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MICROWAVE PROPAGATING STRUCTURES

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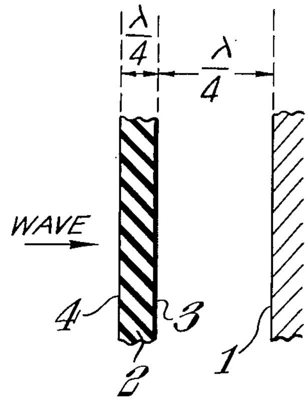

Fig. 1.

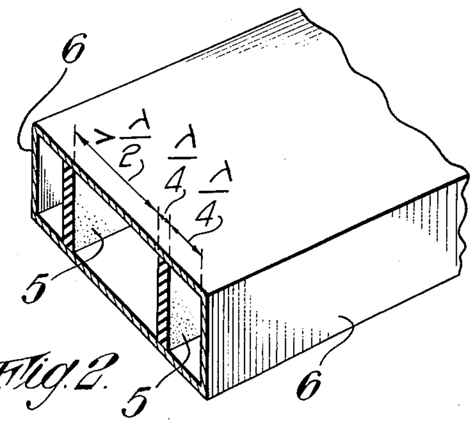

Fig. 2.

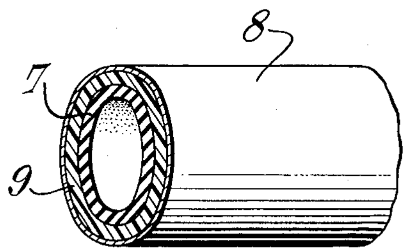

Fig. 3.

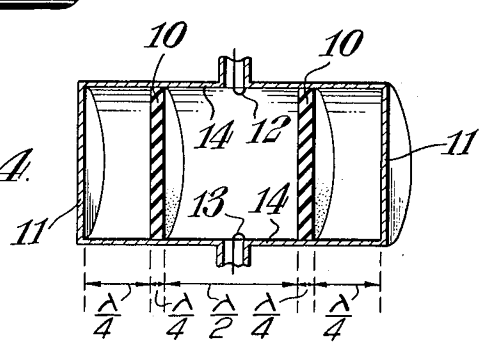

Fig. 4.

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MICROWAVE PROPAGATING STRUCTURES

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This invention relates to microwave propagating structures.

In all microwave devices some power is absorbed by the walls containing the electromagnetic fields, and in many cases the efficiency of the device is largely determined by this wall loss. With metal walls the effective surface resistance increases with frequency owing to skin effect, and so wall loss becomes a more serious problem at higher frequencies. There is no known material which approaches a metal in reflecting power, but the present invention provides means whereby the transformer property of a quarter-wave thickness of dielectric material can be used to provide a surface which is highly reflecting.

According to the present invention in a microwave propagating structure comprising at least one reflecting surface, said surface comprises at least one quarter-wave layer of dielectric material having a loss factor tan δ and a dielectric constant ϵ spaced a quarter-wave from a metal surface, the dielectric material being such as to satisfy the condition

$$\frac{\tan \delta\sqrt{\epsilon}}{\epsilon-1}\,\frac{1}{30\pi 2}\cdot\sqrt{\frac{\mu\omega}{2g}}$$

where ω is the angular frequency, and g and μ are the conductivity and permeability respectively of the metal surface.

To compare the reflecting quality of different surfaces, the ratio of absorbed power to incident power may be taken, and for most purposes a satisfactory comparison can be made by evaluating this ratio for a plane surface on to which a wave is incident in the direction of the normal.

For waves in free space and for all propagating modes in a waveguide the ratio of the amplitudes of the transverse E and H field components is constant and is known as the wave impedance. Since the power flow depends only on the transverse field components it is convenient to express the absorption ratio r in terms of the characteristic impedance Z_A of the incident wave and the impedance Z_1 existing at the absorbing surface. It can be shown that

$$r=4\,ReZ_1\left[\frac{Z_A}{Z_1+Z_A}\right]^2/ReZ_A$$

where ReZ_1 and ReZ_A are the real parts of the complex impedances Z_1 and Z_A.

This ratio tends to zero if Z_1 is very large or very small compared with Z_A, and hence a perfect reflection occurs if the wall acts as an open or as a short circuit. The open-circuit case is not of practical interest. In the short-circuit case the ratio reduces to $4ReZ_1/ReZ_A$.

Consider now the ideal case of a quarter-wave thickness of loss-free dielectric material of characteristic impedance Z_D placed in contact with a metal surface of impedance Z_M. The impedance at the outer (absorbing) face of the dielectric is $Z_D{}^2/Z_M$, i.e. the impedance is inverted. If two dielectric layers are used, having impedances Z_{D1} and Z_{D2}, the latter referring to the material in contact with the metal, the impedance at the outer (absorbing) face is $(Z_{D1}/Z_{D2})^2Z_M$. The process can be continued for multi-layers, each additional layer causing a further inversion.

The case of present interest is that involving an even number of quarter-wave layers, for example, two. Since

for enhanced reflection the impedance at the outer face should be low, it is clearly desirable that Z_{D2} should be large compared with Z_{D1}. For non-magnetic materials the highest wave impedance is that of free space Z_A, and hence the greatest effect is obtained by the use of dielectric layers separated by air spaces.

To enable the nature of the present invention to be more readily understood attention is now directed by way of example to the accompanying drawings wherein:

FIG. 1 is a cross-sectional view of part of a metal surface having a dielectric layer spaced therefrom.

FIG. 2 is a cross-sectional perspective view of a waveguide of rectangular section.

FIG. 3 is a similar view of a waveguide of circular section.

FIG. 4 is a longitudinal section of a cylindrical resonant cavity shown in perspective.

In FIG. 1 a quarter-wave thick sheet of dielectric material **2** is spaced a quarter-wave from a metal surface **1**. As the air space may be regarded as loss free, the wave impedance at the inner surface **3** of the dielectric $Z_A{}^2/Z_M$ as already mentioned, where Z_A and Z_M are again the impedances of free space and of the metal surface respectively. If tan δ is the loss factor of the dielectric material and if tan δ is less than 10^{-3}, which is the case for low-loss materials, then, with an error of less than 0.1%, the wave impedance Z at the outer surface **4** may be written

$$Z=\frac{Z_D{}^2}{Z_A}Z_M+\frac{\pi}{4}\cdot\tan\delta.Z_D \qquad (1)$$

The first of these terms, $(Z_D/Z_A)^2Z_M$ takes account of the metal wall and shows that the loss in the metal wall is reduced by the factor $(Z_D/Z_A)^2$ as mentioned previously. The second term, $\pi/4\tan\delta.Z_D$ depends entirely on the dielectric and accounts for energy absorbed therein. The condition that the reflection from surface **4** is better than that from surface **1** without the interposition of layer **2** is that $ReZ<ReZ_M$ and hence from (1) that

$$\tan\delta<\left(\frac{4}{\pi Z_D}\right)\cdot 1-\frac{Z_D{}^2}{Z_A}ReZ_M \qquad (2)$$

It may be shown that this is a perfectly general condition applicable to any number of layers of the dielectric material separated by air spaces.

Evaluating Z_D and Z_A for an unbounded plane wave, Equation 1 becomes

$$Z=1/\epsilon.Z_M+30\pi 2\,.\tan\delta/\sqrt{\epsilon} \qquad (3)$$

and inequality (2) becomes, after re-arrangement

$$\tan\delta.\sqrt{\epsilon}/(\epsilon-1)<Re\,Z_M/30\pi^2 \qquad (4)$$

As

$$ReZ_M=\sqrt{\frac{\mu\omega}{2g}}$$

where ω is the angular frequency and g and μ are the conductivity and permeability respectively of the metal surface, Equation 4 becomes

$$\frac{\tan\delta.\sqrt{\epsilon}}{\epsilon-1}<\frac{1}{30\pi^2}\cdot\sqrt{\frac{\mu\omega}{2g}} \qquad (5)$$

It is doubtful if a metal surface can be prepared which has an effective conductivity greater than 6×10^7 mhos/metre (pure silver) and hence the use of dielectric materials for which

$$(\tan\delta.\sqrt{\epsilon})/(\epsilon-1)$$

is less than 5×10^{-5} at 300 mc./s. or 9×10^{-5} at 10,000 mc./s. would effect an improvement.

The wall loss is reduced by the factor $R=ReZ/ReZ_M$

which, for a single quarter-wave thickness of dielectric in the unbounded case is

$$R=\frac{1}{\epsilon}+(\tan\delta/\sqrt{\epsilon})\,30\pi^2/ReZ_M \qquad (6)$$

The most suitable materials are ceramics having dielectric constants in excess of 10. If ϵ is large Equation 6 reduces to

$$R=(\tan\delta/\sqrt{\epsilon}).30\pi^2/ReZ_M \qquad (7)$$

Ceramics consisting mainly of titanium dioxide are known to have a tan δ of between 2×10^{4} *and* 3×10^{-4} and an ϵ of about 90. From Equation 7 such materials might be expected to give a loss reduction of about ½, which has been confirmed by experiment. The factor tan

$$\tan\delta\sqrt{\epsilon}$$

can be further reduced by using a laminated dielectric/air material in the manner described by Shersby-Harvie et al. in Proc. I.E.E., Paper No. 2127M, July 1956, provided the electric field is substantially normal to the direction of lamination.

Equation 1 gives the impedance at the surface of a quarter-wave layer of dielectric placed at a distance of a quarter of a guide wavelength from a plane end wall in a waveguide of any section. In the case of a rectangular guide, as shown in FIG. 2, the expression also applies to dielectric layers **5** spaced from the narrow faces **6**. A similar layer in the form of a coaxial tube can also be used with a guide of circular section as shown in FIG. 3 but the analysis of reflections require a slightly modified treatment especially if the dielectric thickness is an appreciable fraction of the guide radius. In FIG. 3 a coaxial dielectric layer **7** is spaced from the guide wall **8** by a layer **9** of expanded polyethylene.

The effect of introducing material into the space between the dielectric and the wall is to modify the left-hand expression in Equation 5 to read

$$\frac{\tan\delta.\sqrt{\epsilon_2}}{\epsilon_2-\epsilon_1}$$

where ϵ_2 and ϵ_1 are the dielectric constants of the dielectric and of the spacing material respectively, provided that the loss in the spacing material is so small compared with that in the dielectric that it can be neglected, which is the case with materials such as expanded polyethylene or expanded polystyrene. Furthermore since with these materials ϵ_1 is only slightly greater than 1 (about 1.03), in the practical case the effect of the spacing material on the expression can be ignored.

In the cylindrical resonant cavity shown in FIG. 4 two discs **10** of dielectric material are spaced from the end walls **11** of the cavity, which is fed by an input loop **12** located opposite an output loop **13**. The cavity losses could be still further reduced by increasing the radius of the side wall **14** by $\lambda/4$ and adding a cylindrical dielectric liner (not shown) spaced $\lambda/4$ from the side wall between the discs **10**.

It may be shown that the reduction in end-wall losses is substantially independent of whether H- or E-mode waves are propagated, provided $\epsilon>10$, except near the cut-off frequency. Hence, in practical cases, the reduction in wall loss obtained in a waveguide or resonant cavity is little different from that obtained for the unbounded wave in Equation 7.

Reflecting surfaces according to the present invention are essentially frequency-sensitive, but this can be advantageous. For example in resonant cavity applications they enable the Q-factor of one cavity resonance to be improved while those of all the other resonances are made worse.

We claim:

1. A microwave propagating structure comprising at least one reflecting surface, wherein said surface comprises at least one quarter-wave layer of dielectric material having a loss factor δ and a dielectric constant ϵ spaced a quarter-wave from a metal surface by a spacing material of substantially negligible loss, the dielectric material being such as to satisfy the condition

$$\frac{\tan\delta.\sqrt{\epsilon}}{\epsilon-1}<\frac{1}{30\pi^2}.\sqrt{\frac{\mu\omega}{2g}}$$

where ω is the angular frequency, and g and μ are the conductivity and permeability respectively of the metal surface.

2. A rectangular waveguide constituting a structure as claimed in claim 1, wherein said reflecting surface forms a narrow face of the guide, and said layer extends between the broad faces of the guide.

3. A circular waveguide constituting a structure as claimed in claim 1, wherein said layer is an internal coaxial tube.

4. A resonant cavity constituting a structure as claimed in claim 1.

5. A microwave propagating structure according to claim 1 wherein said spacing material is air.

6. A microwave propagating structure according to claim 1 wherein said spacing material is expanded polyethylene.

7. A microwave propagating structure according to claim 1 wherein said spacing material is expanded polystyrene.

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