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FERRITE MICROWAVE DEVICES FOR USE AT HIGH SIGNAL ENERGY LEVELS

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FIG. 1

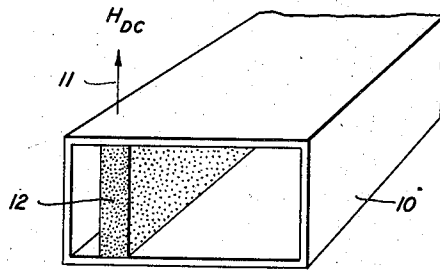


FIG. 2

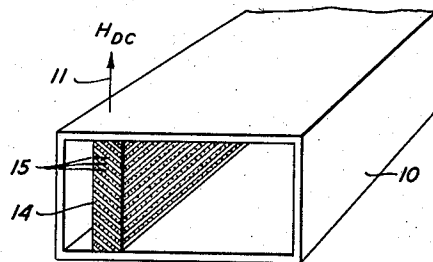
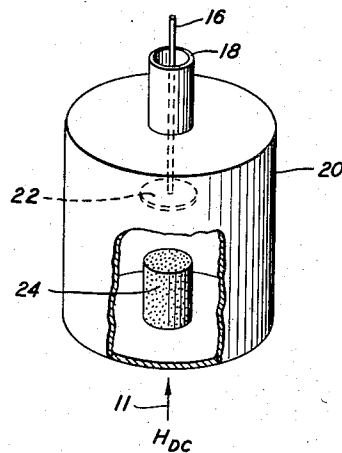


FIG. 3



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2 Claims. (Cl. 333—24)

This invention relates to the use of ferrites in microwave frequency devices to be operated at high signal energy levels. More particularly, it relates to methods and means for avoiding excessive power dissipation resulting from power absorption in ferrite elements used in microwave wave guide and/or resonant cavity devices at high signal energy levels to produce adjustable phase shift or to produce circulators, isolators, tunable resonant cavities, and other microwave frequency devices.

Based upon experience in the use of devices at moderate signal energy levels, which devices included ferrite elements, two effects have, in general, been assumed as resulting from the normal characteristics of ferrites, namely that saturation at the main ferromagnetic resonance of the ferrite occurs at relatively high signal energy level and that dissipation resulting from absorption of power by the ferrite at unidirectional magnetizing fields well below the intensity required for ferromagnetic resonance should be moderate.

It has been discovered, however, that neither of the above-mentioned two effects necessarily holds true for high signal energy levels of operation. Indeed, saturation has been observed at relatively low signal energy level at the main ferromagnetic resonance and intolerably high dissipation resulting from absorption at magnetizing fields much less than the intensity required for ferromagnetic resonance has been encountered.

In the Physical Review for January 1954, volume 93, starting at page 72, the authors Bloembergen and Wang discuss experiments and present data (see particularly Fig. 10 on page 78 and the text relating thereto) illustrating the variation in the behavior of a ferrite test specimen with respect to the above-mentioned two effects as increasing values of signal level energy are employed. Related studies by Damon will be found in the Review of Modern Physics, volume 25, published in 1953, starting at page 239. Said authors, however, are unable to furnish any explanation to account for the results obtained.

In accordance with the principles upon which the present invention is based, the above-mentioned unwanted losses can be explained in the following manner.

At any finite temperature, the ferrite is in a state of random thermal agitation, that is, the magnetization fluctuates slightly from point to point and from moment to moment about its mean position.

This state of agitation can be analyzed spatially, at least to a first approximation, into a set of waves of various wavelengths.

A wave of any particular wavelength and propagation direction varies sinusoidally in time with a corresponding natural frequency.

As a first approximation these waves can be considered to be independent of each other.

However, for a closer approximation, it is evident that these waves must be coupled together, since the magnitude of the instantaneous magnetization in any small region must be a constant. Consequently, the demag-

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netizing and exchange fields acting on each wave must include terms acting on each wave that are dependent upon the amplitudes of all the other waves.

As is well known to those skilled in the art, the desirable properties of a ferrite arise from the uniform precession of the magnetization.

This uniform precession can be regarded as a wave having a relatively long wavelength. This particular wave is excited, not merely by the relatively weak forces of thermal origin but by the very much stronger signal energy field.

Accordingly, the most important coupling terms in the motion of any of the waves of shorter wavelength will be those that involve the amplitude of the uniform precession wave.

As the signal and the resulting uniform precession wave are increased, the couplings to the shorter waves become stronger until eventually a point is reached at which a relatively sudden transfer of power from the uniform precession wave to certain of the shorter spin waves of thermal agitation takes place. These particular spin waves then become of very large amplitude and the energy drawn by them from the uniform precession wave is absorbed and dissipated, seriously impairing the efficiency of the device.

It can be demonstrated mathematically (see applicant's "Letter to the Editor," mailed concurrently with the filing of this application, and published in the Physical Review, volume 101, No. 4, dated February 15, 1956) that this situation can arise only for waves whose natural frequency is $n/2$ times the signal frequency, where n is an integer. Only the cases $n=1$ and $n=2$ will occur for the power levels met in practice. Furthermore, the case $n=2$ will occur only when the applied field is adjusted for ferromagnetic resonance. For the great majority of practical applications only the case $n=1$ is of interest and the applied magnetizing field will usually lie between three-tenths and eight-tenths of the value required for ferromagnetic resonance.

Analysis further shows that the threshold signal power level at which instability arises is inversely proportional to the square of the saturation magnetization. Some gain in stability may therefore be realized by employing ferrites having lower saturation magnetization. However the gain in stability which can, as a practical matter, be realized in this way will usually be limited since the desired effects (phase shift, et cetera) are also reduced proportionately. Likewise, appreciable gain in stability may be realized by appropriate correlation of the geometry of the ferrite member relative to that of the guide and the disposition of the magnetic field, though a larger sweep in the magnetizing field may be required to produce the same change in permeability.

Related arrangements involving subdividing the main body of ferrite by interposing conductive, dielectric or ferroxdure layers in planes perpendicular to the direction of the magnetizing field have, by way of example, been proposed in applications assigned to applicant's assignee by J. H. Rowen, Serial No. 569,143, filed March 2, 1956; and M. T. Weiss, Serial No. 574,783, filed March 29, 1956; respectively.

The present invention, however, includes the broader concept that, since the spin waves arising from thermal agitation which are most likely to produce instability by coupling to the uniform precession wave have wavelengths of at least a micron, coupling of these spin waves to the uniform precession wave can be inhibited by grinding or otherwise comminuting the ferrite into particles having a maximum dimension of less than a micron. Indeed, for particle sizes in the order of 100 angstroms (one-hundredth micron) substantially no coupling of spin

waves to the uniform precession wave will be encountered, and, consequently, a very great increase in signal wave energy level can be realized without encountering substantial power absorption by the ferrite at magnetizations other than the intensity of magnetization required for ferromagnetic resonance.

It has been found practicable, by way of example, to produce particles of less than a micron maximum dimension by ball grinding and centrifugal separation from particles of larger size. The particles of ferrite are then thoroughly mixed with particles of similar size of a low loss dielectric material such as polystyrene, or they may be thinly coated by a fine spray of a solution of polystyrene in a highly volatile solvent. The mixture is then pressed into the size and shape desired at a temperature of between 300 degrees centigrade to 350 degrees centigrade so that the dielectric material will, upon cooling, act as a binder to hold the ferrite particles in the element, with the majority of the ferrite particles substantially insulated from each other.

Alternatively, the element may be built up of alternate layers less than a micron thick of ferrite particles of substantially 100 angstroms maximum dimension and a low loss dielectric material such as polystyrene, the polystyrene layers also being less than a micron thick. Elements of this type should preferably be oriented so that the planes of the component layers make an angle of from 30 to 70 degrees with the direction of the magnetizing field, depending upon the saturation magnetization of the element and the operating frequency.

A principal object of the invention is, accordingly, to substantially eliminate dissipation resulting from absorption of signal energy by ferrite members at high signal energy levels and magnetizing fields other than the magnetizing field intensity required for ferromagnetic resonance.

Another principal object of the invention is to structurally modify ferrite elements for use in microwave transmission devices in such manner that excessive losses will not be encountered at high signal energy levels and magnetizing fields below the intensity required for ferromagnetic resonance.

Other and further objects, features, and advantages of the invention will become apparent during the course of the following detailed description of specific structures illustrative of a number of ways of embodying various of the principles of the invention, as well as from the appended claims.

In the accompanying drawings:

Fig. 1 illustrates one arrangement of the invention as applied to a wave guide transmission line;

Fig. 2 illustrates a related arrangement of the invention as applied to a wave guide transmission line; and

Fig. 3 illustrates an application of particular principles of the invention to the improvement of the characteristics of tunable resonant, microwave frequency, cavities, employing ferrite elements.

In more detail, in Fig. 1 a rectangular wave guide 10, suitable for transmitting microwave frequencies, has assembled therein a ferrite element 12 extending between the upper and lower sides of the guide with the longitudinal axis of the element parallel to that of the guide but offset from the axis of the guide as shown. Arrow 11, designated H_{DC} , represents a steady magnetizing field applied along the vertical dimension of element 12, the value of which can be adjusted as desired. This field can be provided by either permanent magnets or electromagnets (not shown), as is well understood by those skilled in the art.

Element 12 is composed of particles of a ferrite ground to a fineness of less than one micron, and preferably to a fineness of 100 angstroms maximum dimension, the particles being embedded in a matrix of polystyrene so as to be for the most part electrically isolated from each other.

With this arrangement the phase shift along the wave guide 10 can be varied at will by varying the strength of the steady magnetizing field H_{DC} (arrow 11).

As a result of the minute size of the particles, very high signal energy levels can be transmitted along wave guide 10, without substantial dissipation resulting from absorption of energy by element 12 being encountered, provided the strength, or intensity, of the magnetizing field H_{DC} is not made to closely approach that at which ferromagnetic resonance of the ferrite particles occurs.

In Fig. 2 the ferrite element 14 differs from element 12 of Fig. 1 in that it is composed of alternate layers 15, each less than a micron thick, of ferrite particles of fineness as specified for element 12 of Fig. 1 and of a low loss dielectric material such as polystyrene, the layers of dielectric material being also less than a micron thick, the angle of the layers 15 with respect to the direction of the magnetizing field H_{DC} being between 30 and 70 degrees, the layers 15 extending longitudinally along element 14. Due to physical limitations, the layers 15 in Fig. 2 cannot, obviously, be shown in the drawing as less than a micron in thickness, but it is, of course, to be understood that in structures conforming to the invention the alternate layers 15 of particles and of dielectric in Fig. 2 will in fact all be less than one micron in thickness.

The dielectric material may, for example, be dissolved in a volatile solvent and applied as a fine spray to obtain a layer of the desired thinness. The particles of ferrite can be lightly dusted on to obtain a layer of ferrite particles of the desired thinness. Alternatively, various chemical and/or electrical methods, well known to those skilled in the art, can be employed to obtain alternate layers of dielectric and ferrite particles of the desired degrees of thinness. Layers approaching as nearly as practicable 100 angstroms in thickness are to be preferred, but very substantial improvement in the operating characteristics of the element will be realized at high signal energy levels as long as the layers are less than one micron in thickness.

The arrangement of Fig. 2 will be substantially equivalent in electrical performance to that of Fig. 1.

In Fig. 3, a cylindrical resonant conductive cavity 20, having a coaxial line, comprising outer conductor 18 and inner conductor 16, coupling to the cavity by a conductive coupling disc 22 supported within the cavity on an extension of inner conductor 16, is shown. At the opposite end, within cavity 20, a cylindrical ferrite element 24 is mounted concentrically with the cavity, the cavity being partly broken away to show element 24 more clearly. It is subjected to a steady magnetizing field H_{DC} , indicated by arrow 11, the value or intensity of which can be adjusted as desired. As for Figs. 1 and 2, this magnetizing field can be provided by permanent magnets or electromagnets (not shown) in any of the numerous manners well understood by those skilled in the art. Ferrite element 24 is composed of minute particles of ferrite in a matrix of low loss dielectric material as for element 12 of Fig. 1, or, alternatively, of layers of ferrite particles and a low loss dielectric material as for element 14 of Fig. 2, the layers being oriented at an angle of between 30 and 70 degrees with respect to the direction of the steady magnetizing field, indicated by arrow 11. By varying the strength of the steady magnetizing field the frequency at which cavity 20 is resonant can be similarly varied over a wide range of frequencies. So long as the intensity of the magnetizing field is not made to closely approach the value for which the ferrite particles undergo ferromagnetic resonance, no substantial dissipation resulting from absorption of power by the ferrite will be encountered.

Obviously, the principles of the invention are directly applicable to numerous other microwave frequency devices employing ferrite elements, such as isolators, circulators and the like, well known to those skilled in the art.

and many such devices can readily be devised by those skilled in the art to embody said principles.

What is claimed is:

1. Means for producing a modification of the propagation of wave energy in the microwave frequency range exceeding a critical power level without introducing substantial loss to said energy, comprising ferrite material capable of exhibiting in particles of substantial size a gyromagnetic resonance at a frequency within the range of said wave energy in the presence of a polarizing magnetic field of a given value and also capable of producing said modification as well as a further loss introducing resonance at said frequency in the presence of a polarizing magnetic field of a second value greater than zero and less than said given value when the power level of said wave energy exceeds said critical level, means for applying said wave energy of power level greater than said critical level to said material, and means for applying a polarizing magnetic field of said second value to said material, said material being formed of a multiplicity of ferrite particles embedded in a matrix of low loss dielectric material with the ferrite particles isolated from each other and with each particle having a maximum dimension of less than one micron to minimize the loss associated with said further resonance.

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2. The combination of claim 1 in which each ferrite particle of the ferrite material has a maximum dimension not greater than 100 angstroms.

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