April 11, 1961 B. M. DWORK 2,979,678

MICROWAVE ATTENUATORS

Filed Oct. 20, 1955 2 Sheets-Sheet 1

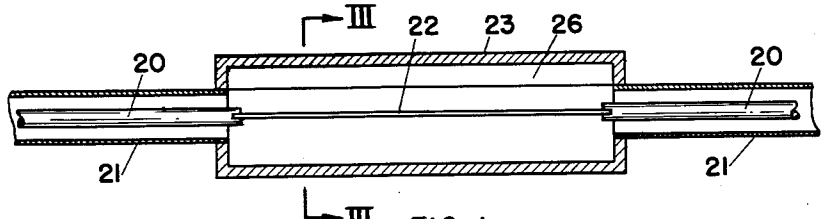


FIG. 1

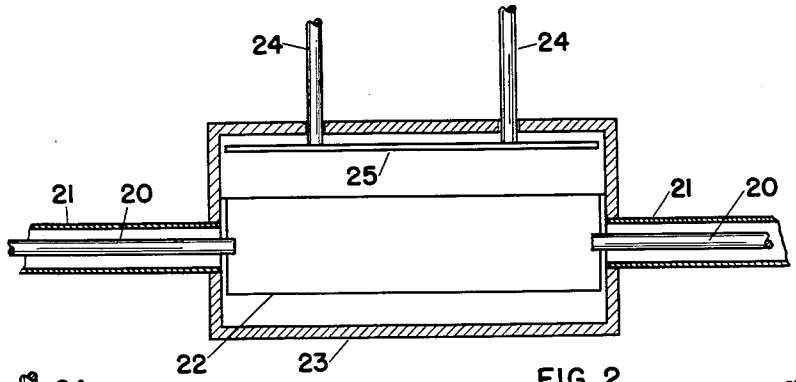


FIG. 2

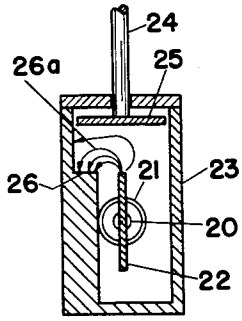


FIG. 3

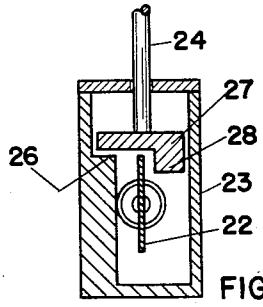


FIG. 4

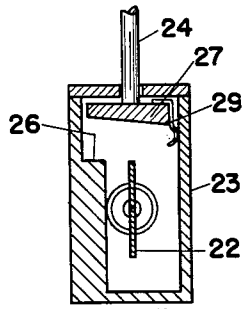


FIG. 5

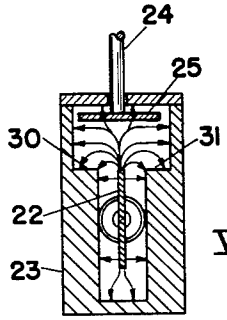


FIG. 6

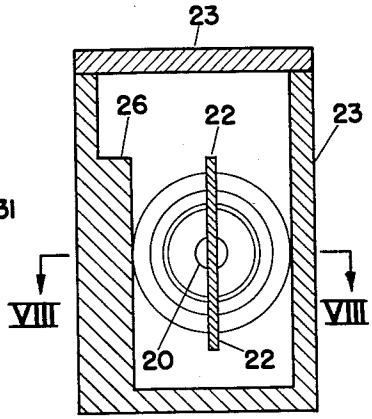


FIG. 7

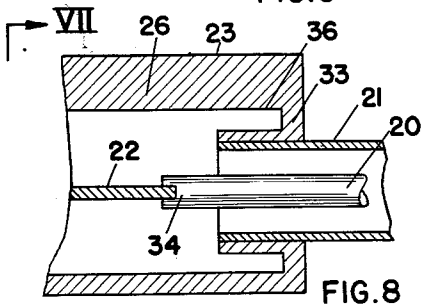


FIG. 8

INVENTOR.
BERNARD M. DWORK

BY

Atty.

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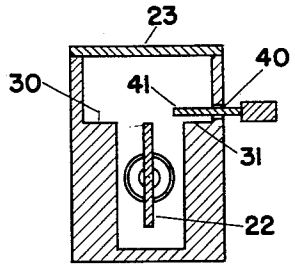


FIG. 9

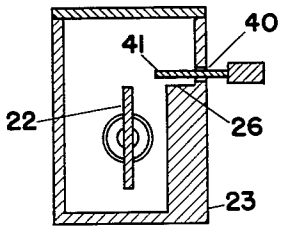


FIG. 10

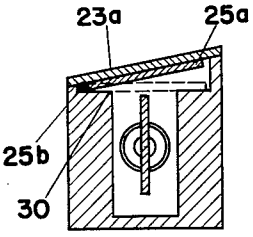


FIG. 11

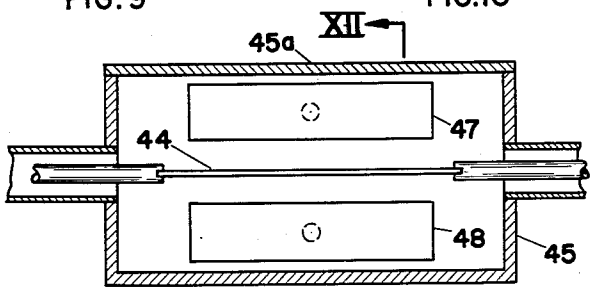


FIG. 13

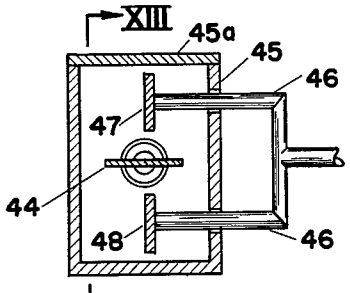


FIG. 12

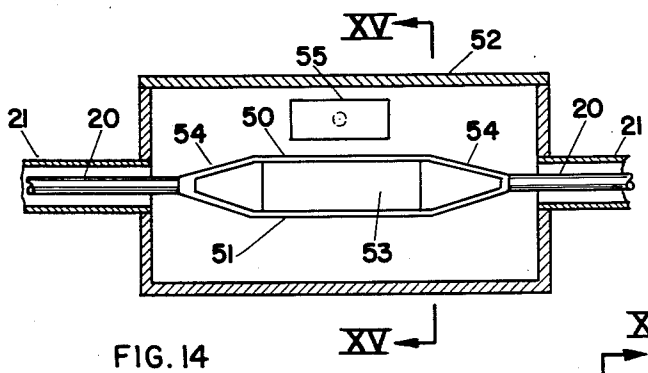


FIG. 14

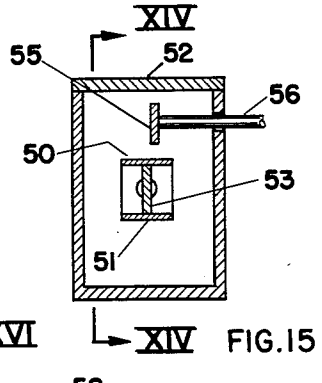


FIG. 15

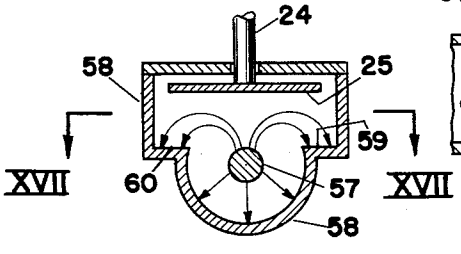


FIG. 16

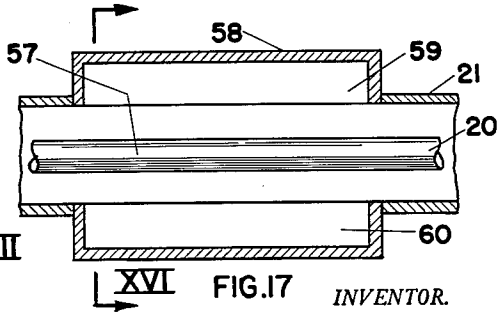


FIG. 17

INVENTOR.
BERNARD M. DWORK
BY
Lucas B. Rice
atty.

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2,979,678

MICROWAVE ATTENUATORS

Bernard M. Dwork, Bedford, Mass., assignor to Merrimac Research and Development Corporation, Flushing, N.Y., a corporation of New York

Filed Oct. 20, 1955, Ser. No. 541,654

11 Claims. (Cl. 333—81)

This invention relates to microwave attenuators.

It is an object of this invention to provide a coaxial type of attenuator which will have low initial loss and furnish relatively large ranges of attenuation in a smoothly controlled manner.

The word "coaxial" is used herein to include all devices which are primarily designed for use with coaxial lines and in which an inner line is substantially completely enclosed by the other whereby the system functions as a coaxial line in that it is completely shielded against external radiation. It is this property which characterizes this device as a coaxial line regardless of whether the conductors be exactly concentric or not.

In achieving this regulated attenuation the lossy material may be placed so that, at the position of maximum attenuation, the lossy material lies in the same plane with the greatest concentration of the electrical lines of force but is withdrawable to a position where it is, as nearly as possible, transverse to the lines of the face of the electrical field, while still maintaining the device free from external radiation. This result may be accomplished with a fixed lossy material and adjustably distorting the lines of force when desired by causing them to lie in the plane of the material; or, it may be accomplished by permanently distorting the lines of force to secure a maximum density in a given plane, and then moving a sheet of lossy material toward or away from that plane at will. The maximum attenuation is obtained when the lossy material lies in the plane of densest concentration of the electrical lines of force, and it diminishes as the material and the plane of concentration are separated.

It is a further object of this invention to provide such an attenuator which will be controlled over a broad frequency range and which, nevertheless, may permit an essentially reflectionless input to be obtained, and yet which will be both efficient and inexpensive.

It is a further object of this invention to provide an attenuator of the character described, which will be simple in construction, easy in manipulation and sensitive throughout its range.

An attenuator in such a line may be provided by the insertion of a lossy material in a plane extending in the direction of a substantial component of the electric field. Difficulties arise in the practical application of this principle in conventional (of annular cross-section) coaxial lines because of the tendency of conduction currents to flow on the highly conducting center conductor, in preference to the more difficult path through the lossy material.

In general, however, any attenuator must in principle possess a relatively large unperturbed field in the region of the attenuating material, with a relatively large electric field component parallel to the lossy vane.

This invention relates to the introduction of elements which set up a high degree of fringing of the fields. This fringing produces flux lines of considerable length housing a relatively large content of stored energy. If lossy material is introduced in the region, these highly extended field lines find the lossy material a preferable path and loss is produced.

It is a further object of this invention to provide a system in which the rate of increase of attenuation shall be as nearly uniform as possible. This result may be accomplished by a local distortion of the direction of the electric field to bring it more nearly parallel to the lossy material, and it may be controlled either by varying the nature of the local distortion, or by varying the position of the lossy material within the distorted field.

Practical embodiments of this invention are hereinafter described and shown in the accompanying drawings, in which Fig. 1 is a horizontal longitudinal section of the device; Fig. 2 is a vertical longitudinal section of the same; Fig. 3 is a section on the line III—III of Fig. 1; Fig. 4 is a section similar to Fig. 3, of a different embodiment; Fig. 5 is a similar section of a third embodiment; Fig. 6 is a similar section of a fourth embodiment; Fig. 7 is a section of a fifth embodiment on the lines VII—VII of Fig. 8; Fig. 8 is a section on the line VIII—VIII of Fig. 7; Fig. 9 is a transverse section of a sixth embodiment; Fig. 10 is a modification of the structure of Fig. 9; Fig. 11 is a further modification of the structure shown in Fig. 9; Fig. 12 is a transverse section on the line XII—XII of Fig. 13; Fig. 13 is a longitudinal section of another embodiment on the line XIII—XIII of Fig. 12; Fig. 14 is a longitudinal section of a further embodiment on the line XIV—XIV of Fig. 15; Fig. 15 is a transverse section on the line XV—XV of Fig. 14; Fig. 16 is a transverse section of still another embodiment on the line XVI—XVI of Fig.17; Fig. 17 is a longitudinal section on the line XVII—XVII of Fig. 16.

In these embodiments it is not necessary that the outer conductor be rectangular in shape, nor that the inner conductor be a flat strip. They may take on a variety of shapes, being restricted only by the principles outlined above. In particular, Figs. 16 and 17 show the application of the principle to a coaxial line in which the conductors are substantially circular, with only sufficient divergence from the circular to produce the effect of this invention.

Since the rectangular type of waveguide is at present preferred by us, we shall first describe it in that form; but it will be made clear that the invention can be effectively embodied in other forms such as the circular form.

The term "generally cylindrical" is used herein to refer to a closed hollow conductor whose walls are parallel to a central conductor regardless of whether the cross section be generally round or square or of irregular shape.

Referring now to the drawings, and particularly at this point to Figs. 1, 2, and 3, the numerals **20** and **21** represent, respectively, the inner and outer conductors of a conventional coaxial line, this line being interrupted by the attenuating device in which the inner conductor **20** has become a flat strip **22** and the outer conductor **21** assumes a generally rectangular form, or box **23**. To avoid a mismatch the inner conductors **20** protrude into the box **23**, as shown. Inserted through one face of the box **23** and preferably generally in the plane of the strip **22** are a pair of guide pins **24**, carrying a vane **25** held transverse to the plane of the strip **22**. This vane is of lossy material or is faced with lossy material on its side next to the inner conductor **22**. By sliding the pins **24** the lossy vane **25** may be brought closer to the strip **22**. The effect of such an adjustment, however, would in itself be small, since the electric field would be essentially normal to the vane. To overcome this difficulty, in accordance with this invention, there is provided on the side of the interior of the box **23** a ridge **26**, preferably in alignment with the edge of the strip **22**. This results

in the strip 22 generally being closer to the box on that side than on the other, although this is not a necessary restriction.

The ridge 26 has the effect of fringing the electric field out considerably far from the strip region and setting up a component of the electric field substantially parallel to the lossy vane 25, as shown at 26a. Since the field extends far from the strip, a smooth non-critical loss variation is obtained as the vane is moved from the wall. If the lossy vane is of relatively thin material the loss is accounted for by that component of the electric field parallel to the vane, so that the fringing field formed is consistent with the function of the attenuator.

The vane should be of thin material to provide low minimum loss. This is accounted for by the fact that the attenuating card when extended flush to the narrow wall experiences essentially normal electric fields because of the continuity of the normal field at the wall through the thin vane. If the vane were thicker, the curving fields would set up tangential currents in the vane even at the minimum attenuation position together with volumetric loss in the vane.

Additional attenuation is obtainable from the volumetric loss which may be obtained by thickening the vane. This construction is shown in Figs. 4 and 5 in which the thin vane 25 is replaced by a thick vane 27, and to still further increase the effect the lossy material may be so disposed as to have a portion intrude into the space between the side of the strip and the side of the box. This can be done by providing the vane with a projection as shown at 28. This will increase the maximum attenuation but it also increases the minimum value.

This vane 27 absorbs energy by setting up conduction currents in the lossy material, and improved absorption characteristics may be achieved from the ridge construction by permitting as free a flow of these currents as possible. This is attained by forming a current return, allowing the vane to wipe the face of the outer conductor guide with spring fingers, as shown at 29 in Fig. 5. It is, incidentally, to be noted that these currents may be maximized when the field has a maximum component tangential to the vane. This may in some instances actually best be accomplished by operating the vane in a tilted fashion. In Fig. 5 the vane is also shown as having its under face tilted. The tilting has advantages in an unbalanced field which is produced when a single ridge is used. It will be understood that this tilting effect may be used in any of the modifications in which the unbalanced field is used.

It will be clear that where a fixed degree of attenuation is desired, it is not necessary to mount the lossy material on movable supports.

In the construction shown in Fig. 6, the box is provided with two ridges 30 and 31, on each side, thereby fringing the fields more completely and producing a symmetrical field distribution with a maximum tangential component. The electric field lines are noted in the figure. The parts are otherwise identical with the previous modifications and bear the same numbers. In this embodiment the inner conductor is, therefore, also symmetrically placed within the box, whereas with a single ridge the inner conductor is generally placed closer to the side having the ridge. In all these embodiments the face of the ridge is preferably aligned with the edge of the inner conductor. Greater attenuation may be achieved by placing two more ridges opposite on the other edge of the strip center conductor, and employing two lossy vanes. The two vanes would then be located symmetrically to each other on opposite sides of the symmetry plane. This use of two lossy vanes rather than one applies also to all of the other embodiments discussed above.

Figs. 7 and 8 show a suitable junction between the attenuator and the coaxial line. The inner strip conductor 22 of the attenuator is attached to the inner conductor 20 of the circular coaxial line, while the outer conductor 23 of the attenuator makes electrical contact with the outer conductor 21 of the circular coaxial line by means of the conducting wall 33. This junction between the two lines produces a lumped shunt capacitance. In order to compensate for this capacitance, two constructional modifications are introduced. First, the inner conductor 20 of the circular coaxial line protrudes somewhat into the ridge coaxial line, as shown at 34, to produce an effective series inductance. Second, the wall 33 has a circumferential choke channel 36 between the outer conductor 21 and the outer conductor 23 comprising a box of the attenuator. The junction between the strip 22 and the protrusion 34 introduces an additional lumped shunt capacitance. The various components of the complete junction thus form a pi network which behaves as a low-pass filter and serves to eliminate the mismatch at the junction.

In the embodiments shown in Figures 1 to 8 the lossy material is completely enclosed within the outer conductor. A similar effect, however, can be achieved by the construction shown in Figs. 9 and 10, in which the double ridge box, as in Fig. 6 (see Fig. 9), or a single ridge box as in Fig. 3 (see Fig. 10) is provided with a longitudinal slot 40 through the outer conductor and almost in alignment with the plane of the top of the ridges 30 and 31, or 26, and a lossy vane 41 is adjustably insertible through this slot. This vane 41 may slide in, being held by friction, or it may be pivoted at one end and move in an arc about its pivot. As has already been shown, this ridge construction causes the electric field to fringe some of the lines of force circling around from the top edge of the inner conductor, and entering the top surface of the ridge. This lossy vane, therefore, is in position to intercept these lines of force resulting in an attenuation corresponding to the extent to which the vane is inserted.

Fig. 11 is similar to the construction of Figs. 6 or 9, except that the lossy vane 25a is mounted on a pivot 25b above one of the ridges 30, so that the lossy vane may be swung up, as shown in full lines of the figure, or swung down to the dotted line position, thereby securing the maximum attenuation. It is also noted that the outer box is no longer rectangular in shape, but that the top 23a is truncated. This is done to permit an angular travel of the lossy vane of only 15° or so rather than a full 90°, since for the larger angles the vane could no longer be substantially parallel to the electric field lines. Truncating the top wall 23a permits the lossy vane to be short-circuited against the top wall in its extended position, thus resulting in a very small minimum loss.

The construction shown in Figs. 12 and 13 is called a split vane attenuator. As here shown, the inner strip 44 is parallel to one of the sides 45a of the outer conductor or box 45, and the lossy vane element is divided into two vanes 47 and 48, one above and one below the inner strip 44 and in a plane perpendicular to it. These vanes 47 and 48 are mounted on common studs 46 which may be slid into and out of the box, so as to be either flat against the side walls, or in the center plane of the inner strip 44, as shown.

In the former case the attenuation is at a minimum, whereas in the latter it is at the maximum, since the vanes are in the plane of the maximum electric field.

In Figs. 14 and 15 another construction is shown, which is called a twin mode attenuator. In this construction the inner conductor is divided into two separate parallel strips 50 and 51 within a single outer coaxial conductor or box 52, these two strips being united to each other and to the inner conductor 20 of the coaxial line at each end by converging sections 54 to avoid a sudden mismatch. The strips are, however, separated from each other at their middle portion by a block of lossy material 53.

A vane, or unbalancing arm 55, which may be of conducting, lossy or dielectric material, is mounted parallel

to a plane which bisects both of the parallel strips, and this vane is mounted on a support **56** so that it may be moved from the side to the central position, as desired. This line is capable of supporting two dominant modes, both of which can exist at all frequencies. In one of the modes, the even mode, the inner conductors **50** and **51** are at the same potential, and the outer conductor **52** is at a different potential. In the other mode, the odd mode, the two inner conductors are at different potentials, and the outer conductor is half way between in potential.

When the unbalancing arm **55** is not present, or is completely withdrawn, only the even mode is excited in the structure. This occurs because the two inner conductors are connected together and to the inner conductor **20** of the connecting circular coaxial lines. The outer conductor **21** of the circular coaxial line is connected to the outer conductor **52** of the double plate coaxial line. The connection of the inner conductor is made by means of the taper **54** rather than abruptly, in order to achieve a good impedance match.

Since only the even mode is excited, negligible attenuation is produced in spite of the presence of the lossy material **53**, located between the two inner plate conductors **50** and **51**. When the unbalancing arm **55** is moved by means of the supporting arm **56** toward the center of the field distribution, it transforms some of the energy of the even mode into that of the odd mode. Since the latter mode produces a strong electric field between the two inner plates, conductors **50** and **51**, the lossy material now exerts a significant effect on the line, and attenuation is produced. Further insertion of the unbalancing arm casts a larger proportion of the energy into the odd mode, with a consequent larger attenuation value.

It is stressed that in all of the embodiments except the last two (Figs. 12, 13, 14, and 15) the presence of the ridges to fringe out the electric field lines is the significant common feature. It is not at all necessary that the outer conductor be rectangular in shape, nor that the inner conductor be a flat strip.

For example, in the embodiment of Figs. 16 and 17 the center conductor **57** is circular in cross-section and is the same as that (**20**) of the connecting conventional coaxial line. Outer conductor **58** coincides with a portion of the outer conductor **21** of the connecting line. The electric field lines are fringed out by the ridges **59** and **60** in a fashion similar to the previous embodiments, although there is a smaller concentration of field near the center conductor because the sharp edge of the strip center conductor is now not present. The lossy vane **25** and the support arm **24** are the same as those in Fig. 6. The concentration of field near the center conductor may be enhanced somewhat by locating the center conductor eccentrically (raising it slightly in Fig. 16).

I claim:

1. A microwave attenuator comprising an outer conductor and an inner conductor forming together a coaxial line, said outer conductor being generally cylindrical but having a portion of its inner surface at a greater distance from the inner conductor than the remainder thereof, the two portions of the inner surface being connected by a surface extending toward the inner conductor, said extending surface tending to concentrate the electromagnetic field in the region of the extending surface to a degree greater than that normally present in the remainder of the coaxial line, and a lossy member within said outer conductor extending in the direction of the lines of force fringed by said connecting surface.

2. A device in accordance with claim 1 in which the connection between the two portions of the inner surface comprises a ridge extending inwardly toward said inner conductor.

3. A device according to claim 2 in which the said ridge is in substantial alignment with the edge face of said inner conductor.

4. A device according to claim 2 in which the lossy member is a vane which is shorted to the side of the outer conductor in its minimum attenuation position.

5. A device in accordance with claim 1 in which the lossy member is movable into said fringed lines of force.

6. A coaxial attenuator comprising an outer conductor and an inner conductor enclosed thereby and a lossy vane within said outer conductor, means for increasing the electromagnetic field in the plane of the lossy vane to a degree greater than normally present in the coaxial line, and means for moving said lossy vane transverse to said plane to vary the concentration within said vane.

7. An attenuator for coaxial lines comprising a rectangular box and a flat strip forming together a coaxial line, a lossy vane within said box mounted parallel to one face of the box and movable toward said strip and means within said box for increasing the electromagnetic field about said vane to a degree greater than normally present in the coaxial line.

8. A device according to claim 7 in which said means for increasing the electromagnetic field comprises a ridge extending inwardly from said box.

9. A coaxial attenuator comprising an outer conductor and an inner conductor enclosed thereby and a volume of lossy material within said outer conductor, means for increasing the electromagnetic field in the region of said lossy material to a degree greater than normally present in the coaxial line, and means for moving said lossy material to vary the concentration of field within said lossy material.

10. An attenuator for coaxial lines comprising a rectangular box and a flat strip forming together a coaxial line, a volume of lossy material within said box and movable toward said strip, and means within said box for increasing the electromagnetic field in the region of said lossy material to a degree greater than normally present in the coaxial line.

11. A device according to claim 10 in which said means for increasing the electromagnetic field comprises a ridge extending inwardly from said box.

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