

March 5, 1957

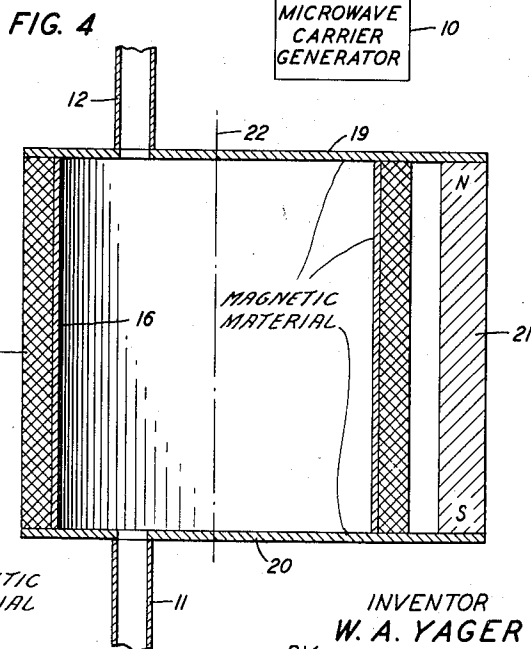
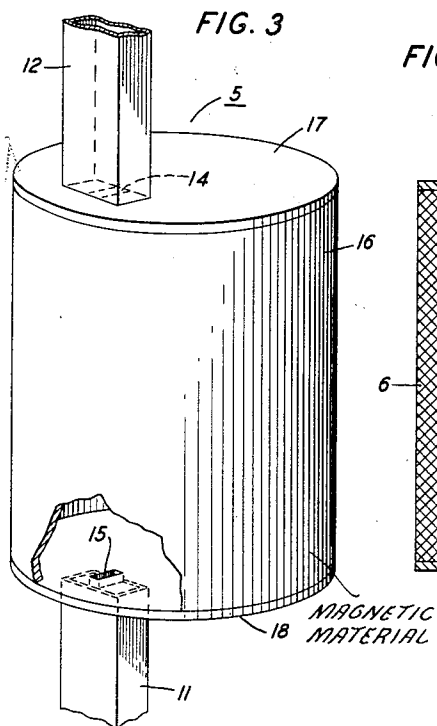
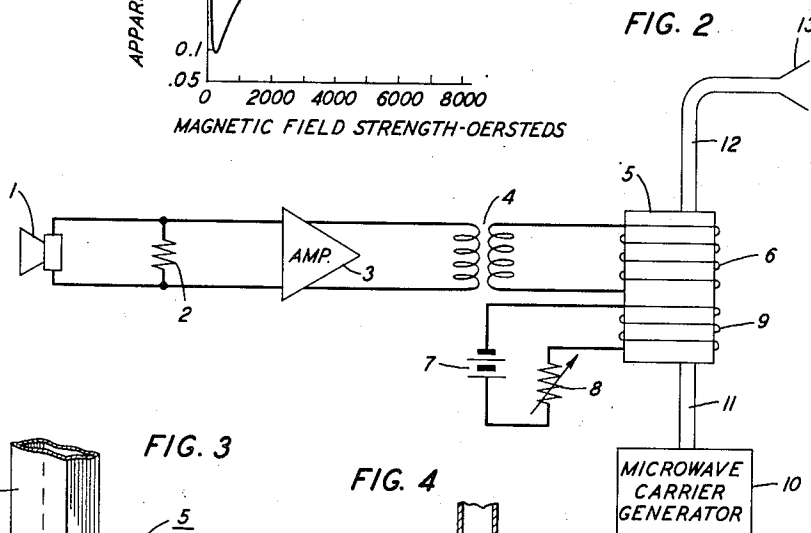
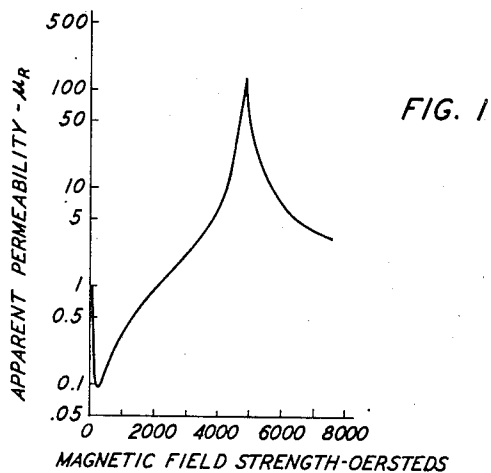
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2,784,378

MAGNETICALLY CONTROLLED MICROWAVE STRUCTURES

Filed May 10, 1952

2 Sheets-Sheet 1



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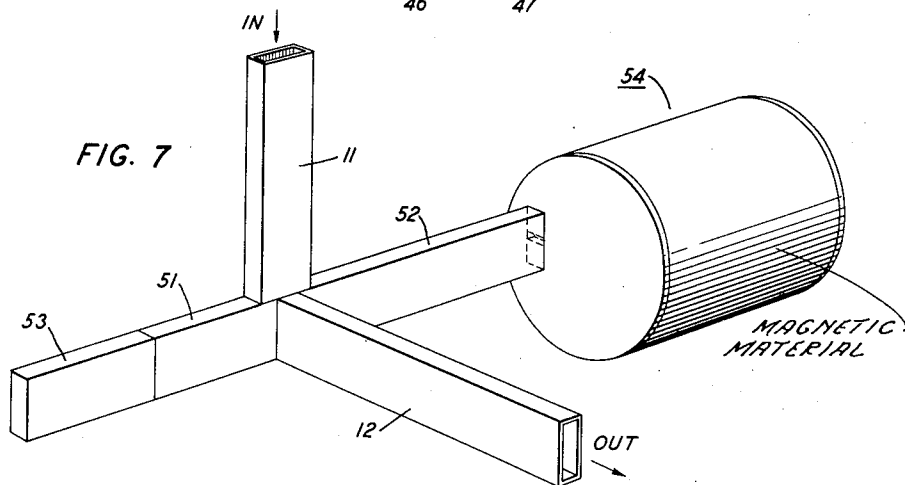
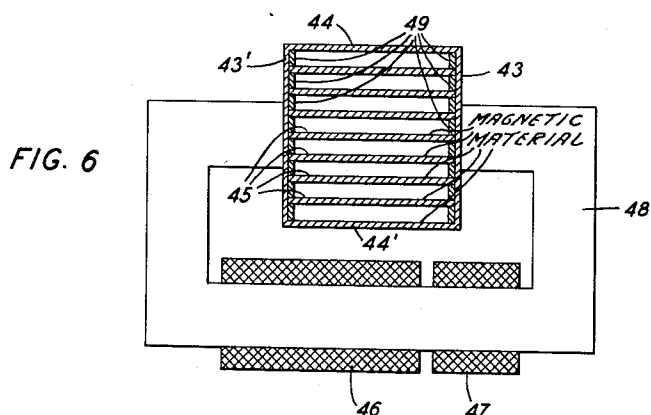
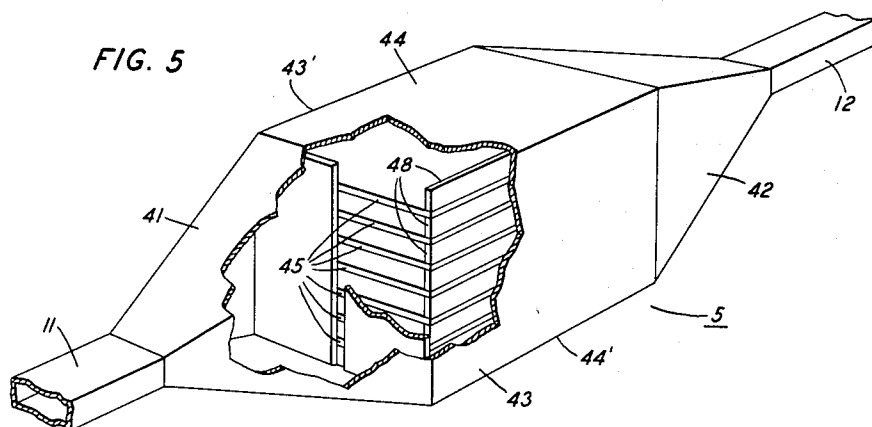
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MAGNETICALLY CONTROLLED MICROWAVE STRUCTURES

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2 Sheets-Sheet 2



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MAGNETICALLY CONTROLLED MICROWAVE STRUCTURES

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7 Claims. (Cl. 332-51)

This invention relates to the phenomenon of ferromagnetic resonance absorption and more particularly to the modulation of microwave energy and the reduction of microwave attenuation in ferromagnetic materials.

One object of this invention is to utilize the anti-resonant or minimum absorption operating range of the ferromagnetic absorption characteristic to reduce microwave attenuation.

Another object of this invention is to utilize the steep slope adjacent the minimum absorption point for modulation purposes.

A further object of the invention is to improve the efficiency of magnetically controlled microwave components.

In accordance with one aspect of the present invention, the objects set forth above are realized by making certain of the walls of high frequency resonators of ferromagnetic material, and these walls are magnetized at critical values of field strength. The walls which are to be magnetized are selected because of their relationship with the particular microwave field configuration in the wave guide. In the illustrated embodiments to be described in detail hereinafter, certain resonant cavity walls are formed of magnetic material and are magnetized at right angles to the high frequency magnetic field at the surface of the particular wall.

In accordance with another aspect of the invention, magnetic plates are located in a conductively bounded passageway for electromagnetic wave energy, and an induction device is provided for applying a magnetic field to the plates.

The nature of the present invention and various objects, features, and advantages in addition to those noted above will appear more fully from the following description of the embodiments shown in the drawings, in which:

Fig. 1 is a plot of apparent permeability against magnetic field strength for a particular magnetic material;

Fig. 2 illustrates a modulation system in accordance with the invention;

Fig. 3 represents cylindrical microwave resonant chambers of the transmission type which may be utilized in the system of Fig. 2;

Fig. 4 depicts an alternative resonant chamber with permanent magnet biasing;

Fig. 5 shows a rectangular transmission type resonant chamber in accordance with the invention;

Fig. 6 is a cross section of the resonant cavity of Fig. 5 and also shows a magnetic yoke to the device of Fig. 5; and

Fig. 7 represents a reflection type resonant cavity and a matched hybrid junction which may also be used with the system of Fig. 1.

As set forth by the inventor and his associates in a number of articles, including C. Kittel, Phys. Rev. 71, page 270 (1947); 73, page 155 (1948); W. A. Yager and R. M. Bozorth, Phys. Rev. 72, page 80 (1947); W. A. Yager, Phys. Rev. 73, page 1247 (1948); 75, page 316 (1949); W. A. Yager and F. R. Merritt, Phys. Rev. 75,

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page 318 (1949); such curves of apparent permeability plotted against magnetic field strength, as shown in Fig. 1, are known in the art. In the case of Fig. 1, the frequency involved is 24,000 megacycles, the material is annealed Supermalloy, and the magnetic field strength is the static magnetic field in the Supermalloy at right angles to the tangential component of the high frequency magnetic field.

To summarize the results set forth in certain of the above-enumerated articles, it has been determined that the point of antiresonance or minimum apparent permeability will occur when

$$\omega = \gamma B$$

where:

ω = the angular frequency

γ = magneto mechanical ratio, and

B = the magnetic induction.

Analyzing each of these quantities in greater detail, $\omega = 2\pi f$, where f is the frequency of the radio frequency magnetic field.

The magneto mechanical ratio

$$\gamma = \frac{ge}{2mc}$$

where g is the so called "g" or splitting factor, e and m are the charge and mass of an electron, and c is the velocity of light.

The magnetic induction

$$B = H_{ap} - \frac{NB_s}{4\pi} + B_s$$

where H_{ap} is the applied magnetic field, N is the demagnetizing factor which may be determined for a given specimen, as set forth at pages 320 to 326 in the Journal of Applied Physics, May 1942, vol. 13, and B_s is the saturation induction for the particular material employed.

In any particular case, it may thus be determined what applied magnetic field is required for antiresonance.

A pertinent prior art device is disclosed in the patent to King 2,197,123, issued April 16, 1940. The magnetic attenuator in this patent is a section of a straight transmission wave guide and is not operated at any critical level of magnetization.

The foregoing being a summary of what is old and known in the art, the particular devices illustrated in this application will now be discussed in greater detail.

Initially, in accordance with the invention, a substantial portion of the internal surface area of a resonant cavity is formed of magnetic material. These cavity walls are magnetized in the direction perpendicular to the direction of the greater portion of the high frequency magnetic field adjacent the particular wall, at or close to the critical magnetic field required for antiresonance. A cavity resonator is used rather than the walls of a straight transmission wave guide, because a given percentage change in permeability results in a much greater change in reflected or transmitted power for the former than the latter.

Fig. 2 represents a schematic diagram of a modulation system employing the invention. In this figure, a microphone 1, shunted by the high resistance 2, excites the amplifier 3. The transformer 4 matches the impedance of the amplifier to the modulation coil 6 which encircles the resonant cavity 5. The biasing coil 9, which is energized by the direct current power supply 7 through the variable resistance 8, also encircles the resonant cavity 5. As will be described in greater detail in connection with Figs. 3-6, the apparent permeability of certain magnetic walls of the cavity 5 vary with applied magnetic field. As the apparent permeability increases or decreases, the transmission loss of the cavity 5 increases or decreases

correspondingly. Energy from the microwave carrier generator 10 is coupled to the variable loss cavity 5 by the waveguide 11. The resonant cavity 5 thus serves to modulate the microwave energy generated by the carrier wave source 10 in accordance with variations in the modulating and biasing current in the coils 6 and 9. The speech modulated waves are then transmitted through the output wave guide 12 to the antenna 13.

Fig. 3 represents one form of transmission type resonant cavity 5 which may be used with the system of Fig. 2. In this figure, the wave guide 11 is the input to and the wave guide 12 is the output from the right circular cylindrical cavity 5. The two coupling slots 14 and 15 are located off center in the end plates 17 and 18 and serve to excite the cavity in a TM_{01n} mode. When energized in this mode, the component of the high frequency magnetic field adjacent the cylindrical wall is parallel to the two ends walls 17 and 18. When the cavity 5 of Fig. 3 is associated with the circuit of Fig. 2, the coils 6 and 9 set up a magnetic flux lengthwise in the ferromagnetic cylinder 16 which makes up a large portion of the internal surface of the cavity. This longitudinal magnetic field in the cylinder is perpendicular to the high frequency magnetic field in the cavity adjacent the cylindrical inner surface, and thus is properly oriented to obtain the ferromagnetic resonance absorption effects set forth hereinbefore. The length of the cylindrical cavity is an integral number of half wavelengths of the excitation frequency in order to resonate in a TM_{01n} mode. Inasmuch as the end plates 17 and 18 are not in the magnetic circuit, they may be of conducting non-magnetic material.

Referring to Figs. 1 and 2, the current flowing in the biasing coil 9 could, for example, be adjusted to the point where the plot of permeability vs. magnetic field strength is very steep. The negative slope region of the curve in the 0-150 oersted section of the plot is perhaps the best section of the curve because of the low steady biasing flux required and the steep slope of the curve. Thus, with a reasonably low level of modulating current in the coil 6, a substantial modulation of the microwave carrier can be effected by the substantial change in the loss of the cavity 5. Modulation by biasing to a point on either side of the resonance absorption peak would, of course, also be satisfactory.

Fig. 4 represents a cross section of an alternative cavity arrangement in which permanent magnet biasing is employed in place of the separate magnetic coil 9 shown in Fig. 2. The carrier wave is introduced to the right circular cylindrical modulating cavity 16, 19, 20 through the wave guide 11 and is coupled to it by a slot which is off-center in the end plate 20, and thus asymmetric with respect to the center line 22 of the cavity. Similarly, the modulated microwaves are coupled to the output wave guide 12 by means of an off-center coupling slot in the end plate 19. As in the embodiment of Fig. 3, the cylindrical surface 16 is of magnetic material. In this case, however, the end plates 19 and 20 are of magnetic rather than conducting non-magnetic material to provide a magnetic path for the steady biasing flux from the permanent magnet 21 to the magnetic cylinder 16. The coil 6, which encircles the magnetic cylinder 16, introduces the modulating flux which is superposed on the steady flux of the permanent magnet just as the modulating flux from the coil 6 is superposed on the direct current flux of the coil 9 in the embodiment of Fig. 2.

Figs. 5 and 6 show another alternative transmission type resonant cavity in accordance with the invention. Fig. 5 is an isometric view of the wave guide and resonant cavity, while Fig. 6 is a transverse cross section of the resonant cavity and also shows the external magnetic circuit for the cavity. Referring now to Fig. 5, the wave guides 11 and 12 again represent the input and output to and from the resonant cavity. Suitable transition elements 41 and 42 are employed to match the wave guides to the resonant cavity. As seen to advantage in Fig. 6,

the top 44 and bottom 44' of the resonant cavity, as well as the intermediate plates 45, are of magnetic material and are energized transverse of the direction of microwave propagation by the modulating coil 46 and the biasing coil 47 through the magnetic yoke 48 and the magnetic side plates 43 and 43'. With the cavity energized in the TE_{01n} mode, the transverse magnetic field in the plates 44 and 45 is seen to be perpendicular to the greater portion of the high frequency magnetic field adjacent these plates. The side plates 43, which are not directly involved in the antiresonance phenomenon, may be covered with conducting non-magnetic plates 49 to reduce the over-all losses in the cavity.

Fig. 7 represents still another modulating resonant cavity arrangement, in this case a reflection type cavity. The inherent properties of a matched hybrid junction are used in connection with this embodiment. The parallel hybrid arm 11 and the series arm 12 represent the input and output from this modulation arrangement. The arm 51 of the hybrid junction is provided with the impedance matching and absorbing termination 53 as is well known in the art. The reflection type resonant cavity 54 is coupled to the hybrid junction by means of the wave guide 52 aligned with the arm 51. Applying the known properties of hybrid junctions to this device of Fig. 7, the input energy in arm 11 will split evenly between arms 51 and 52, with no direct energy passing from the parallel arm 11 to the series arm 12. In addition, half the reflected energy from the cavity 54 will be transmitted to the output series arm 12. The apparent permeability of the cavity 54 is varied by means of the coil 6, as explained in connection with Figs. 2-4, and is adjusted to a suitable operating point by means of a permanent magnet or a steadily energized coil. The reflected energy from the cavity is, of course, a function of the apparent permeability of the cavity, and, as this is changed in accordance with the modulated signal, the amount of energy transmitted from the hybrid junction through the series arm 12 will vary.

The above-described resonant cavities could, of course, also be used as low loss cavity resonators merely by employing a proper steady biasing flux so that the device would operate precisely at the antiresonant point. With suitably low values of minimum apparent permeability, it appears that cavities with even less loss than copper or silver would be possible.

While particularly well adapted for use in connection with modulators or low loss cavity resonators, it is to be understood that the above-described arrangements are merely illustrative embodiments made in accordance with the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A rectangular cavity resonator having a plurality of spaced magnetic plates extending substantially across said cavity, means for establishing a biasing magnetic field in said plates, and a wave guide coupled to said cavity.

2. A rectangular cavity for electro-magnetic waves having a plurality of spaced magnetic plates extending substantially across said cavity, means for establishing a biasing magnetic field in said plates, and a wave guide coupled to said cavity.

3. In combination, a longitudinally extending wave guiding passageway, a plurality of plates of magnetic material located in said passageway and having the greater portion of the surface area thereof spaced from the walls of said passageway, said plates being oriented parallel to the longitudinal axis of said passageway, induction means for applying a biasing magnetic field to said plates, and means for introducing microwave energy into said passageway in a mode in which the magnetic components of said microwave energy are perpendicular to said biasing magnetic field.

4. In combination, a first elongated, conductively

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bounded passageway, a plurality of spaced magnetic plates extending substantially from one conducting boundary of said passageway to another, said plates being substantially parallel with the longitudinal axis of said passageway, means for establishing a biasing magnetic field in said plates, and second and third conductively bounded passageways connected to said first passageway at opposite ends thereof to transmit electromagnetic wave energy through said first passageway.

5. In combination, a first elongated, conductively bounded passageway, a plurality of spaced magnetic plates located within and having their wide surfaces spaced from the walls of said passageway and being oriented substantially parallel to the longitudinal axis of said passageway, means for establishing a biasing magnetic field in said plates, and second and third conductively bounded passageways connected to said first passageway at opposite ends thereof to transmit electromagnetic wave energy through said first passageway.

6. In combination, a longitudinal extending conductively bounded structure for electromagnetic wave energy, a plurality of spaced magnetic plates located within said structure and being oriented substantially parallel to the longitudinal axis of said structure, means for establishing a biasing magnetic field in said plates, and second and third conductively bounded structures connected to said first structure at opposite ends thereof to transmit electromagnetic wave energy through said first structure.

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7. In combination, a first elongated, conductively bounded passageway, a plurality of spaced magnetic plates extending substantially from one conducting boundary of said passageway to another, said plates being substantially parallel with the longitudinal axis of said passageway, means for establishing a steady biasing magnetic field in said plates, means for superposing a variable magnetic field to said steady biasing field, and second and third conductively bounded passageways connected to said first passageway at opposite ends thereof to transmit electromagnetic wave energy through said first passageway.

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