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MICROWAVE FREQUENCY-SELECTIVE MODE ABSORBER

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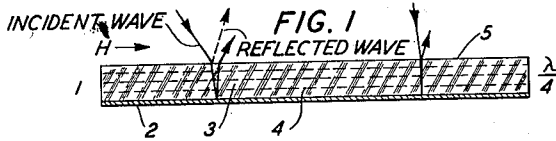


FIG. 2

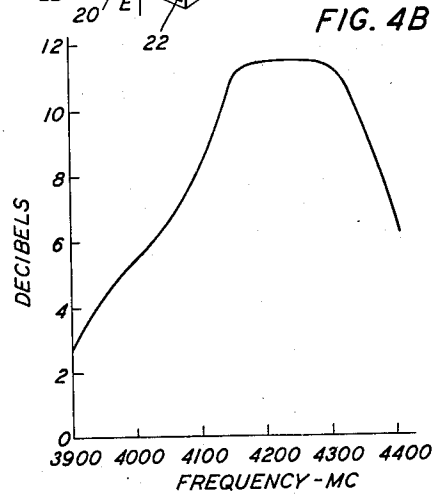
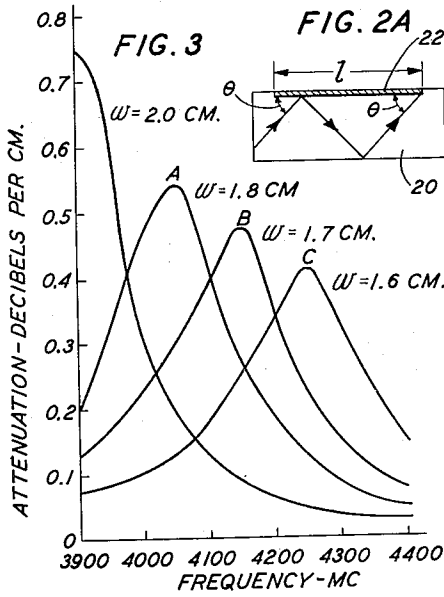
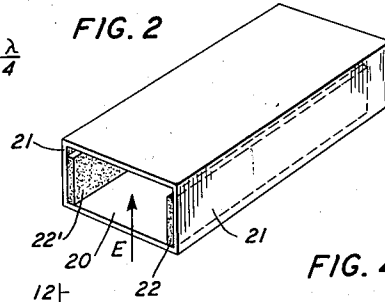


FIG. 4A

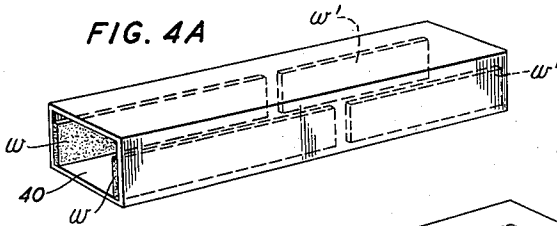


FIG. 5

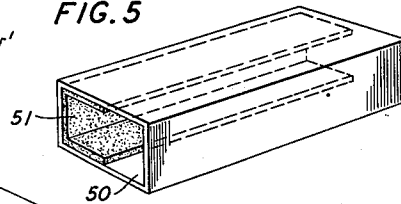


FIG. 6 A

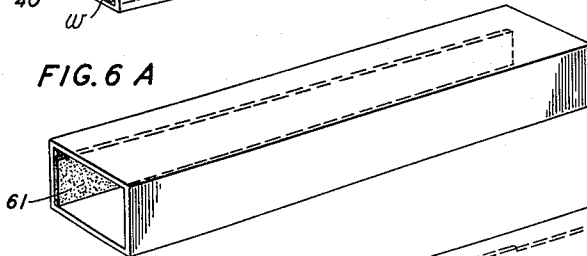


FIG. 6B

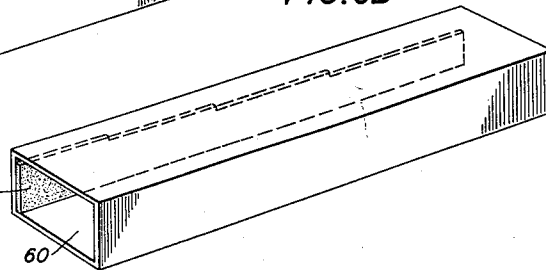
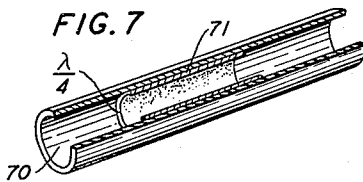


FIG. 7



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MICROWAVE FREQUENCY-SELECTIVE MODE ABSORBER

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This invention relates to microwave filters, networks and the like.

An object of this invention is to simplify the construction of frequency-selective filters and networks utilizing waveguide components, particularly in the range of 1 to 100-millimeter wavelength.

Another object of the invention is to incorporate frequency-selective characteristics in hollow conductors and wave guides, without introducing impedance mismatches or secondary reflections along the direction of propagation, by lining the walls of the conductors or wave guides with thin strips of metallically loaded dielectric material of high effective dielectric constant k .

A feature of the invention is a microwave frequency-selective circuit comprising a hollow wave guide lined with energy-absorbing dielectric sheets, having metallic flakes dispersed therethrough, to thereby provide effective dielectric constants k of the order of 100 to 10,000 in a direction parallel to the electric field vector E . The loaded dielectric sheets are a quarter wavelength in effective thickness for selectivity and have a metallic foil backing for reflecting waves back into the sheet. The sheets are so thin with respect to the cross-section of the wave guide as to present correspondingly small transition discontinuities to the propagated waves.

Heretofore, various types of wave-guide filters and networks were known which utilized sections of wave guide provided with tuning stubs, screws, adjustable irises and fixed projections connected to the walls thereof. As the wavelength decreased toward the millimeter range, such devices became increasingly difficult to manufacture, particularly in view of the restricted size of cross-section in the hollow guides and the severe limits of manufacturing tolerance involved.

Moreover, wave-guide selective circuits of the past have suffered from the disadvantage of not possessing a constant impedance throughout the frequency-selective range.

The frequency-selective linings of the present invention remove this disadvantage in that their presence in the wave guide does not alter substantially the impedance exhibited at the input or output of the containing wave-guide section per se. The transmission of waves through these lined guides is substantially free from the presence of secondary reflected waves propagating along the principal wave-guide axis.

Accordingly, in accordance with various embodiments of the present invention, longitudinal sheets of loaded dielectric material, $\lambda/4$ in effective thickness, are provided as a lining for the walls of the wave guides, to thereby provide various frequency-selective characteristics. The loaded dielectric may consist of thin superposed layers of rubber or the like, having fine carbon and microscopic sized aluminum flakes or the like dispersed uniformly therethrough to provide absorption effects and dielectric constants k , as high as 1500 when the electric field vector is parallel to the sheet. Sheets of this material need be

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only a few mils thick to equal $\lambda/4$ for waves in the centimeter range, in order to provide frequency selectivity characteristics in the wave guide lined thereby.

Electromagnetic wave energy of a narrow range of frequencies transmitted through such a lined wave guide is either absorbed directly in the lining material or reflected by the metal foil backing into the dielectric sheet for additional absorption.

The principal dimension of the anisotropic dielectric determining the absorption frequency thereof is its thickness. However, it has been discovered experimentally that the width of the longitudinal strip also effects the frequency absorbed, so that it can also be utilized as a secondary parameter for frequency variation.

Because of its absorptive characteristic, such a strip lining the side wall of a wave guide, will absorb selectively energy at a particular frequency from a wide band of input waves, providing thereby a single-frequency or a narrow-band elimination filter. Wide band filtering can be accomplished by using two or more strips in a wave guide, wherein the additive combination of the individual characteristics of the separate elimination filters aforementioned produces the requisite wider band over-all characteristic.

Referring to the figures of the drawing:

Fig. 1 shows in cross-section a sheet of metallically loaded dielectric material, which is frequency selective;

Fig. 2 shows a rectangular wave-guide filter lined thereby in accordance with the invention;

Fig. 2A is an explanatory diagram for illustrating the wave propagation in a lined wave guide;

Fig. 3 shows attenuation-frequency characteristic curves for the filter of Fig. 2;

Fig. 4A shows a wide band, elimination wave-guide filter in accordance with the invention;

Fig. 4B shows its attenuation versus frequency curve;

Fig. 5 shows a modification of the Fig. 2 type of wave-guide filter;

Figs. 6A and 6B show modifications utilizing tapered lining sheets in a wave guide; and

Fig. 7 shows a lined cylindrical wave guide used as a frequency filter for TE_{01} waves.

Fig. 1 shows a sheet of material known in the art as Harp material (i. e., Halpern's Anti Radar Paint) or a similar form of loaded dielectric, having an effective thickness of one-quarter wavelength, and mounted on a reflecting surface which comprises a backing of metal foil 2. The loaded dielectric 1 consists of a rubber matrix 3 having small aluminum flakes 4 or the like dispersed therethrough rather uniformly with their surfaces and major axes parallel to the metal foil 2. With aluminum loaded dielectrics, as in Fig. 1, effective dielectric constants k as high as 1500 for 10-centimeter waves have been attained. In addition, the sheet 1 contains some lossy, absorbing material, such as fine carbon particles or the like admixed therethrough.

The sheet 1 may be formed by spraying or painting successive layers of a liquid rubber having admixed therein lossy carbon particles and microscopically fine aluminum flakes for attaining high dielectric constants k as a forementioned. Each deposited layer has a thickness less than the length of the flakes, whereby the latter orient themselves parallel to the backing surface 2. The first layer is deposited on the backing 2 and allowed to dry, whereupon successive layers are similarly deposited until the proper thickness is achieved. This may be determined experimentally by placing a horn transmitter and a horn receiver above the backing plate and measuring the received power as the successive layers are built up. A sheet effectively $\lambda/4$ in thickness, where λ is the wavelength of incident microwaves, may in this

manner be built up, which will be critically selective and absorb the energy of the incident wavelength λ . When the rubber hardens, it provides a supporting matrix for the metal flakes and provides electrical insulation therebetween.

The required electrical conductivity σ of the sheet 1 is given by:

$$\sigma = 0.5v\sqrt{k}10^{-10} \text{ mhos/meter}$$

where k is the effective dielectric constant of the loaded sheet parallel to the electric vector E and v the frequency. In practice, absorption coefficients obtained are of the order to 95 to 98 per cent.

The dielectric thickness d required for maximum absorption in the sheet is:

$$d = \frac{1}{4} \frac{\lambda}{\sqrt{k}}$$

The loaded dielectric sheet 1 is anisotropic due to the layering in its mode of manufacture and exhibits the high dielectric constant k aforementioned when the electric vector E of the propagating waves is parallel to backing surface 2.

Microwaves incident upon the top surface 5 are partially reflected and partially transmitted as shown in Fig. 1. The transmitted component undergoes loss in passing through the lossy dielectric 1 toward the metal foil 2, which then reflects it so that it arrives again at the surface with a reversal in phase and with added loss. If the lossy admixture in sheet 1 be properly proportioned, the transmitted component will just cancel the initially reflected component at surface 5. Energy absorption occurs throughout the sheet over a fairly broad angle due to the high index of refraction of the loaded dielectric 1. Since the path length $\lambda/4$ in the sheet 1 is an important factor in creating the proper boundary conditions for wave cancellation at the incident surface 5, and since the path length is nearly constant over a wide range of incident angles, absorption occurs over relatively wide angles of incidence.

Fig. 2 shows a rectangular wave guide 20 having its side walls 21 lined with identical sheets 22, 22' of loaded dielectric of the type disclosed previously in Fig. 1. However, a single lining sheet 22 may be used if desired, although two sheets as shown provide a greater total absorption of energy. In either case, impedance matching is provided over a wide band of frequencies due to the non-existence of secondary waves propagating along the guide axis.

Dominant waves E transmitted through the rectangular wave guide 20 are absorbed at a particular frequency by strips 22, 22' and it is possible to control the maximum or peak frequency of such absorption by either varying the thickness or width of the sheet. In order to make the resonance as sharp as possible, it is necessary to use as wide a strip as will fit inside the wave guide and then the resonant frequency is determined by adjusting the thickness of the dielectric sheet.

A preferred physical picture of this phenomenon may be presented thus. The dominant waves E transmitted through the rectangular wave guide 20 may be considered as composed of plane waves, which are reflected back and forth zigzag between the side walls 21 of the guide 20, and strike the side walls at an angle θ as illustrated in Fig. 2A. When the component plane waves strike a dielectric strip 22, they are either absorbed or reflected therein depending upon the frequency. If they are reflected in the dielectric strip 22, the dominant wave propagates past unattenuated and unchanged in any way. If they are absorbed, the dominant wave disappears or is diminished.

Fig. 3 shows the frequency characteristics of the frequency filters disclosed in Fig. 2. As is apparent from the individual curves, these filters are peaked, narrow-band elimination filters and it has been experimentally determined that filtering therein is accomplished with-

out objectionable reflection effects. The rectangular strips 22, 22' were cut from a large sheet of loaded material originally designed with a thickness of $\lambda/4$ to resonate at 9.1 centimeters wavelength and were mounted in standard one inch by two inches rectangular wave guide. The curves A, B, C, show how the resonant frequency ν varies with the strip with ω and also indicate that the maximum loss becomes lower as the width is decreased. The attenuation or loss provided by a single strip is linear with length, and doubling of length doubles the attenuation in decibels. The length of strip utilized in connection with curves A, B, C was approximately five inches.

It is possible to produce a variety of attenuations versus frequency characteristics by combining strips of material having various widths and lengths. One may also utilize various shapes for the strips in order to obtain a variety of transmission characteristics in connection with concentric conductor or hollow wave-guide transmission. Fig. 4A shows a wide-band elimination filter consisting of strips of two different widths w , w' respectively mounted on opposite sides of the rectangular wave guide 40. It will be noted that the strips are arranged in pairs, so that the strips having the same width are opposite one another in the wave guide.

Under these circumstances, the corresponding wide-band elimination filter characteristic is as shown in Fig. 4B. The broad band results from the overlapping of resonant characteristics of the type shown in Fig. 3, further indicating inappreciable coupling or interaction between the strips. Should the corresponding strips on opposite sides of the rectangular wave guide 40 have different widths, then the resultant curve has still a band elimination characteristic, but is not compounded by the simple addition of the characteristics of the individual strips, suggesting the existence of a coupling or interaction between the strips.

Fig. 5 shows a folded U-shaped dielectric strip 51 lining a wave guide 50 along the top, bottom and side walls. In one case, the strip 51, which was five inches long, was folded into a U-shape to line an X or 3-centimeter band standard wave guide, and the filter displayed a resonance peak shifted below the frequency obtained with a single side strip per se.

Instead of combining strips of differing widths as in Fig. 4A, one might use a single strip 61 tapered as shown in Fig. 6A or a strip 62 having a stepped taper as in Fig. 6B, whereby various amplitude versus frequency characteristics of the broad band filter type are provided.

It should be understood that band-pass filters may be provided by combining a plurality of separate tapered strips. Each strip provides individually a band elimination effect, which attenuates frequencies outside the desired limits of the pass band. In a similar manner, high-pass or low-pass filters can be constructed.

Since the loaded sheet 1 of Fig. 1 absorbs in a narrow range of frequencies and reflects per se at all other frequencies, it may be mounted on the interior surfaces of cylindrical wave guides capable of carrying higher order modes.

A TE_{01} mode in such a cylindrical wave guide may be resolved into component plane waves, which strike the cylinder walls at an angle.

Fig. 7 shows a mode filter for transmitting exclusively a TE_{01} mode in a cylindrical wave guide. It may be produced by coating the inside walls of the cylindrical guide 70 to an effective depth or thickness of $\lambda/4$ to provide a loaded dielectric lining or insert 71 in the interior of the guide. The symmetry of this arrangement provides a single frequency filter for the TE_{01} mode, without concomitantly giving rise to spurious higher order modes, as might develop in an iris, stub or screw type filter construction. Such mode filters or suitable modifications thereof may be similarly provided in concentric conductor wave transmission.

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It should be understood that the loaded dielectric strips may be supported in a wave guide or in a cavity resonator at or away from the walls thereof for varying the attenuation of low and high power waves propagated therethrough. They also may be moved to and fro in a wave guide in known manner at a periodic rate or under the control of modulating signals to effect the modulation of microwaves transmitted through such guide.

Also the use of the foregoing lined wave-guide sections for equalizing transmission through hollow pipe long lines, where for example, the thickness of the strip is $\lambda/4$ at a frequency above or below the transmitted band, and in microwave radio relay link circuits, would likewise fall within the scope of the present invention.

It will be evident that by the proper proportioning and compounding of strips, the transmission versus frequency characteristic curve can be made to correspond to almost any desired shape and such composite devices may therefore be used in transmission control of phase, amplitude and frequency.

Likewise, the strips may be shaped and fashioned to provide higher order mode filters for use in wave guide and concentric conductor transmission and in cavity resonators in accordance with the teachings of the invention.

It will be evident that the techniques described here are also applicable to the construction of frequency-selective circuits for physical waves other than electromagnetic waves. One might, for example, apply a similar layer of elastic material of a thickness corresponding to $\lambda/4$ for a sound wave to the side walls of an acoustical horn or other propagating means in order to produce frequency-selective characteristics.

What is claimed is:

1. A mode filter comprising a hollow cylindrical wave guide having a loaded, longitudinal dielectric sheet lining its interior wall, said sheet being effectively $\lambda/4$ in thickness, where λ is a wavelength propagated through said guide, said sheet comprising a lossy dielectric matrix with fine metallic particles parallelly disposed therein, said sheet having a reflecting backing thereon in contact with the guide wall.

2. A frequency-selective circuit comprising a hollow rectangular wave guide having a side wall thereof lined with a loaded dielectric sheet effectively $\lambda/4$ in thickness, where λ is a wavelength propagated through said guide, said sheet comprising a lossy dielectric matrix having fine metallic flakes distributed therethrough uniformly and lossy material admixed therewith.

3. A filter for microwaves comprising a rectangular hollow wave guide having a pair of very thin lining sheets therein longitudinally disposed therein, each in contact with one of a pair of parallel longitudinal walls of said guide, each sheet being lossy and having metallic flakes dispersed therethrough to provide an effective dielectric constant greater than 100 in a predetermined direction, each sheet being a quarter-wavelength in effective thickness and having a metallic foil backing, said lining sheets each being a few mils thick at centimeter wavelengths and thereby providing negligible discontinuities to the microwaves propagated through said guide.

4. A microwave filter comprising a short section of hollow wave guide having a critical frequency cut-off characteristic, an absorptive lining therein fixed to a longitudinal wall thereof comprising a loaded dielectric sheet having metallic flakes dispersed therethrough to provide an effective dielectric constant k of the order of 100-10,000, said sheet having a thickness equal to

$$\frac{\lambda}{4\sqrt{k}}$$

where λ is the wavelength in the guide and having dimensions providing frequency selectivity, said loaded dielectric having a reflecting metallic foil backing thereon in contact with the guide wall, the characteristic impedance of said guide being substantially equal to the

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characteristic impedance of the lined section of wave guide the cross-sectional dimensions of the hollow interior of said guide being unappreciably altered by the presence of said sheet.

5. A microwave filter comprising a short section of hollow rectangular wave guide having a critical frequency cut-off characteristic, a longitudinal thin sheet of lossy dielectric having a metallic reflecting foil in contact with a wall of said guide, said sheet being loaded with metallic flakes oriented parallel to said guide wall and having a dielectric constant k in the range of 1000, the thickness of said sheet being equal to

$$\frac{\lambda}{4\sqrt{k}}$$

where λ is the guide wavelength and the characteristic impedance of said guide being substantially unaltered by the presence of said sheet, and the hollow cross-section of said guide being unappreciably filled by said sheet.

6. A filter in accordance with claim 5, wherein said sheet comprises a series of layers, each containing a rubber matrix having glossy particles, and said flakes being insulated from each other by said matrix.

7. The structure of claim 6, wherein the flakes are aluminum oriented with their surfaces and major axes parallel to said reflecting foil.

8. The structure of claim 6, wherein the sheet is tapered along its length to provide a band filter characteristic.

9. The structure of claim 5, wherein the length and width of said lining provides a sharp resonance absorption.

10. The structure of claim 5, wherein a longitudinal sheet of equal width is mounted on the opposite side wall.

11. The structure of claim 5, wherein the lining is U-shaped in cross-section and is in contact with the top, bottom and side walls of said guide.

12. A frequency-selective device comprising a hollow wave-guide section having open ends and being excited in a dominant mode, a loaded sheet of a few mils thickness lining a wall of said guide and having an effective dielectric constant k greater than 100, said sheet comprising layers formed from a lossy dielectric matrix of low dielectric constant having metallic flakes therein oriented along parallel directions, said flakes being insulated from each other by said matrix, the length and width of said sheet determining the frequency characteristic of said device and the thickness of said sheet being

$$\frac{\lambda}{4\sqrt{k}}$$

where λ is the wavelength propagated through said wave guide between its ends.

13. The structure of claim 12, wherein the loss provided by said sheet is linear with length, and a plurality of sheets collinearly spaced apart on one wall are contained in said wave guide to compound their frequency characteristics.

14. A filter for centimeter waves comprising a hollow conductor having open ends for incident electromagnetic waves, an absorber sheet having an effective high dielectric constant $k > 100$, lining the wall of said conductor, said absorber being uniformly loaded with metallic particles oriented in one direction and insulated from each other, the thickness of said sheet being effectively one-quarter wavelength at the operating frequency, whereby the characteristic impedance of said conductor remains substantially unaltered throughout between its open ends.

15. A filter for microwaves comprising a section of hollow rectangular wave guide carrying waves in the dominant mode, a pair of thin, loaded dielectric sheets lining the side walls of said guide and spaced at least a half wave length apart, the characteristic impedance of said wave guide per se being substantially equal to the characteristic impedance of the lined section of wave

guide, each sheet comprising a lossy dielectric matrix having metallic flakes dispersed therethrough to provide an effective dielectric constant $k > 100$ and having a thickness effectively equal to one-quarter wavelength at the operating frequency to provide a phase reversal in incident wave components to provide frequency selective characteristics in said guide section without altering appreciably the internal cross-sectional dimensions of said section.

16. Frequency selective microwave apparatus comprising a conductive-walled hollow pipe wave guide adapted to propagate electromagnetic waves of predetermined field configuration and frequency, at least a portion of the conductive wall having a dissipative internal coating of dielectric material that exhibits to said waves a dielectric constant of at least several hundred and an effective electrical thickness of the order of a quarter wavelength.

17. The apparatus of claim 16, wherein the dielectric material contains dissipative material dispersed throughout.

18. The apparatus of claim 16, wherein the dielectric material is artificial, anisotropic, and contains metallic flakes in a predetermined orientation.

19. Frequency selective microwave apparatus comprising a hollow section of wave guide of rectangular cross-section adapted to propagate electromagnetic waves of predetermined field configuration and frequency, and a film of lossy anisotropic dielectric material mounted therein parallel to the narrower side walls thereof and having a thickness equal effectively to a quarter wavelength at the operating frequency, the frequency selectivity of said film being controlled by its thickness and width.

20. The apparatus of claim 19, wherein the film thickness

$$d = \frac{\lambda}{4\sqrt{k}}$$

where k is the effective dielectric constant > 100 , and λ is the wavelength in the guide, said waves being selectively transmitted through said section substantially free from secondary reflected waves arising from characteristic impedance mismatching.

21. A microwave filter comprising a short section of hollow wave guide supporting a dominant mode, an absorptive film having frequency selective characteristics fixed to a longitudinal wall thereof, said film comprising a dielectric sheet whose thickness is equal effectively to a quarter wavelength at the operating frequency and having metallic particles dispersed therein to provide an effective dielectric constant $k > 100$ and having a width dimensioned to determine the absorbed frequency, the cross-section and characteristic impedance of said guide being substantially unaffected by said film to preclude generating secondary reflected waves.

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