United States Patent

Siekanowicz

[15] **3,648,197**

[45] **Mar. 7, 1972**

[54] **MICROWAVE LIMITER THAT SUPPRESSES LEADING EDGE SPIKE OF RADIOFREQUENCY SIGNAL**

[72] Inventor: **Wieslaw Wojciech Siekanowicz,** Trenton, N.J.

[73] Assignee: **RCA Corporation**

[22] Filed: **June 1, 1970**

[21] Appl. No.: **42,153**

[52] **U.S. Cl.** **333/17,** 333/1.1, 333/24.1

[51] **Int. Cl.** **H03g 11/04,** H01p 1/32

[58] **Field of Search** 333/1.1, 17, 24.1, 24.2

[56] **References Cited**

UNITED STATES PATENTS

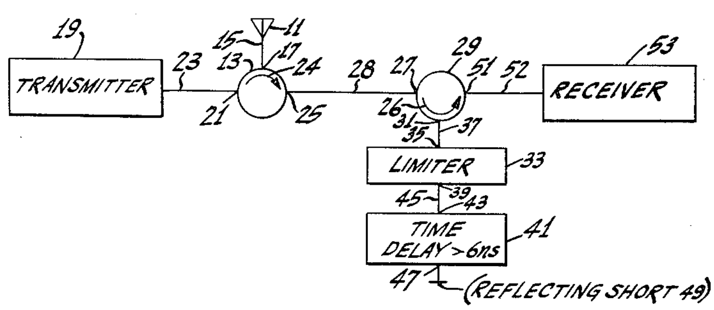
3,082,383	3/1963	Stern	333/17 X
3,221,276	11/1965	Stern	333/24.2 X
3,500,256	3/1970	Carter et al.	333/17

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorney—Edward J. Norton

[57] **ABSTRACT**

An RF limiter includes a section of transmission line having ferrite material so arranged therewith and biased as to act as a reciprocal limiter. An RF signal passing in one direction through the transmission line is reflected so that the signal passes back through the transmission line in the opposite direction. The reflected signal is delayed at least a time period approximately equal to the fall time of a leading edge spike such that, when the delayed RF reflected signal reaches the transmission line section, the ferrite material in the transmission line section is in its nonlinear operating condition.

8 Claims, 5 Drawing Figures



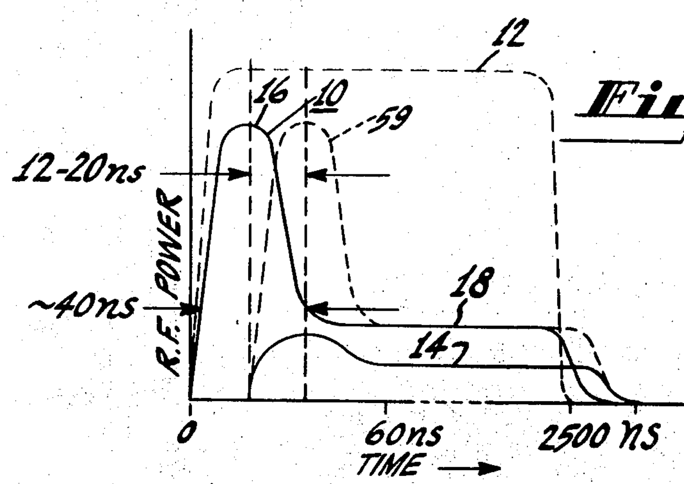


Fig. 1.

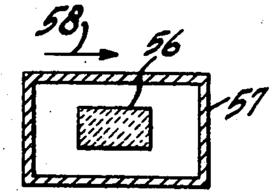


Fig. 3.

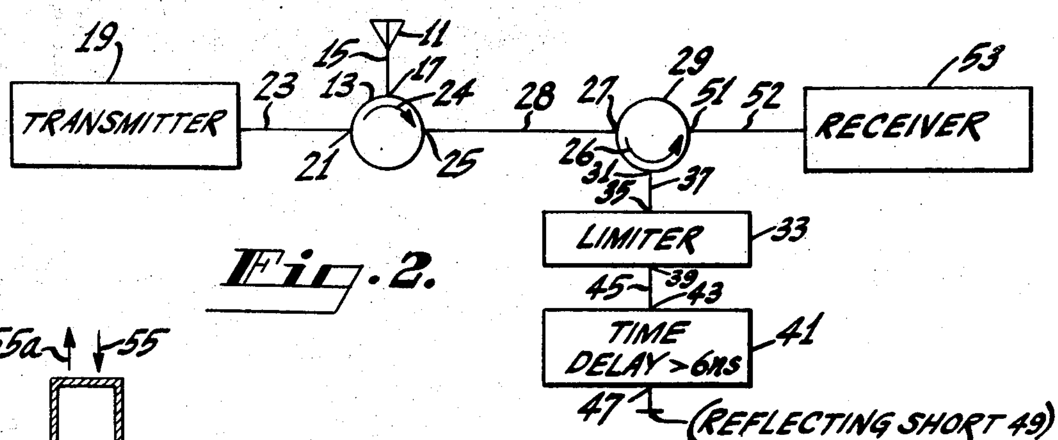


Fig. 2.

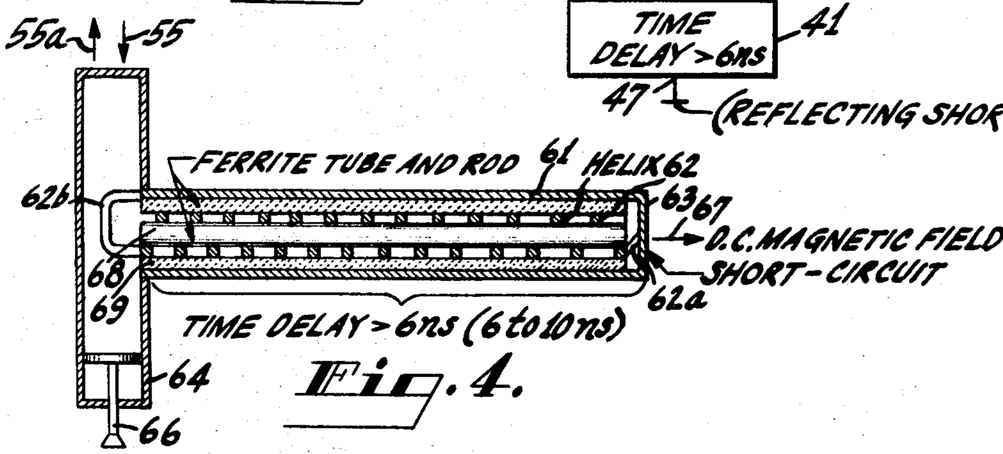
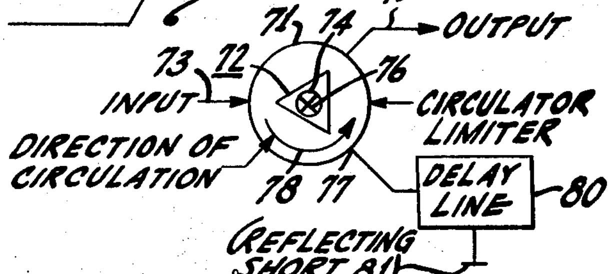


Fig. 4.

Fig. 5.



INVENTOR.
WIESLAW W. SIEKANOWICZ
BY Robert L. Troike
Attorney

MICROWAVE LIMITER THAT SUPPRESSES LEADING EDGE SPIKE OF RADIOFREQUENCY SIGNAL

This invention relates to microwave limiters and, more particularly, to microwave limiters including as a part thereof materials which when biased by a steady magnetic field exhibit a nonlinear effect to RF (radio frequency) microwave signals above a predetermined power level. In the case of ferromagnetic, ferrimagnetic or antiferromagnetic materials biased by a steady DC magnetic field, RF microwave signals above a given power level are absorbed due to spin dipoles in the material changing from a uniform processional mode to certain spin waves which dissipate this RF energy as heat in the crystal lattice and thusly provide power limiting. A further description of these forms of microwave limiters may be found in sections 5 and 12 of "Microwave Ferrites and Ferrimagnetics" by Lax and Button published by McGraw-Hill. Other descriptions may be found in an article entitled "Characteristics of Ferrite Limiters" by G. S. Uebele in *IRE Transactions of Microwave Theory and Techniques*, Jan. 1959, and in an article entitled "-Solid-State X-Band Power Limiters" by W. F. Krupke, F. S. Hartwick and M. T. Weiss in *IRE Transactions of Microwave Theory and Techniques*, Nov. 1961.

A most serious problem with the prior art limiters described above has been the high power level leading edge spike which passes through the limiter when an applied RF signal pulse has a rapid rise time and a magnitude which exceeds the threshold of the limiter. The energy level of this spike can be as high as several hundreds or thousands of ergs. This type of limiter is not generally considered practical for transmit-receive applications because the receiver can tolerate a maximum energy of only about 1 erg. Although a great deal of effort has been put forth to reduce the peak of the spike by proper ferrite geometries and selection of DC magnetic field bias, this leading edge leakage spike has not been suppressed effectively to date.

It is an object of this invention to provide an improved microwave limiter where suppression of this leading edge spike is effectively achieved.

Briefly, this and other objects of the present invention are provided by a microwave limiter including a section of transmission line having therein a material which when biased with a DC magnetic field passes from a linear to a nonlinear state upon the application of high powder level RF signals thereto. By the construction provided, a high power level RF signal after being applied to the transmission line section is delayed such that when the RF signal finally passes out of the limiter, the limiter has been changed from its linear state to its nonlinear state and suppression of the leading edge spike is accomplished.

This invention will be better understood from the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a plot (RF power versus time) of the waveforms associated with a microwave ferrite limiter,

FIG. 2 is a block diagram of a transmit-receive system incorporating a limiter and a delay line in accordance with the applicant's teaching,

FIG. 3 is a cross-sectional view by way of example of the limiter of FIG. 2,

FIG. 4 is a sketch of a ferrite loaded helix limiter in accordance with the applicant's teaching, and

FIG. 5 illustrates another embodiment of the invention using a circulator-limiter combination.

Referring to FIG. 1, waveform 10 illustrates a typical output response of a conventional microwave ferrite power limiter to an applied input signal of waveform 12 (shown in dashed lines). Waveform 10 includes a leading edge spike portion 16 and a flat attenuated portion 18. The leading edge spike portion 16 represents only a small time portion of waveform 10. This spike portion 16 is exaggerated in FIG. 1 by a time scale change after the first 60 nanoseconds. This leading edge portion 16 with its high energy level has been the problem which has rendered this type of limiter impractical for many applications.

The duration of the spike (about 40 nanoseconds in FIG. 1) represents the time required for the ferrite material to pass from its linear to its nonlinear or attenuating condition. In the case of ferromagnetic, ferrimagnetic or antiferromagnetic materials, sometimes referred to collectively as "gyromagnetic" materials because of the similarity to gyroscope action, significant limiting occurs only when the required time is taken to develop excitation of this material. These gyromagnetic materials are discussed by Lax and Button in the above-cited book entitled "Microwave Ferrites and Ferrimagnetics" as ferromagnetic, ferrimagnetic and antiferromagnetic materials. The duration of the spike depends on the power level of the applied RF signal. When the RF power level is such that the material is operating just within the nonlinear region, the spike is relatively long, several hundred nanoseconds, and its peak is only a few db. above the flat or nonlinear portion 18 of the output pulse. At high RF power levels however, when the gyromagnetic materials operate well within the nonlinear region, the duration of the spike is short and typically 40 nanoseconds. The fall time of these short duration high level spikes or the time required for the peak of the spike portion 16 to drop to a level of approximately 10 db. below the peak depends on the material. This range may be from about 12 to 20 nanoseconds. The spike peak of portion 16 can be as high as 20 db. above the flat portion 18 of the output pulse.

Referring to FIG. 2, there is illustrated in connection with a transmit-receive system a microwave limiter having a suppressed leading edge spike. In this system a single antenna 11 is coupled to one port 17 of a conventional three port junction circulator 13 by means of a transmission line 15. A transmitter 19 is coupled to a second port 21 of circulator 13 by a transmission line 23. The third port 25 of the circulator 13 is coupled to a second three port circulator 29 by transmission line 28. The second port 31 of second circulator 29 is coupled to one end 35 of a ferrite limiter 33 by transmission line 37. The opposite end 39 of ferrite limiter 33 is coupled to one end 43 of a delay line 41 by means of transmission line 45. The opposite end 47 of delay line 41 is coupled to a reflecting short 49. The third port 51 of second circulator 29 is coupled to receiver 53 by transmission line 52.

The limiter 33 in FIG. 2 is preferably a reciprocal-type ferrite limiter. A reciprocal type limiter is preferable because it has low insertion loss and good limiting in both directions, an important consideration in the type of limiter described herein. The particular limiter 33 may be, for example, a parallel-pumped subsidiary resonance limiter using polycrystalline YIG (yittium iron garnet) material shown as slab 56 in FIG. 3. This slab is centered in a cross section of rectangular waveguide 57 designed to propagate the applied signals in the TE_{10} mode. Principles of subsidiary resonance and subsidiary-resonance limiting are discussed in the above-described book by Lax and Button entitled *Microwave Ferrites and Ferrimagnetics* published by McGraw-Hill. Particular reference to subsidiary resonance and microwave power limiting is found in sections 5 and 12 of this publication.

The YIG slab 56 is biased by a proper DC magnetic field, as indicated by arrow 58, perpendicular to the direction of propagation of the applied signals and perpendicular to the electric field of the signals in the waveguide. This DC magnetic field is of a magnitude and direction to provide reciprocal limiting of the signals applied above the given power level.

In accordance with the design criteria herein the delay line 41 is arranged to provide as a minimum a total time delay to the applied RF signal after it has been applied to the limiter about equal to the fall time of the leading edge spike where the fall time of leading edge spike is, as defined above, the period of time it takes the peak of the leading edge spike to drop to a level 10 db. below that peak.

In the case of the type of limiter described above operating with an input signal about 9.3 to 9.4 GHz. (gigaHertz) with an input signal level of 80 kilowatts, this time period may be about 12 nanoseconds. The delay line 41 may be a section of waveguide with one end coupled to the waveguide section 57 of limiter 33 and the other end of the delay line waveguide section terminated in a reflecting short so that all of the signals traveling in one direction in the delay line waveguide section 57 are reflected back to the limiter 33. The length of the waveguide is arranged to provide as a minimum a total time period of delay equal to at least 12 nanoseconds. Greater delay will probably give somewhat better results by giving more time for the gyromagnetic material to attain its nonlinear state. This total time delay includes the time period it takes the signal to pass in one direction from the limiter 33 along the delay line 41 to the reflecting short 49, be reflected, and pass back along the delay line 41 to the limiter 33.

In accordance with the operation of the arrangement of FIG. 2, high power RF microwave signals from the transmitter 19 are coupled along transmission line 23 to port 21 of the circulator 13. The circulator 13 is properly biased to couple signals in a clockwise direction. The RF signals from the transmitter 19 at port 21 are coupled out of the circulator 13, through port 17, and along transmission line 15 to antenna 11.

Radiofrequency signals at the antenna 11 are coupled along the transmission line 15 to port 17 of the circulator 13. With the circulator biased as shown by the clockwise arrow 24, RF signals at the antenna are nonreciprocally coupled from port 17 to port 25. RF input signals at the third port 25 are coupled by means of transmission line 28 to the port 27 of circulator 29. This circulator has a proper DC bias to provide counterclockwise coupling as indicated by arrow 26. Incoming RF signals at port 27 are coupled out of port 31 and along transmission line 37 to the input of ferrite limiter 33.

Upon the application of significantly high power RF signals (above the critical value) to the reciprocal limiter 33, the YIG material begins to change its state from a linear to a nonlinear condition. The output from the limiter 33 looks somewhat like that shown by portions 16 and 18 of waveform 10 in FIG 1. The output from the limiter 33 is coupled to delay line 41. The delay line 41 delays the signal approximately 6 nanoseconds after which the signal is reflected at the short 49 and is passed in the opposite direction through the delay line 41, thus providing the full amount of delay of about 12 nanoseconds. The delayed and reflected signal is illustrated by the dashed line 59 in FIG. 1. The delayed and reflected signal 59 passes through the limiter 33, the limiter is in a substantially nonlinear state and consequently the leading edge spike is reduced. The output from the limiter is like that illustrated in waveform 14 in FIG. 1. The output from the limiter 33 is coupled by means of lead 37 to port 31 of circulator 29. The circulator 29 couples this limited signal to the receiver 53 over transmission line 52.

A system as shown above in connection with FIG. 1 was operated with a input signal applied to the limiter 33 in the 9.3 to 9.4 gigaHertz frequency region. The input signal 12 had a power level of 80 kilowatts. The particular limiter was a slab of YIG material about 0.375 by 0.190 inches wide in cross section positioned in a section of WR112 rectangular waveguide which had an outer cross-sectional dimension of 1.112 by 0.500 inches. The inner cross-sectional height of the waveguide section was made short and was only about 0.190 inch or just enough height to place the YIG slab 56 in the waveguide. This reduced height provided increased magnetic driving field intensity and consequently produced critical magnetic driving field intensity at lower power levels and microwave power absorption at lower power levels. The DC magnetic field used for the slab 56 was on the order of 1,000 Gauss. The particular YIG material was G113 made by Trans Tech of Gaithersburg, Md. The inner cross-sectional width of the waveguide was also made small with only about 0.375 inch or just enough to place this YIG slab 56 in the waveguide. This reduced width suppresses higher order moding within the waveguide. In the system designed above to operate in the 9.3 to 9.4 GHz. frequency region, the particular delay line 41 was a conventional 6-foot long straight section of WR112 waveguide having the same outer cross section as that of the limiter (1.112 by 0.500 inches cross section) coupled at one end to the limiter 33 and terminated at the other end by conductive reflecting short 49, across the opposite end of the waveguide. The delay line 41 need not be arranged in this manner, but may be, for example, packaged in a spiral configuration with portions of the delay line overlapping each other or may be in overlapping serpentinelike configuration in order to accommodate packaging. In this system operated between 9.3 and 9.4 GHz. with a signal input level of 80 kilowatts, the signal at the output of the limiter with only one pass through the limiter had a flat portion 18, 19.5 db. below the input signal, but the peak of the spike portion 16 was only 0.5 db. below the input signal level. After the signal was delayed in the above example about 12 nanoseconds by the waveguide delay line 41, described above, and the signal was reflected back a second path through the limiter 33, the output signal had a leading edge spike reduction of 15.5 db. below the input signal 12 and a flat portion 18 that was 36 db. below the input signal 12. This magnitude of reduction (15.5 db.) in the leading edge spike level (portion 16) allows the above-described type of limiter 33 to now be practical in the presence of high level RF signals.

In summary, the above teaches that the leading edge spike problem is eliminated by providing a means for providing sufficient delay of the RF signal after it has been applied to the gyromagnetic material of a limiter to allow certain attenuating spin waves to be established in the gyromagnetic material of the limiter. This sufficient amount of delay has been determined to be at least equal to the herein defined fall time. In the particular arrangement described above, this delay and limiting was accomplished by the combination of a reciprocal limiter and a delay line having a reflectible termination to provide a total delay which is equal to as a minimum the herein defined fall time of a particular spike.

An alternate approach for providing a power limiter with suppressed spike feature is illustrated in connection with FIG. 4. FIG. 4 shows a combination of a delay line and a ferrite limiter. This ferrite limiter is made up of a section of circular waveguide 61 with a terminated short 63 at one end. A helix 62 is placed inside a circular waveguide 61 with one end 62*a* of the helix 62 connected to the short circuit end 63 and the other end 62*b* extends as a pickup device in a section of rectangular waveguide 64. This section of rectangular waveguide 64 may be part of transmission line 37 in FIG. 2. The pickup end 62*b* of coil 62 is mounted in the middle of the broad wall of the rectangular waveguide 64. The rectangular waveguide 64 is terminated at one end with an adjustable plunger 66 which is arranged with the pickup device 62*b* to provide maximum coupling to and from the coil 62 with minimum losses and minimum standing waves. One ferrite rod 68 is placed through the helix 62 and another outer ferrite tubing 69 passes around the outside of the helix 62 as illustrated in connection with FIG. 4.

In the operation of the power limiter of FIG. 4, electromagnetic RF signals 55 traveling along the waveguide 64 toward the plunger 66 are picked up by the end 62*b* of coil 62 and travel along the coil 62 to the shorted end 63 and are reflected back along the coil 62 to the waveguide 64. Propagation along such a helix is similar to that of microwave signal propagation in traveling wave tubes. Further description of this type of propagation is discussed by J. R. Pierce in Appendix II of his book entitled "Traveling Wave Tubes" (A Bell Laboratories series published by D. Van Nostrand Company, Inc., Princeton, New Jersey. Also see U.S. Pat. No. 2,848,695 of Mr. Pierce pertaining to such a delay line. Because the signal travels along a helix 62 and the helix 62 is surrounded by the dielectric of the ferrite rod 68 and tubing 69, a delay of the signal is provided. The delay including the reflected delay provided by this arrangement must provide a delay which is at least equal to the fall time, or as described in the previous arrangement, at least equal to 12 nanoseconds. The ferrite material of tube 69 and rod 68 also when biased by the DC magnetic field, as indicated by the direction of arrow 67, causes the certain spin waves and the associated absorption of microwave power to be provided if the RF signal exceeds a given power level. By making the helix 62 sufficiently long with closely spaced spirals (changing the pitch of the coils of the helix) and by making the dielectric constant of the ferrite material sufficiently high, the length of the delay line can be made quite short. If the total delay time (both passes through the delay line) is made around 12 to 20 nanoseconds, as described in the previous arrangement, then the reflected signal will travel through a portion of the ferrite loaded helix limiter when it is in its sufficiently nonlinear state and the leading edge pulse spike is reduced. The reflected and limited signal along coil 62 is coupled to waveguide 64 by the pickup end 62*b* and passes out of the waveguide 64 in the opposite direction as indicated by arrow 55*a*.

Various other arrangements for providing ferrite limiting and delay can be accomplished. It must be remembered however that the sufficient delay is required so that when the signal passes through the limiter, the limiter provides sufficient attenuation for suppression of the RF spikes and that this occurs only when the ferrite material has been given sufficient time to swing toward the nonlinear operation.

Referring now to FIG. 5, there is illustrated an alternate system for providing limiting. In this arrangement, a circulator-limiter is used in combination with the delay line. The circulator 71 is made up of transmission lines 73, 75 and 77 joined to a common region 72. The circulator 71 is a conventional junction circulator like that described, for example, by Chait et al. in U.S. Pat. No. 3,089,101. A single slab 74 of gyromagnetic material is located at the junction 72 of three transmission line arms 73, 75 and 77 in the circulator 71. The slab 74, when properly biased by a proper DC magnetic field into the drawing as indicated by arrow 76, provides coupling in the direction indicated by the solid arrow 78. Signals traveling along transmission line 73 are coupled to transmission line 77 and signals traveling along transmission line 77 are coupled to transmission line 75 in a nonreciprocal manner. The same slab 74 of gyromagnetic material, when properly biased as described above causes the said certain spin waves associated with absorption to occur upon the application of high level RF signals and hence the circulator can double as a power limiter. At the output of port 77 is coupled the delay line 80 and at the end of the delay line, a reflecting short 81. In an arrangement illustrated in FIG. 5, the delay line 80 is again made to be of sufficient length and the reflecting short located at a given point to provide a total delay (both passes through the delay line 80) of at least equal to the fall time or, in the previous case a delay of at least about 12 nanoseconds.

In the operation of the arrangement in FIG. 5, RF input signals above the desired level approaching input port 73 are coupled to output port 77 of the ferrite circulator 71. By the coupling of these high level signals to the ferrite circulator properly biased, the ferrite 74 in the circulator becomes energized and begins changing from a linear to a nonlinear state. The signal from port 77 is passed through the delay line 80, is reflected by the short 81 and is passed again through delay line 80 in the opposite direction to port 77. This gives a total delay of 12 nanoseconds. The signal now passes through the ferrite 74 of circulator-limiter 71, 12 nanoseconds later, which is now operating in the sufficiently nonlinear state to significantly reduce the leading edge spike. Since the circulator-limiter 71 is made up of ferrite material which is DC biased by a magnetic field and has been given sufficient time by the delay line 80 to be near the nonlinear state, the signal passing through the circulator toward port 75 is limited. The limited signal passing from the output port 75 is then coupled to the receiver.

What is claimed is:

1. A power limiter for radiofrequency signals comprising:
 a section of transmission line having a body of gyromagnetic material therealong characterized by the changing from a linear power limiter state to a nonlinear power limiter state where all signals above a given power level are absorbed in the body when properly biased by a DC magnetic field and upon the application of the radiofrequency

signals above said given power level, and further characterized by the passing of an undesirable high level short duration leading edge spike when the radiofrequency signal has a rapid rise time and a magnitude above said given level,
 means for delaying the radiofrequency signals after being applied to said body of material for a time period at least equal to the time period it takes the peak of the leading edge spike to drop 10 db. such that when the radiofrequency signal finally passes out of the limiter the material in the limiter has changed from its linear to its nonlinear state and suppression of the leading edge spike is accomplished.

2. The combination claimed in claim 1 above wherein said delay means delays the signals at least 12 nanoseconds.

3. The combination as claimed in claim 1 wherein said limiter is a reciprocal limiter.

4. A power limiter for radiofrequency signals comprising:
 a first section of transmission line,
 a body of gyromagnetic material positioned along said first section of transmission line,
 means for providing a DC magnetic field bias of a direction and strength to cause upon the application of said signals in either direction along said first section of transmission line power limiting of said radiofrequency signals above a given power level, said body of gyromagnetic material when so biased being characterized by, upon the application of said signal above a given power level, an undesirable, short duration, leading edge spike, and
 a second section of transmission line having one end coupled to said first section of transmission line and the opposite end terminated in a reflecting short, said second section of transmission line being arranged to provide a time period of delay along the length of said second section of transmission line of at least equal to half the time period it takes the peak of the leading edge spike to drop about 10 db.

5. The combination as claimed in claim 4 wherein said second section of transmission line is a waveguide.

6. The combination as claimed in claim 4 wherein the first section of transmission line is a waveguide.

7. A microwave power limiter for suppression of undesirable leading edge spikes associated with applied radiofrequency signals comprising:
 a cylindrical waveguide,
 a helical coil positioned in the waveguide,
 gyromagnetic material positioned in the waveguide with portions of the gyromagnetic material both inside and outside of the helical coil,
 means for providing a DC magnetic field so that upon the application of said radiofrequency signals above a given power level along the coil said body of gyromagnetic material favors excitation of certain spin waves which lead to absorption of the radiofrequency signal power,
 means for providing a reflecting short at one end of said coil, said gyromagnetic material, said coil length and pitch being arranged so that a time delay of at least 12 nanoseconds is provided between the application of said radiofrequency signals to said body and when said reflected signal passes out of said body in the opposite direction.

8. A microwave power limiter for suppression of undesirable leading edge spikes associated with applied radiofrequency signals comprising:
 a circulator of the type having a plurality of transmission lines joined at a common region with a body of gyromagnetic material located at said common region, said gyromagnetic material being of the type that when properly biased by a DC magnetic field provides coupling of said radiofrequency signals from one of said lines to the next adjacent line in a nonreciprocal manner,
 one of said transmission lines of said circulator having a reflected short at an end furthest removed from said com-

mon region, said one transmission line being dimensioned and arranged to provide a total delay from the gyromagnetic material to the short of at least about 6 nanoseconds, said body of said gyromagnetic material being arranged and having sufficient DC magnetic biasing such that upon the application of said radiofrequency signals above a given power level said body of gyromagnetic material favors excitation of certain spin waves which lead to power absorption of the radiofrequency signals.

* * * * *