Sept. 25, 1962 D. J. RICH ETAL 3,056,097

VARIABLE ATTENUATOR

Filed July 15, 1960 2 Sheets-Sheet 1

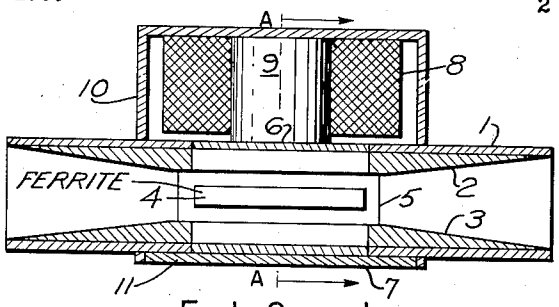


FIG. 1

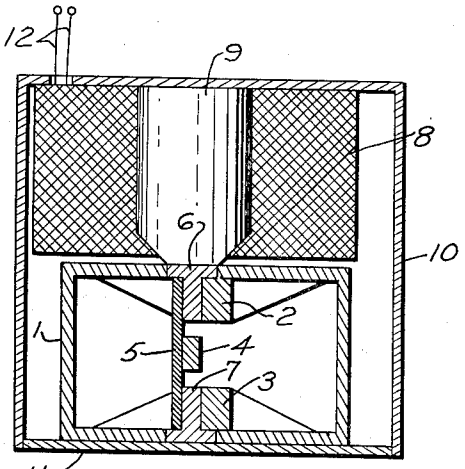


FIG. 2

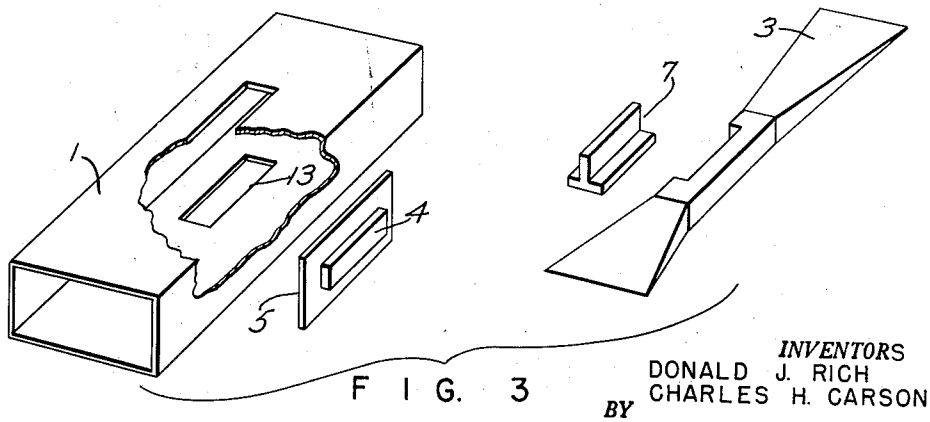


FIG. 3

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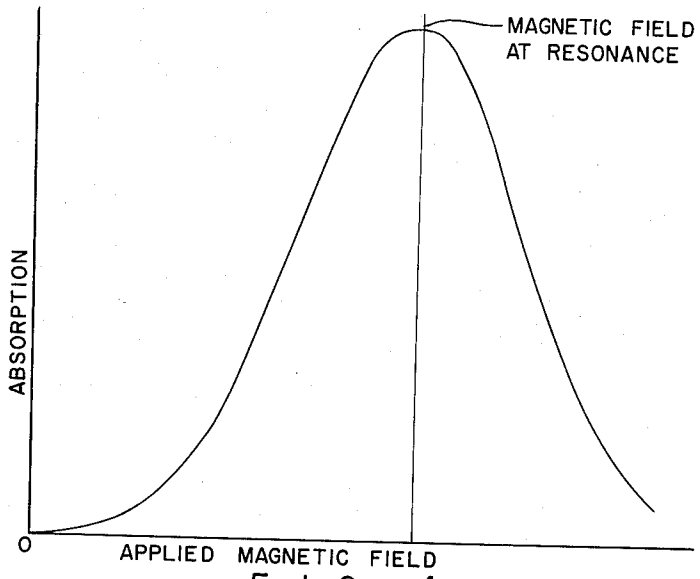


FIG. 4

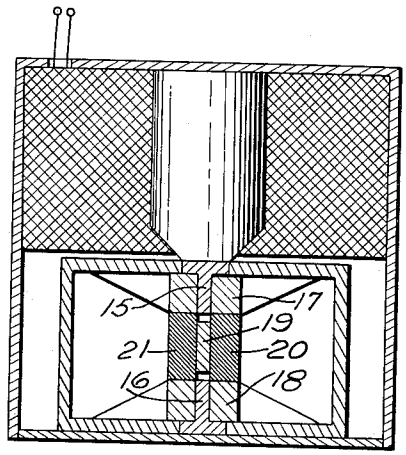


FIG. 5

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VARIABLE ATTENUATOR

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2 Claims. (Cl. 333—81)

This invention relates in general to devices for dissipating radio frequency wave energy and more particularly pertains to a controlled variable attenuator for use in the microwave region of the electromagnetic spectrum.

A ferrite slab is utilized in the invention as the energy attenuating element and the amount of attenuation is varied by adjusting the strength of the magnetic field in which the ferrite slab is situated. The magnetic field is established between a pair of pole pieces by an electromagnet. A rectangular waveguide is employed, of the type having internal ridges on opposite broad walls. This type of waveguide is known to have wideband characteristics. The pole pieces protrude through openings in the broad walls and form part of the waveguide's ridges. The ferrite slab is located between the pole pieces in a region where the magnetic field component of the wave energy in the guide is intense. A dielectric sheet is provided in the waveguide which serves the dual functions of supporting the ferrite slab and concentrating the wave energy so that more of it is incident upon the ferrite slab. By this construction the pole pieces are brought inside the waveguide and because they are close together the size of the electromagnet is materially reduced compared with the electromagnet required when the pole pieces cannot be brought inside the waveguide. The invention results in an attenuator which is more compact and lighter than conventional ferrite devices and is able to operate over greater band widths with lower drive power requirements.

The invention, both as to its mode of operation and its construction, can be better understood by a perusal of the following exposition when considered in conjunction with the accompanying drawings in which,

FIG. 1 depicts a sectional view of a preferred embodiment of the invention;

FIG. 2 is a sectional view taken along the plane A—A of FIG. 1;

FIG. 3 is an exploded view showing some of the component parts of the preferred embodiment;

FIG. 4 is a graph showing the absorption of energy by the ferrite as a function of the applied magnetic field;

FIG. 5 depicts another embodiment of the invention having a symmetrical construction.

The invention utilizes ridge waveguide because waveguide of that type combines small cross-sectional size with wideband characteristics. Ridge waveguide is essentially an extension of rectangular waveguide in which the band width is greatly increased by capacitively loading the center region in the rectangular guide. The principal effect of the capacitive loading of the center region is the lowering of the dominant mode cut-off frequency which permits the attainment of band widths two or three times larger than the band width of conventional rectangular waveguide.

Referring now to FIGS. 1 and 2 of the drawings, there is shown a rectangular waveguide **1** having central ridges

2, **3** extending longitudinally along the broad wall of the guide. The ridges, as illustrated in FIG. 1, gradually taper at their ends into the conventional rectangular guide. The energy dissipative element of the attentuator is a ferrite bar **4**, preferably of rectangular cross-section. The ferrite bar **4** is disposed between the waveguide ridges and extends longitudinally of the waveguide. The length of the ferrite bar, as well as its width and thickness, is dependent upon the maximum amount of attenuation to be effected by the device, since the amount of attenuation is a function of the length of the ferrite through which the wave energy in the ferrite must pass. The ferrite bar **4** is secured by an epoxy resin cement to a dielectric sheet **5**, the dielectric being constituted by a material such as aluminum oxide. The dielectric sheet acts to concentrate in the vicinity of the ferrite slab the magnetic component of the electromagnetic energy passing through the waveguide. The thickness and configuration of the dielectric sheet has a pronounced affect upon the operation of the device. The dielectric sheet may be a septum, as shown in FIG. 2, dividing the waveguide into two parts since it extends between the broad walls of the guide. The dielectric sheet is at least of coextensive length with the ferrite bar **4** and preferably the dielectric sheet extends, as indicated in FIGS. 1 and 3, slightly beyond the ends of the ferrite bar.

The ferrite bar **4**, shown in FIG. 2, is situated between two T-shaped pole pieces, the upper pole **6** forming a part of the ridge **2** and the lower pole piece **7** forming part of the ridge **3**. The waveguide **1** is fabricated of a non-magnetic material such as brass or aluminum whereas the pole pieces are constructed of a material such as soft iron which is highly permeable to magnetic flux. The broad walls of the waveguide are provided with slots for accommodating the pole pieces **6** and **7**. Since the pole pieces form part of the ridges which project into the waveguide, the pole pieces are physically as close to the ferrite as can be achieved without disturbing the operation of the waveguide. A magnetic field is established between the pole pieces **6** and **7** by an electromagnet **8** which has a cylindrical core **9** at its center, the core **9** resting upon the pole piece **6**. The end of the cylindrical core **9** in contact with pole piece **6** is shaped to fit over the crossbar of the T. As the pole piece is somewhat longer than the diameter of the core, the ends of the pole piece extend, as shown in FIG. 1, beyond the core. The housing **10**, which encloses the electromagnet and part of the waveguide, acts as a magnetic shield to prevent the leakage of magnetic flux, while simultaneously completing a magnetic circuit between the pole pieces. The housing **10** is a hollow cylinder of soft iron closed off at one end and having its other end sealed by a cover plate **11**. The cover plate **11** presses against the pole piece **7** and the cylindrical core **9** is maintaining in contact with the closed end of the housing. The housing **10** is cut away where necessary to permit the rectangular waveguide to extend through it and leads **12** to the electromagnet are brought out through a suitable aperture.

In the operation of the device, the rectangular waveguide is excited at its input port in the dominant TE_{10} mode. As the wave energy progresses down the guide, the energy is largely contained between the ridges of the guide. The dielectric sheet further concentrates the wave

energy so that most of the wave energy is incident upon the ferrite slab. Within the waveguide, the magnetic field of the wave energy, as seen from a fixed point on the ferrite, appears to rotate, the speed of the rotation depending upon the frequency of the wave. By passing a direct current through the electromagnet, an aligning magnetic field is established between the pole pieces, the direction of the aligning field being such as to cause the ferrite to absorb energy from the electromagnetic wave travelling down the guide. The absorbed energy is utilized to cause precession of the electrons in the ferrite. By adjusting the strength of the aligning field, the precession frequency can be tuned to the frequency of the wave in the guide. Where the precessional frequency is made to coincide with the frequency of the wave in the guide, the wave energy can be almost completely absorbed upon travelling through less than an inch of the ferrite.

FIG. 4 is a graph showing the absorption of energy in a ferrite as related to the strength of the aligning magnetic field. It will be noted that the energy absorption becomes larger and larger as the magnetic field strength is increased, and that the maximum absorption occurs at the magnetic resonant frequency of the ferrite.

In an ideal attenuator, all the wave energy applied at the input would be attenuated equally without regard to frequency. That is, the curve of FIG. 4 would remain unchanged whatever the frequency of the input wave energy. However, for reasons which are somewhat obscure, the frequency of the wave energy being attenuated causes the absorption curve to be shifted so that the amount of energy absorbed is not only dependent upon the applied magnetic field but also depends upon frequency. The invention does not entirely eliminate the frequency dependence of the absorption curve, but it does materially reduce that factor so that the attenuation is very nearly the same over a large band of frequencies for any given applied magnetic field strength.

It can be appreciated from the absorption curve of FIG. 4 that the attenuation of wave energy incident upon the ferrite slab can be controlled merely by controlling the strength of the magnetic field applied to the ferrite. Thus, the amount of direct current flowing in the electromagnet **8** determines the magnetic field established between the pole pieces **6**, **7** and the strength of that aligning magnetic field is controlled simply by regulating the direct current. By bringing the pole pieces as close to one another as possible, the intensity of the field in the gap is increased without increasing the current in the electromagnet. The invention is constructed so that the pole pieces are physically as close together as it is possible to get them without interferring with the operation of the waveguide. By employing ridge waveguide operation over a broad band of input frequencies is achieved while the ridges, at the same time, are used to bring the pole pieces into the interior of the waveguide and into positions closely adjacent to the ferrite slab. In addition, easy adjustment of the attenuation performance of the device is obtained by changing the thickness or configuration of the dielectric sheet. The dielectric sheet distorts the field of the wave energy in the guide and thereby more or less of that energy can be made to be incident upon the ferrite slab by changing the dielectric sheet.

The interior of the waveguide, including the ridges, is plated with silver to reduce losses in the guide. Since the device is intended to operate at kilomegacycle frequencies, the currents are confined to a thin layer of the interior surface of the waveguide. A silver plate in the order of three or four ten thousandths of an inch in thickness is entirely adequate to reduce losses in the guide.

FIG. 3 is an exploded view showing some of the components in the waveguide. The rectangular guide **1** has been broken away in part to show the aperture **13** in the lower broad wall into which fits the cross bar of the T-shaped pole piece **7**. The ridge **3** is actually fabricated as a separate part and has a lateral channel which accommodates the stem of the pole piece **7**. The upper broad wall of the guide has a corresponding aperture through which the pole piece **6** (FIG. 2) projects into the guide. The ferrite bar **4** is cemented to the dielectric sheet **5** by a suitable low loss adhesive, preferably an epoxy resin. The dielectric material should be a good heat conductor in order to conduct heat away from the ferrite, since the energy absorbed by the ferrite is dissipated as heat.

The embodiment of the invention illustrated in FIGS. 1 to 3 is not a reciprocal device because the ferrite and the pole pieces are positioned asymmetrically in the waveguide. That is, the attenuation characteristics will be different depending upon the direction of propagation of wave energy in the guide. The attenuation of wave energy travelling in the waveguide from port **1** towards port **2** is different from the attenuation occuring when wave enery travels in the opposite direction.

The invention can be made to act reciprocally by the modified arrangement shown in FIG. 5. In the embodiment of FIG. 5, T-shaped pole pieces **15** and **16** are respectively part of the ridges **17** and **18** but are now centered in the ridges. The ferrite bar **19** is disposed between the pole pieces and extends along the longitudinal axis of the rectangular waveguide. In order to concentrate the wave energy in the guide upon the ferrite bar, two dielectric sheets **20** and **21** are disposed on opposite sides of the ferrite. In other respects the embodiment of FIG. 5 is similar to the device depicted in FIG. 2. As the structure of FIG. 5 is symmetrical, the device acts reciprocally. The attenuation characteristics of the FIG. 5 device is the same regardless of the port at which the input energy is applied. The wave energy is a ridge wave guide is largely contained between the ridges and that energy is most intense at the center. The ferrite, in the embodiment of FIG. 5, is therefore most advantageously placed to attenuate the wave energy in the guide.

While two embodiments of the invention are illustrated in the drawings, it is evident that modifications can be made which do not depart from the essentials of the invention. It is therefore intended that the invention not be limited to the precise structure depicted, but rather that the scope of the invention be delimited by the appended claims.

What is claimed is:

1. A variable attenuator comprising a hollow rectangular waveguide, a pair of internal ridges having opposed faces extending longitudinally along the waveguide's broad walls, each ridge being formed by a non-magnetic member and a pole piece of high magnetic permeability, the non-magnetic member having a recess receiving the pole piece whereby the end of the pole piece is flush with and is a part of the face of the ridge, each of the waveguide's broad walls having an aperture, the pole pieces extending into the broad wall apertures, an elongate ferrite slab situated between the pole pieces, dielectric means in the waveguide disposed to concentrate the wave energy in the guide upon the ferrite slab, the ferrite slab being secured to the dielectric means, an electromagnet having its core in contact with one of the pole pieces, and a hollow cylindrical housing having openings permitting the rectangular waveguide to extend therethrough, the housing and core providing a low reluctance magnetic path between the pole pieces.

2. A variable attenuator comprising a hollow rectangular waveguide of non-magnetic material, a pair of elongate non-magnetic members disposed centrally within the waveguide and secured to the waveguide's broad walls, the elongate members forming a pair of opposed internal ridges extending longitudinally along the guide, a pair of T-shaped pole pieces, each of the ridge members having a recess receiving the stem of a pole piece whereby a continuous ridge is provided, each of the waveguide's broad

walls having an aperture receiving the cross-bar of the T-shaped pole piece, the pole piece having one end flush with the innermost surface of the ridge member, an elongate ferrite slab in the waveguide, the ferrite being spaced from and disposed between the pole pieces, a dielectric sheet in the waveguide for concentrating the wave energy in the guide on the ferrite slab, the ferrite slab being secured to the dielectric sheet, an electromagnet having a core resting upon the cross-bar of one of the pole pieces, and a hollow cylindrical housing enclosing the electromagnet and pole pieces, the housing having openings permitting the rectangular waveguide to extend there-

through, and the housing and core providing a magnetic path of low reluctance between the pole pieces.

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