator of electromagnetic energy, whereby electromagnetic energy passes from said radiator through said apparatus.

3. The combination defined in claim **2** wherein each sheet of said dielectric material is $\lambda/4+k(\lambda/2)$ in electrical thickness, where k represents zero or any whole number.

4. The combination defined in claim **2** wherein said ceramic magnetic material has a dielectric constant equal to the dielectric constant of the dielectric sheets raised to the second power.

5. The combination defined in claim **2** wherein said energy absorbing elements are thin sheets of resistive material, parallel to one another and affixed perpendicularly at the surface of a dielectric sheet most proximate to the radiator of electromagnetic energy.

6. The combination defined in claim **2** wherein said energy absorbing elements include wires of resistive material disposed parallel to one another at the surface of a dielectric sheet most proximate to the radiator of electromagnetic energy.

7. Apparatus for elimination of electromagnetic energy reflected from a reflecting medium comprising:

(a) a sheet of arbitrarily thick but uniformly thick ceramic magnetic material bonded to;

(b) a dielectric material having energy absorbing elements disposed at a surface of said dielectric material said dielectric material being disposed between said sheet of arbitrarily thick but uniformly thick ceramic magnetic material and said energy absorbing elements in sandwich fashion and said energy absorbing elements being most proximate to;

(c) a radiator of electromagnetic energy disposed to cooperate with said apparatus so that electromagnetic energy emitted from said radiator passes through said apparatus and through a juxtapositioned plasma medium with minimum attenuation.

8. The combination defined in claim **7** wherein said dielectric material is $\lambda/4+k(\lambda/2)$ in electrical thickness, where k represents zero or any whole number.

9. The combination defined in claim **8** wherein said ceramic magnetic material has a dielectric constant equal to the dielectric constant of the dielectric sheets raised to the second power.

10. The combination defined in claim **9** wherein said energy absorbing elements include metallic wires parallel to one another and affixed to a surface of said dielectric material most proximate to the radiator of electromagnetic energy.

11. The combination defined in claim **10** wherein said energy absorbing elements include parallel sheets of resistive material affixed to a surface of said dielectric material most proximate to the radiator of electromagnetic energy.

12. A composite mechanical structure disposed to cooperate with a radiator of electromagnetic energy and to effect electromagnetic energy transmission through the composite mechanical structure and subsequently through a juxtapositioned dense plasma medium with a minimum of attenuation of electromagnetic energy and to absorb electromagnetic energy reflected from a reflecting medium at a distance from the composite mechanical structure comprising:

(a) at least one sheet of arbitrarily thick but uniformly thick ceramic magnetic material bonded to;

(b) at least one sheet of a dielectric material, having energy absorbing elements disposed at a surface of said at least one sheet of dielectric material, said at least one sheet of a dielectric material being disposed between said at least one sheet of arbitrarily thick but uniformly thick ceramic magnetic material and said energy absorbing elements in sandwich fashion and said energy absorbing elements being most proximate to the radiator of electromagnetic energy and wherein each sheet of said dielectric material is $\lambda/4+kx(\lambda/2)$ in electrical thickness, where k represents zero or any whole number.

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CHESTER L. JUSTUS, *Primary Examiner.*

G. M. FISHER, *Assistant Examiner.*