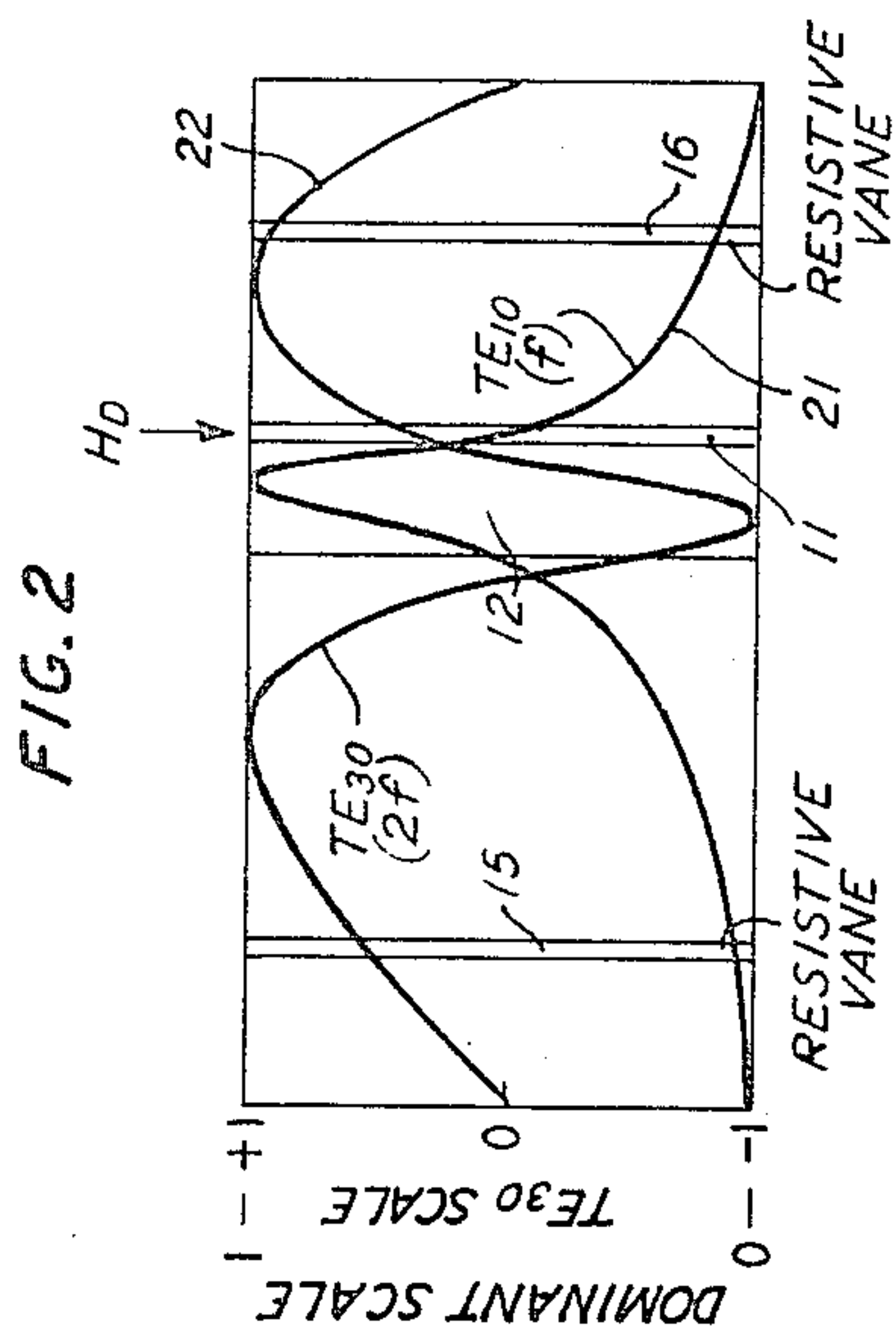
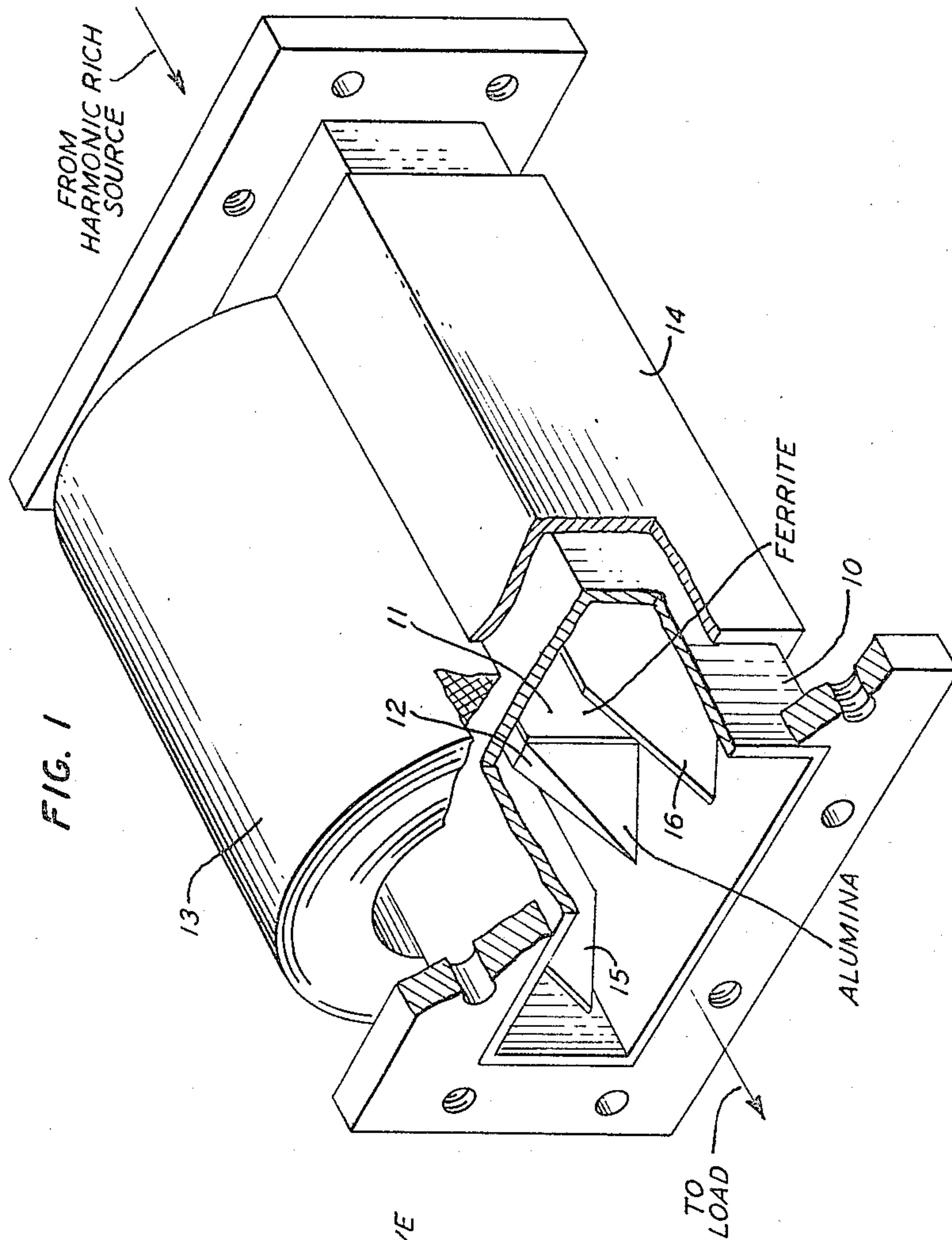


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J. J. DEGAN, JR
 RESONANCE ISOLATOR RECIPROCALLY ABSORBING
 SECOND HARMONIC POWER
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RESONANCE ISOLATOR RECIPROCALLY ABSORBING SECOND HARMONIC POWER

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This invention relates to nonreciprocal electromagnetic wave transmission systems and more particularly to isolators which allow wave energy in a given frequency band to travel in one direction but which attenuate wave energy in the band as well as harmonics thereof which travel in the opposite direction.

The art is now familiar with isolators in which an element of gyromagnetic material, such as ferrite, is placed asymmetrically in the path of electromagnetic wave energy at a point in the magnetic field pattern thereof that is circularly polarized and biased to the strength at which the material becomes resonant in a gyromagnetic sense to the frequency of the applied wave energy. When the direction of propagation is such that gyromagnetic precession is the same as the direction of circular polarization, the wave energy is substantially absorbed thus providing the desired isolation. When the directions are opposite there is little absorption allowing the desired transmission. Since the band of absorption is no greater than the bandwidth of gyromagnetic resonance, the art has proposed numerous ways of broadening the absorption band over a spectrum that has always been substantially less than one octave.

An important use of isolators, however, has been in the output of magnetrons, glystrons and other microwave generators which have outputs rich in harmonics. These harmonics are not isolated by present isolators and when reflected back into the source, produce "long line effects" and oscillator pulling to an undesirable extent even though reflections at the fundamental are suppressed. While separate filters can, of course, be employed to eliminate the harmonics, the extra components add substantially to the expense and bulk of the equipment.

It is therefore an object of the present invention to simultaneously isolate the fundamental frequency from an electromagnetic wave source and attenuate harmonics thereof in a single unitary structure.

In accordance with the invention unique advantage is taken of the asymmetrical distortion introduced to the wave field distribution in a conductively bounded guide by the dielectric loading of the ferrite element therein either alone or in combination with additional dielectric loading. Thus, at least one and preferably a pair of resistive vanes are placed one on either side of and spaced from the ferrite at points of substantial difference in the electric field intensity of the distorted fundamental and the harmonic field patterns. So located, these vanes add little loss to the fundamental and substantial loss to the harmonics because the distortion is such that energy at the fundamental travels predominantly in the dielectric of the ferrite while the mode of propagation preferred by the harmonics is nearly that of the TE_{30} having a large electric field at the position of the vanes.

These and other objects and features, the nature of the present invention and its various advantages, will appear more fully upon consideration of the specific illustrative embodiments shown in the accompanying drawings and described in detail in the following explanation of these drawings, in which:

FIG. 1 is a cutaway perspective view of a harmonic selective isolator in accordance with the invention; and

FIG. 2, given for the purpose of explanation, is a sim-

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plified cross-sectional view of the structure of FIG. 1 showing electric field distribution of certain modes of wave propagation therein.

The basic construction and principles of operation of ferromagnetic resonance isolators are well known in the art and only a summary need be given here. For further details reference may be had to Patent 3,076,946 granted Feb. 5, 1963 to W. H. Hewitt, Jr., Patent 3,063,028 granted Nov. 6, 1962 to M. T. Weiss, Patent 3,095,546 granted June 25, 1963 to W. P. Ayres et al. or Patent 3,105,946 granted Oct. 1, 1963 to H. G. Beljers et al.

Referring more particularly to FIG. 1, the usual components of the isolator comprise a section 10 of conductively bounded rectangular waveguide having internal transverse cross-sectional dimensions which support the dominant TE_{10} mode of propagation in the frequency band of interest but are cut off to higher order modes in this band. Asymmetrically located in guide 10 at a position displaced to one side of the guide center line and thus in the region known to have predominant circularly polarized magnetic field components, is a thin vane 11 of ferrite or other gyromagnetic material. Next to vane 11, preferably on the center line side thereof, is a thicker slab 12 of high dielectric material, such as alumina or aluminum oxide, having tapered end sections. Slab 12 serves both to aid in the support of the fragile vane 11 and also to increase in known ways the energy level and effectiveness of circular polarization at the position of vane 11. Vane 11 is magnetically polarized by a C-shaped magnet 13 having pole pieces bearing against the top and bottom broad walls of guide 10 to direct a magnetic field through the guide perpendicular to these walls. A magnetic shunt 14, formed from a steel alloy having a suitable reluctance versus temperature characteristic is placed against magnet 13 to bypass an amount of flux which varies with temperature in accordance with the principles analyzed in further detail in an article entitled, "Temperature Compensation of Ferrite Isolators" by G. Wheeler and P. Rajcok, Microwave Journal, February 1959.

The combination of components thus far described is well known in the prior art and forms no part of the present invention. The functions of these components are also understood and involve the absorption of circularly polarized magnetic field components propagating in one direction along guide 10 that are rotating in the same sense and at substantially the same frequency as the gyromagnetic precession of the spinning electrons within the material of vane 11. Since wave energy propagating in the opposite direction has components rotating in the opposite sense that are not absorbed, the loss introduced is non-reciprocal leading to the desired isolating property of the structure. The frequency of precession depends upon the strength of the biasing field and the magnetic saturation properties of the ferrite. It can therefore be adjusted to absorb a fundamental signal of any frequency but will have no effect upon any harmonic energy of this signal.

The present invention is concerned with the additional and reciprocal absorption of these harmonics by means of at least one and preferably a pair of resistive vanes 15 and 16 without interfering in any substantial way with isolator action at the fundamental. Thus, in accordance with the invention, vanes 15 and 16 are located on either side of members 11 and 12 within guide 10 and spaced therein nearer to the narrow walls of the guide than to the center line thereof. Each resistive vane may be constructed from a thin card of dielectric material that has been provided with end tapers at each of its ends and then covered on at least one face by a film of resistive material. Alternatively, vanes 15 and 16 may be formed from a lossy dielectric.

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The operation of the structure in accordance with the invention may be understood with the aid of FIG. 2 which shows the relative positions of the component parts of FIG. 1 together with a superimposed representation of the electric field distribution of the dominant TE_{10} mode at the fundamental frequency f and the TE_{30} mode of the harmonic frequency $2f$. The dielectric loading caused by the ferrite vane 11 and dielectric slab 12, which for the present purposes may be considered as a single homogeneous dielectric member, distorts the dominant mode of the fundamental as shown by curve 21 such that the majority of its energy is contained within the dielectric and falls off rapidly and exponentially on either side thereof. Even though this distortion makes the field pattern asymmetrical, the dominant mode cannot degenerate into any other mode of propagation since the dominant mode itself represents the only mode capable of being supported at the frequency f . Curve 21 therefore represents the energy to which nonreciprocal absorption is introduced by ferrite vane 11 in accordance with the prior art.

With the harmonics, however, support of higher order modes is possible. The dielectric mismatch introduced to the dominant mode at the harmonic frequency $2f$ is substantial and causes a predominant portion of its energy to degenerate into other modes. Experiments have verified that most of the harmonic power is in fact converted into the TE_{30} mode. The explanation of this is believed to reside in the fact that the TE_{30} mode can most nearly of all modes form a symmetrical field pattern about the dielectric in the manner shown by curve 22 while other modes such as the TE_{20} and all other even order modes could only be supported in a highly distorted asymmetrical pattern. It is a well known principle of electromagnetic propagation that any discontinuity along the path tends to convert the energy into its most symmetrical and most easily propagated form.

The newly generated TE_{30} mode has substantial electric field components at the position of vanes 15 and 16 and is substantially dissipated thereby while the energy remaining in the dominant mode at the fundamental frequency has only small intensity in these same positions and is only incidentally effected.

It should be apparent that the optimum position of vanes 15 and 16 corresponds to that of the maximum difference between the electric field intensities of the dominant TE_{10} mode at the fundamental frequency f and the TE_{30} mode at the harmonic frequency $2f$. This in turn depends upon the physical dimensions of the ferrite and dielectric vanes, their respective dielectric constants and the dimensions of the waveguide 10 and may best be determined empirically. Thus, in an embodiment that has been reduced to practice, nickel alumina ferrite vane 11 had a thickness approximately one-tenth that of Al_2O_3 member 12 which in turn had a width approximately one-tenth of the waveguide width. Resistive vanes 15 and 16, centered approximately one-tenth of the waveguide width away from each narrow wall, were found to produce a 50 to 1 increase in the forward loss to the harmonic frequency $2f$ as compared to the design frequency f .

In all cases it is to be understood that the above-described arrangement is merely illustrative of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An isolator comprising a conductively bounded rectangular waveguide having wide and narrow transverse dimensions for supporting electromagnetic wave energy in a given frequency band in the dominant TE_{10} mode,

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a magnetically polarized member of gyromagnetic material biased to its gyromagnetic resonance point positioned within said waveguide at a point of predominant circular polarization of said mode, and at least one resistive vane coextensive with and transversely spaced along said wide dimension from said gyromagnetic member at a point of substantial difference between the electric field intensity of the TE_{30} mode in a band substantially twice the frequency of said given band and intensity of said TE_{10} mode.

2. An anharmonic resonance isolator comprising a conductively bounded rectangular waveguide having wide and narrow transverse dimensions for supporting electromagnetic wave energy in a given frequency band in the dominant TE_{10} mode, an elongated member of gyromagnetic material positioned within said waveguide at a point of predominant circular polarization of said mode, means for magnetically polarizing said member to ferromagnetic resonance in said given band, and a pair of resistive vanes each spaced along said wide dimension from said gyromagnetic member on either side thereof at a point of substantial electric field intensity of the TE_{30} mode in a band substantially twice the frequency of said given band.

3. An anharmonic resonance isolator comprising a conductively bonded rectangular waveguide for supporting electromagnetic wave energy in a given frequency band in the dominant TE_{10} mode, an elongated member of gyromagnetic material positioned asymmetrically within said waveguide at a point displaced to one side of the center line of said guide, means for magnetically polarizing said member to ferromagnetic resonance in said given band, a slab of dielectric material positioned adjacent to said member between said member and said center line, and a pair of resistive vanes each spaced from the adjacent combination of said dielectric member and said gyromagnetic member on either side of said adjacent combination at a point nearer to the walls of said guide than to said center line to produce substantial absorption of a higher order mode at a frequency twice the frequency of said given band as compared to absorption of said TE_{10} mode in said given band.

4. In combination, a source of electromagnetic wave energy having fundamental components in a given frequency band and harmonics in a band substantially twice said given band, a load isolator for preventing reflections into said source of both said fundamental and said harmonics, said isolator comprising a conductively bounded rectangular waveguide having wide and narrow transverse dimensions for supporting wave energy in said given band in the TE_{10} mode, an elongated member of gyromagnetic material positioned within said waveguide at a point of predominant circular polarization of said mode, means for magnetically polarizing said member to ferromagnetic resonance in said given band, a slab of dielectric material positioned adjacent to said member, and a pair of resistive vanes each spaced along said wide dimensions from said gyromagnetic member at a point of substantial electric field intensity difference between the TE_{30} mode of said harmonics and said TE_{10} mode of said fundamental.

References Cited

UNITED STATES PATENTS

2,903,656	9/1959	Weisbaum	333—24.2
2,922,964	1/1960	Turner	333—24.2
3,247,472	4/1966	Turner	333—24.2 X

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