United States Patent [19]

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[54] **FERRITE POWER LIMITER COMPRISING SYNCHRONOUSLY TUNED, RESONANT CAVITIES**

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[52] **U.S. Cl.** **333/17;** 333/24.2

[51] **Int. Cl.** **H01p 1/00;** H01p 1/22

[58] **Field of Search** ..... 333/17, 73 W, 24.2

[56] **References Cited**

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[57] **ABSTRACT**

A section of microwave transmission line is made in the form of three contiguous, in-line, synchronously-tuned, resonant cavities. The end of each cavity is terminated by a symmetrical inductive iris and the spacing between irises is approximately a half wavelgnth at the center frequency of the selected passband. In each cavity there are supported alternate rods of ferrite and nonmagnetic dielectric material all of the same dimensions and of substantially the same dielectric constant. An adjustable magnetic field is provided for the ferrite. The limiting threshold is greatly lowered because of the combined effects of increased RF magnetic field intensity in the cavities compared to that in the transmission line and the nonmagnetic separator rods that direct more of the magnetic flux through the ferrite.

1 Claim, 4 Drawing Figures

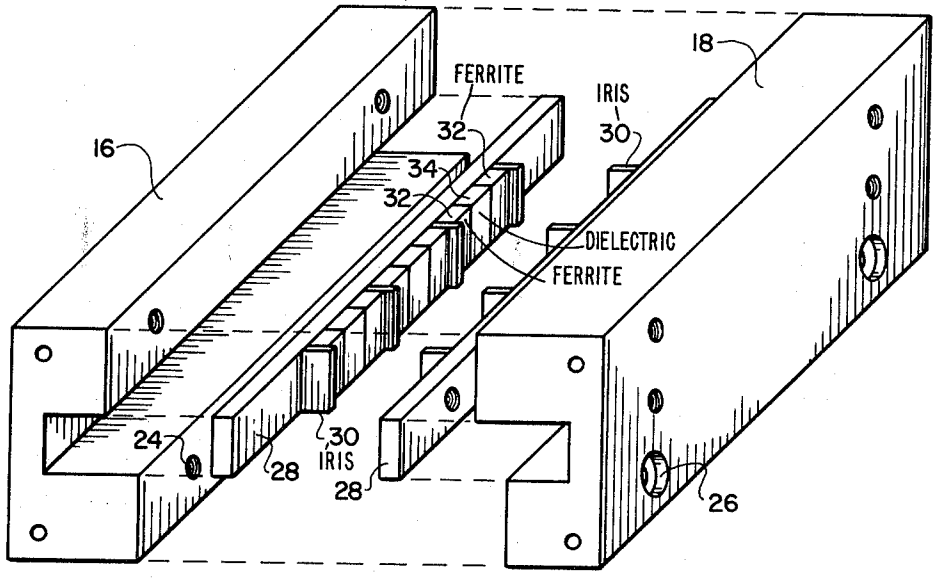


FIG. 1

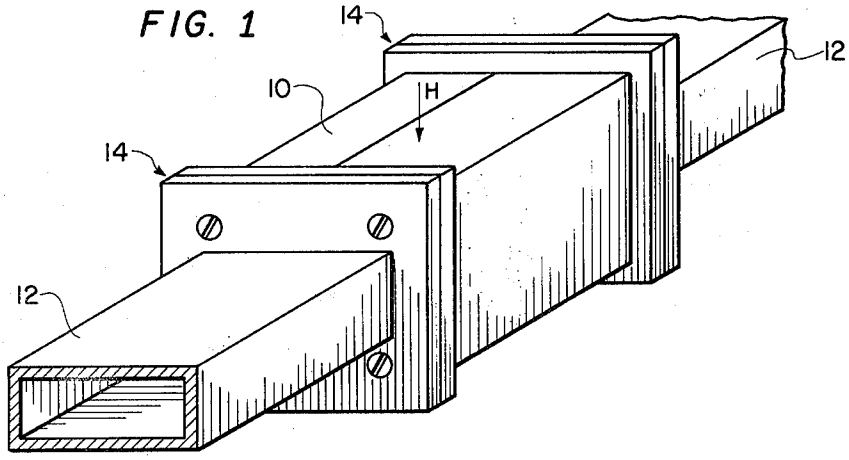


FIG. 2

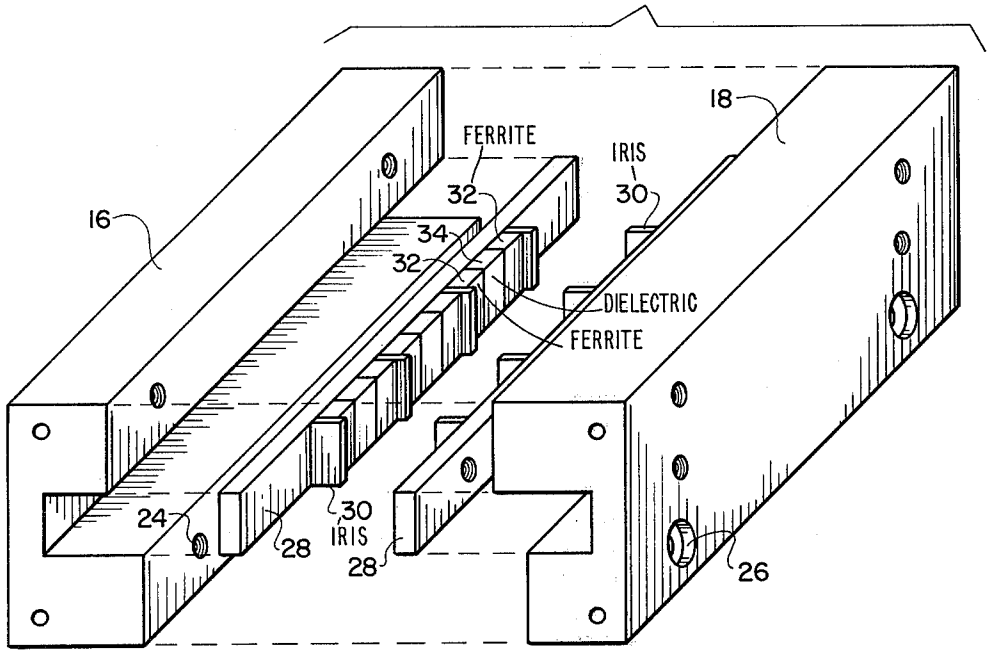


FIG. 3

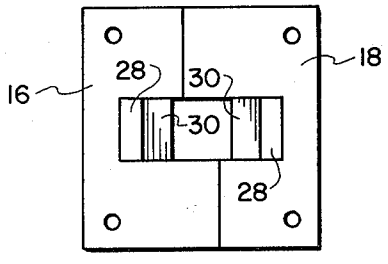
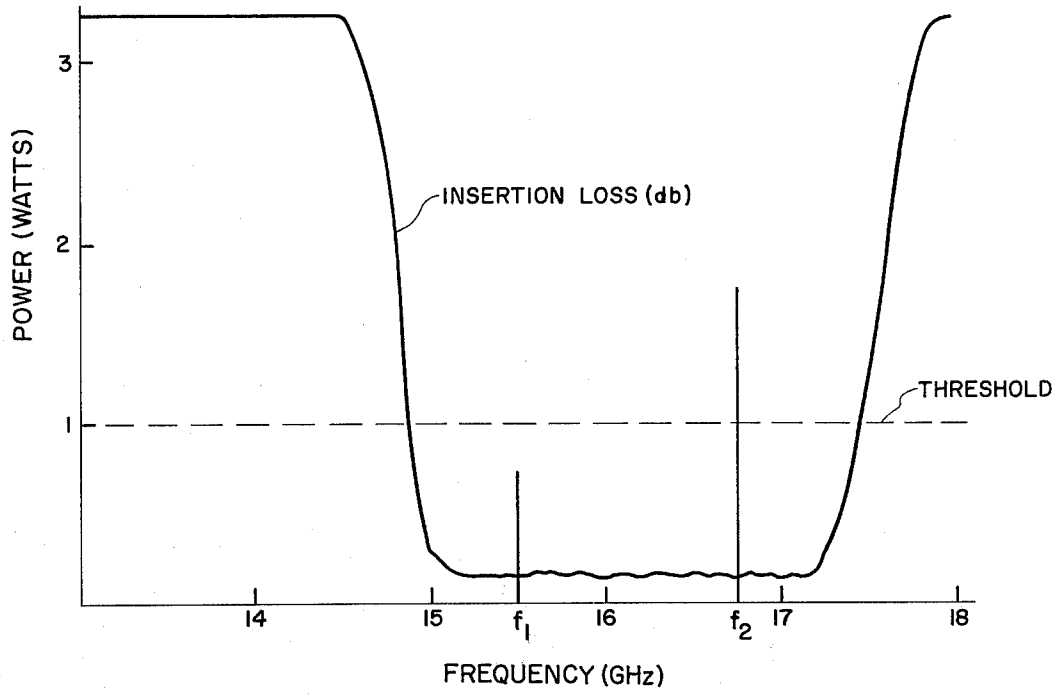


FIG. 4


POWER (WATTS)
3
2
1
INSERTION LOSS (db)
THRESHOLD
14
15
f_1
16
f_2
17
18
FREQUENCY (GHz)

FERRITE POWER LIMITER COMPRISING SYNCHRONOUSLY TUNED, RESONANT CAVITIES

BACKGROUND OF THE INVENTION

Most high frequency power limiting devices now are fabricated around a nonlinear element, generally a ferrite. Ferrites have proven to be more reliable as power limiters than predecessor gas TR tubes. One disadvantage of ferrite power limiters has been narrow bandwidth, which has been nominally 3% at K_u band (12–18 gigahertz). Narrow bandwidth has restricted ferrite limiter usefulness to radar applications. Another disadvantage of ferrite power limiters has been threshold levels of at least 20 watts, too high for broadband wide-open receivers.

Ferrite has three nonlinear physical mechanisms that may be exploited for power limiting. These mechanisms are known as premature decline of the main resonance, subsidiary resonance, and coincidence of the main resonance with the subsidiary resonance. The first and third of these mechanisms are applicable to devices that are too narrow-band and have thresholds that are too high for a broadband wide-open receiver. Generally, ferrite power limiter devices have been designed to utilize the subsidiary resonance mechanism because it offers broader frequency range and sharper frequency selectivity. These characteristics of subsidiary resonance are particularly suited for electronic warfare receivers and troposcatter communication receivers that operate in K_u band. In electronic warfare systems, the frequency selective property makes it possible to monitor a plurality of signals within the passband of the receiver and if one or more monitored signals exceed the limiting threshold and others do not, the signals that exceed the threshold are limited to threshold level and the other signals are passed unaffected. In troposcatter communication systems, the frequency selective property allows more efficient allocation of the frequency spectrum by reducing the frequency separation of transmitter and receiver.

Ferrite used for subsidiary resonance is crystalline, ferrimagnetic and nonconductive. Each molecule of crystal has a magnetic moment. A DC magnetic field is established through the crystal in a direction such that the magnetic moments are aligned with the applied magnetic field. Microwave energy traversing the ferrite material cause the magnetic moments to precess relative to the magnetic field direction at a rate determined by constants of the material. Output is directly proportional to input up to critical threshold power. At critical threshold power, spin waves are generated in the material and more of the incident microwave energy is absorbed. This nonlinear action limits microwave output power as microwave input power at any frequency within the passband increases from the threshold level. When a power limiter operates in subsidiary resonance and two or more time-coincident signals of different frequencies within the passband are transmitted to the power limiter and one signal exceeds the threshold, the limiter operates to limit the one signal, while passing the other signals with substantially no attenuation. It is unnecessary to separate out signals that exceed the threshold for transmission through the limiter.

There have been two problem areas in the design of a subsidiary resonance limiter. First, the relaxation time of the ferrite material permits pass-through of a substantially full amplitude spike of the steep leading edge of an input pulse. Second, the limiting threshold of subsidiary resonance ferrite limiters has been too high for the crystal at the input end of a receiver. Since relaxation time is a basic material parameter that cannot be decreased, this problem is minimized by using the best ferrite material available. Single crystal YIG (yttrium iron garnet) is the best material in the range from S-band to X-band. Above X-band, at about 16 gigahertz there is a breakout frequency at which single crystal lithium ferrite with a higher saturation magnetization has a lower threshold that single crystal YIG. In most receivers of electronic warfare systems and troposcatter communication systems, the minimal amplitude spike transmitted by the best ferrite may be tolerated because it generally does not have sufficient energy to cause crystal burnout. The main problem is the limiting threshold which is too high for broadband wide-open receivers.

An object of this invention is to provide an improved microwave transmission line with ferrite power limiter for use over a broad band and that has a substantially lower limiting threshold than prior art arrangements.

A further object is to provide a broadband microwave energy transmission line with a threshold on the order of 0.5–2.0 watts, flat response and negligible spike leakage over a wide passband that is approximately 15–17 gigahertz and that has a relatively wide dynamic range, e.g. at least 20 db.

SUMMARY OF THE INVENTION

A substantial improvement in subsidiary resonance ferrite limiters in terms of reduced threshold power and increased frequency range of operation is achieved by employing synchronously tuned, multiple resonance cavities, in-line in a waveguide transmission line. A ferrite limiter structure is in at least one of the cavities or in all of the cavities. Because there is intensification of RF magnetic field in a resonance cavity compared to that in the transmission line, the interaction of cavity and ferrite operates to lower the limiting threshold. The ferrite structure is of alternate rods of ferrite and of dielectric material of equal dielectric constant and the dielectric provides magnetic isolation between ferrite rods.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. 1 is a view in perspective of a short length of a microwave transmission line that includes the invention as part of the transmission line,

FIG. 2 is an exploded view of an embodiment of the invention shown in FIG. 1 on a larger scale, and not including the coupling flanges of FIG. 1,

FIG. 3 is an end view of the assembled embodiment of the invention shown in FIG. 2, on a smaller scale than in FIG. 2, and

FIG. 4 is a graphical showing of passband, insertion loss and power limiting character of the described embodiment.

A broadband limiter structure 10, shown in outline in FIG. 1, is series-connected in microwave transmission line 12. Though the transmission line 12 is shown as rectangular waveguide, the rectangular geometry is not essential in this invention and is not intended as a limitation. Conventional coupling flanges 14 affix the limiter structure 10 in series in the microwave transmission line. A magnetic field vector H represents DC magnetic field generated by a conventional selectively

adjustable means for directing a steady magnetic field through the structure **10** in the direction of the arrow or in the reverse direction and of selected intensity. The magnetic field may be uniform or tapered along the length of the limiter structure **10.**

The embodiment of broadband limiter **10** shown in FIG. **2** includes a pair of identical complementary channel-like housing members **16, 18** with sets of aligned bolt holes such as **24, 26.** A flat bar **28** nests in the bight of each channel member **16, 18.** The bars **28** are of the same length as members **16, 18** and each bar **28** and each member **16, 18** are formed with holes for screw fastening the bars **28** in place in the members **16,** 18. The distance between the bars **28** and the width of the channels of members **16** and **18** shown in FIG. **3** correspond to the height and width dimensions of the interior of waveguide **12.** The limiter structure forms a bridging section in the interrupted length of waveguide **12.** Three resonant cavities are defined by four matched pairs of iris inserts **30** removably fastened to bars **28** by screws not shown in FIG. **2.** The iris inserts are perpendicular to bars **28** and extend across the full width of the bars. The cavities are coupled by the symmetrical inductive spacings defined by the irises. In each cavity, there are supported at least two ferrite rods **32** separated by dielectric rods **34** all of the same dimensions, cemented across one or both of the bars **28** in the E-field direction. A suitable material for dielectric **34** is barium titanate. The dielectric is nonmagnetic and serves the purpose of causing the magnetic field intensity to be greater in the adjacent ferrite than it would be otherwise. By the use of two ferrites, i.e. a combination of single crystal YIG and single crystal lithium ferrite rods along the limiter, there was achieved a threshold of **0.75** watts at **16.0** GHz to **2.0** watts at **17.0** GHz with insertion loss of **0.9** db. Initial design is directed to the center frequency of the desired passband as resonant frequency. The dimensions of the waveguide structure **10** are derived empirically in stages to approach the desired limiter characteristic. An initial set of dimensions are established taking into account the number of cavities desired. The ferrite **32** and dielectric **34** are installed parallel to the E-field direction. Tests are made using iris inserts of several different dimensions. The design is improved in this manner until it is optimized in terms of desired bandwidth and insertion loss. Cavity dimensions may be changed during the process. Increasing the number of resonant cavities steepens the skirts of the passband. This invention contemplates any number of cavities including a single cavity.

The cross section of the ferrite rod is made small in comparison to its length for more efficient limiting. If the volume of ferrite material is too small the dynamic range is inadequate. The volume of material is increased by increasing the number of ferrite elements. Contiguous ferrite elements in each cavity are separated by dielectric material of the same dimension and dielectric constant as the ferrite. Only two ferrite rods are shown in each cavity. They may be made thinner than shown and their number may be increased.

When using single crystal YIG rods as the ferrite, addition of external magnetic field downshifts the passband. However, the leading edge skirt of the passband is shifted upward by increasing the magnetic field intensity. Therefore the bandwidth can be stretched by using a tapered magnetic field. Upon comparing the response of single crystal YIG ferrite material and equivalent single crystal lithium ferrite in a particular embodiment, the response for YIG ferrite was a threshold that varied from **0.5** watts at **16.0** GHz to **12.0** watts at **17.0** GHz and the response for lithium ferrite was approximately **2.0** watts from **16.0** to **17.0** GHz. Magnetic field intensity was on the order of **2000–3000** gauss. Between **16** GHz and **17** GHz a combination of single crystal YIG rods and single crystal lithium ferrite as the ferrite rods along the cavities as shown in FIG. **2** manifests better characteristics than either material alone.

The synchronously-tuned multiple cavity resonator structure acts as a high Q filter over a very wide bandwidth because symmetrically inductive coupling elements are essentially perfect impedance inverters or quarter wave transformers. Because the quarter wave quality of the impedance inverter is broadband, design accuracy is good over a wide range of frequency. The magnetic field H may be tapered along the longitudinal dimension of the multiple cavity structure in order that the ferrite be active over a wide passband; signals at widely separated frequencies within the passband are subject to limiting without changing the preadjusted external magnetic field.

FIG. **4** is a typical example of the relationship among passband, insertion loss, and threshold of an embodiment of this invention as shown in FIG. **2.** Insertion loss on the order of one db across a 2+ gigahertz passband is readily achieved. The limiting threshold is shown by the dashed line. There are shown two input signals f_1 and f_2 of widely separated frequencies; only f_2 exceeds the threshold. The power level of signal f_2 is reduced to the threshold level while the signal f_1 traverses the limiter with negligible attenuation. Two signals f_1 and f_2 are not shown in any limiting sense. There may be one or there may be several signals. In any one time period signals occur at the same frequencies. Subsequently, signals at one frequency cease and signals at another frequency commence. During any given time interval there may be no signals or there may be signals at several spaced frequencies in the passband.

What is claimed is:

1. A broadband ferrite limiter for connection between two rectangular waveguide transmission line sections for the frequency range **16–17** GHz comprising a pair of complementary channel-like housing members contiguous with each other so as to form a rectangular waveguide, a flat bar secured in the bight of each channel-like housing member, the widths of the bars and of the channels in the housing members being the same, several symmetrical iris means secured along the lengths of the bars to define a plurality of resonant cavities between iris means in the **16–17** GHz frequency range, at least two rectangular ferrite rods affixed normal to one face of one of said bars between each pair of successive iris means, every two successive ferrite rods between successive iris means sandwiching and separated by a nonmagnetic dielectric rod, the ferrite rods including single crystal YIG rods and single crystal lithium ferrite rods, all of said rods having substantially the same dimensions and the same dielectric constant, whereby in the presence of a dc magnetic field of **2000–3000** gauss the limiting threshold is low because of the combined effects of RF magnetic field intensity in the cavities and the nonmagnetic separator rods that direct more of the magnetic flux through the ferrite and whereby any propagated signal within the frequency

range that exceeds critical power level is limited to critical power level and any propagated signal within the frequency range that does not exceed the critical power level is substantially unattenuated even when signals that exceed critical power level and signals that do not exceed critical power level but differing in frequency are substantially time coincident.

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