A Multi-Octave Frequency Selective Limiter*

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Abstract

A frequency selective limiter operating over more than 2 octaves bandwidth has been developed. The design uses single crystal epitaxial YIG films. Limiting threshold and leakage are about 1 milliwatt. Dynamic range approaches 20 dB. Selectivity bandwidth for 3 dB weak signal compression is about ± 20 MHz at 100 mW input. An analytical method gives accurate predictions of limiting behavior when linear loss terms are included.

Background

Frequency selective power limiters are based on the saturation of the precession angle of the magnetic dipoles in a magnetic insulator when a strong RF magnetic field is applied. The precession angle is proportional to the strength of low-level RF fields. At higher levels, coupling to the precessing dipoles becomes nonlinear, and half-frequency spinwaves are excited.[1] These transfer energy to the crystal lattice, where the excess power is dissipated as heat. This nonlinear coupling takes place only over a frequency band whose width is a few times the spinwave linewidth ΔH_K, or a few tens of megahertz in YIG. Low-level signals separated in frequency by more than this amount are not coupled to the half-frequency spinwaves, and pass through the device unaffected by the strong signal.

In most previous limiter designs, bulk-grown, single-crystal YIG slabs or spheres were placed in a resonant structure to build up the RF magnetic field in the ferrite.[2] The approach taken here to intensify the RF magnetic field is to concentrate the RF exciting current in a very narrow conductor. By maintaining constant impedance throughout, no transformers or matching networks are needed, and uniform broadband coupling results.

Microstrip Transducer

An epitaxial YIG film grown on a GGG substrate is placed over a microstrip line of width w, as shown in figure 1. A simple first order analysis shows that the limiting threshold is $P_{th} = (2\gamma\Delta H_K w)^2 Z_o$, where Z_o is the characteristic impedance of the microstrip. All other factors held equal, the width should be made small to reduce the threshold. We found a threshold of about 1 milliwatt at S-band with a 25 micron-wide microstrip coupled to a 57 micron-thick YIG film. Wider lines gave proportionately higher threshold, while making the microstrip narrower did not significantly reduce the threshold further. This is probably because a smaller volume of ferrite is involved in the interaction when the microstrip is comparable to or smaller than the YIG thickness.

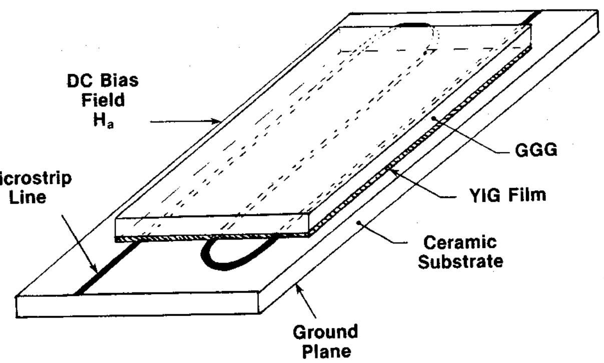

Figure 1. Schematic Representation of Thin Film YIG Limiter.

A 25 micron wide microstrip was deposited on a high-dielectric constant ceramic substrate to maintain 50 ohms impedance. The microstrip is also an efficient transducer of magnetostatic waves (MSW) which carry energy away from the microstrip. This results in wide bands of high insertion loss even for below-threshold signals. Surface waves can be excited when the bias field is parallel to the microstrip. Volume waves can be excited when the bias field is perpendicular to the microstrip. For wideband operation above 2 GHz, the surface wave band must be avoided. Perpendicular bias accomplishes this. Slightly lower threshold and higher dynamic ranger were found when the bias field was applied in the plane of the film. The bias field strength is approximately 200 Oe.

Analysis

Power is coupled to the half-frequency spin waves continuously along the length of the microstrip. This is represented by the differential equation[4]:

$$dP(x)/dx = -C\,(P(x)/P_{th}-1)^{1/2} = -C\,\phi(x) \qquad P(x) > P_{th} \qquad (1)$$

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where $P(x)$ is the travelling power at point x, P_{th} is the threshold power, assumed to be constant over the full-length L, C is an empirically determined coupling constant, and $\phi(x)$ is the excess power parameter. The solution to (1) is:

$$P(x) = P_{th} (1 + ((P_{in}/P_{th} - 1)^{1/2} - Cx/2P_{th})^2)$$

For $P_{th} < P_{in} < P_{th} (1 + (CL/2P_{th})^2)$, the leakage is $P_{out} = P_{th}$. At higher input levels:

$$P_{out} = P_{th} (1 + ((P_{in}/P_{th}-1)^{1/2} - CL/2P_{th})^2) \qquad (2)$$

We define dynamic range as the ratio of the change in input power to change in output power, between threshold and the second knee of the limiting curve (where the slope of P_{out} vs. P_{in} equals one). From eqn (2), for example, if $CL = 20\ P_{th}$, the dynamic range would be 20 dB if there were no other losses.

Conduction loss in the microstrip and dielectric and magnetic loss in the substrate and YIG are independent of the limiting mechanism and can be treated as additive to the original differential equation:

$$dP(x)/dx = -C\ \phi(x) - AP(x) \qquad (3)$$

The numerical value of A can be determined from the below-threshold loss: $P(x) = P_{in} \exp(-AL)$, so $A = \text{Loss (dB)}/4.343\ L$. We have not found an analytical solution for the lossy case, so eqn (3) must be integrated numerically.

Power travelling along a lossy transmission line is attenuated according to $P(x) = P(0)\exp(-2\alpha\ x)$. The attenuation constant is $\alpha = \mathrm{Im}((R + j\omega L)j\omega C)^{1/2}$, where R, L, and C are the series resistance, series inductance, and shunt capacitance per unit length. If $R < \omega L$, we have $A = 2\alpha = R/Z_o$. Then:

$$dP(x)/dx = -P(x)\ R/Z_o \qquad (4)$$

and we can identify the radiation resistance from eqn(3):

$$R = -Z_o(dP(x)/dx)/P(x) = Z_o\ (C\ \phi(x) + A\ P(x))/P(x) \qquad (5)$$

The travelling power and radiation resistance are plotted in figure 2 for a 20 dB lossless limiter with inputs at 10 P_{th} and 100 P_{th}. The radiation resistance peaks at $R_{max}/Z_o = C/2P_{th}$, and falls to zero when $P(x)$ reaches P_{th}. Figure 3 compares the travelling power and radiation resistance in lossless and lossy limiters.

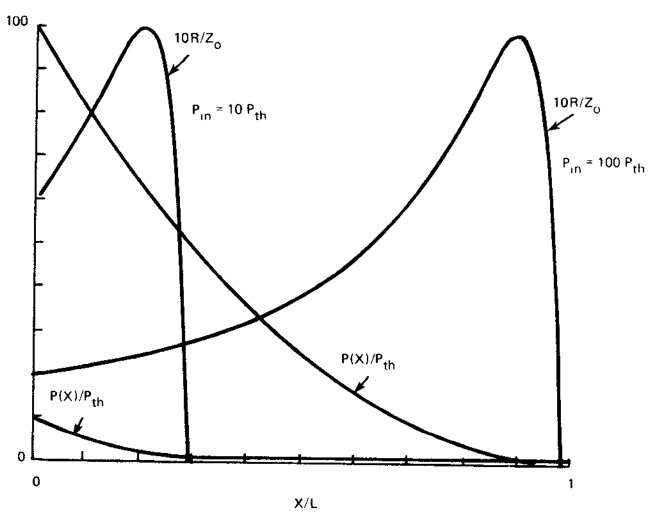

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Figure 2. Traveling Power and Radiation Resistance in Lossless Limiters. Results are shown for P_{in} = 10P_{th} and P_{in} = 100 P_{th} with CL = 20 P_{th}.

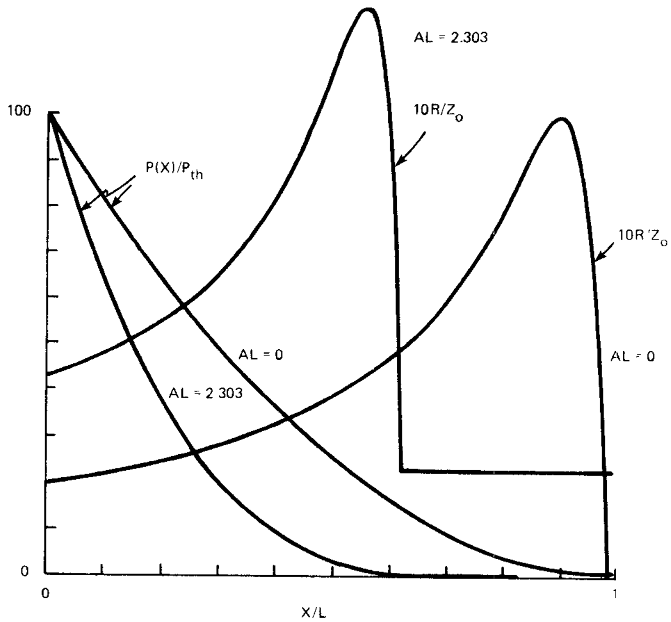

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Figure 3. Traveling Power and Radiation Resistance in Lossless (AL = 0) and Lossy (AL = 2.303) Limiters having CL = 20 P_{th}. Input Power is P_{in} = 100 P_{th}.

Experimental Results

Experiments were performed with a 7-inch long microstrip, formed into a meander line to conserve space. The active length L_{YIG} could be varied by changing the position of YIG/GGG slabs laid over the line. The calculated output leakage is plotted as a function of input power, with fixed total length and different interaction lengths, for C = 4 watts/inch, in figure 4.

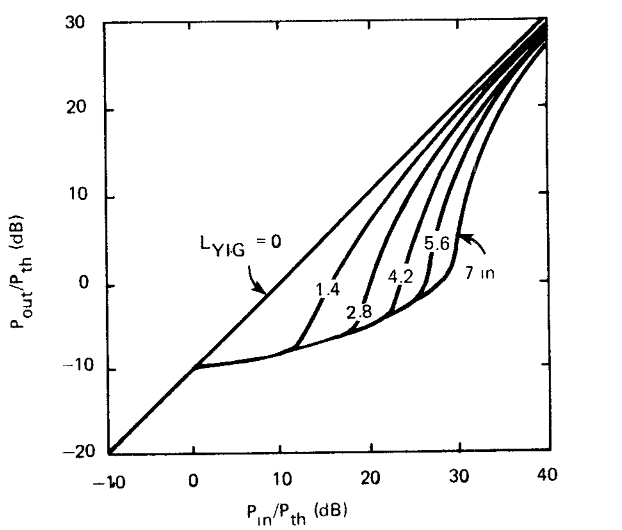

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Figure 4. Calculated Power Limiting with C= 4 watts/in. AL = 2.303.

The most important difference from the lossless case is that the output rises from P_{th}/loss to P_{th} for inputs between threshold and the second knee. As the interaction length is increased, the second knee occurs at higher power, but the below-threshold loss increases as well. Thus, for a given transducer design, beyond some finite length, there is no real increase in dynamic range.

Figure 5 shows the measured limiting characteristic obtained with a 57-micron thick YIG film, at several frequencies. Agreement with the calculated curve for L_{YIG} = 7 inches in figure 4 is good.

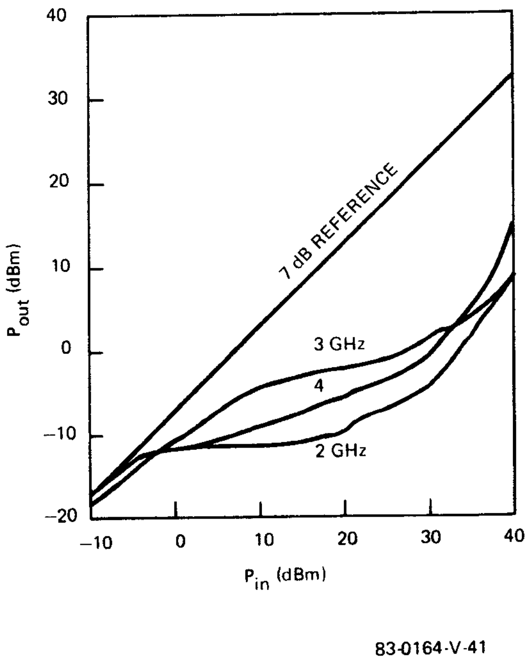

Figure 5. Measured CW Limiting with 57 micron YIG films, L = 7 inches.

Swept Limiting

Figure 6 is a plot of the measured insertion loss from 2-to-8 GHz, for several power levels. The below-threshold loss rises smoothly with frequency, due mainly to conduction loss in the microstrip. The limiting threshold is fairly constant at 1 milliwatt over the band. At 1 watt input, the minimum limiting is 18 dB; maximum leakage is 3 milliwatts. Only test equipment limitations prevented us from sweeping above 8 GHz; there is no reason to expect anything but a gradual deterioration in limiting ability above 8 GHz.

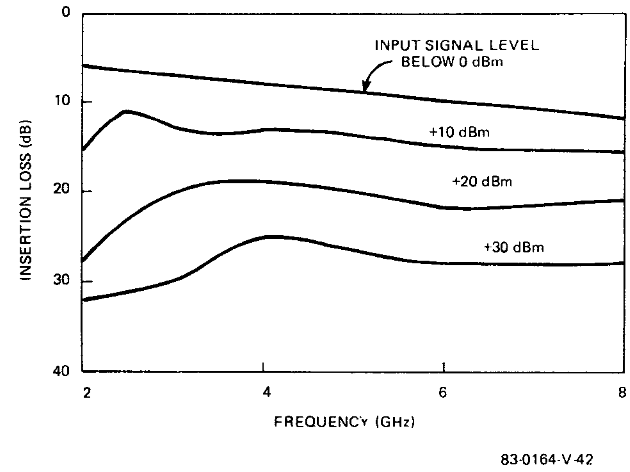

Figure 6. Swept Insertion Loss Below Threshold and at +10, +20, +30 dBm.

Frequency Selectivity

Frequency selectivity was measured by injecting a below-threshold signal at frequency f_{weak} and an above-threshold signal at f_{strong}. The level of the weak signal output was recorded as a function of frequency separation $\Delta f = f_{weak} - f_{strong}$. A below-threshold signal is suppressed less than 3 dB in the presence of a 100 mW signal for $|+\Delta f| > 30$ MHz and $|-\Delta f| < 15$ MHz. Such asymmetry is common in frequency selective limiters is not yet understood.

Conclusions

Frequency selective limiting has been demonstrated over more than two octaves bandwidth. An analytical technique has been developed which accurately predicts the limiting characteristic in practical devices.

Acknowledgements

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References:

1. H. Suhl, "The Theory of Ferromagnetic Resonance at High Signal Levels," J. Phys. Chem. Solids Vol. 1, 1957, pp. 209-227.
2. P. S. Carter, Jr., R. A. Craig, J. Dixon, "A Hybrid YIG Rod and Sphere Ferrite Limiter," European Microwave Conference Digest.
3. S. N. Stitzer, P. S. Carter, Jr., H. Goldie, "A High Power X-Band Frequency Selective Passive YIG Limiter," 1977 International MicrowaveSymposium Digest, pp. 528-531.
4. P. R. Emtage, S. N. Stitzer, "Interaction of Signals in Ferromagnetic Limiters," IEEE Trans. MTT-25, March, 1977, pp. 210-213.