A HIGH POWER X-BAND FREQUENCY SELECTIVE PASSIVE YIG LIMITER*

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Abstract

This paper describes a multistage frequency-selective power limiter in which the limiting takes place in three tandem connected stages. The diameters of the YIG sphere power limiting elements used in each stage are optimized for sharpest selectivity, lowest threshold, and widest dyanmic range. The passive YIG limiter provides 28 dB of dynamic range, will handle up to 3 watts CW, has a 1 percent bandwidth in X-band and a below threshold loss of 1.7 dB. Limited output power is under 5 milliwatts; third order intermodulation products at the output are better than 20 dB down from a 0 dBm in-band signal beating with a second in-band signal of +33 dBm.

The device has application to high power FW/CW monostatic radars when simultaneous transmission and reception is required, RF signal leveling, ordinary limiting, and protection of communications receivers from strong RF signals without causing loss of reception during the overload period.

Introduction

FM/CW monostatic radar systems have long been limited to transmitter power levels on the order of tens of milliwatts because of feedthrough to the receiver. This high level of feedthrough power drives the low noise receiver into the nonlinear region, giving rise to undesirable intermodulation products. In the device reported in this paper, the transmitter feedthrough is limited to 5 milliwatts for CW power levels up to 3 watts. Since the device is frequency selective, it will limit only at the frequencies above threshold while allowing below-threshold echo signals that are more than ± 10 MHz from the X-band carrier frequency to pass with less than 2 dB loss. The device requires no external power supplies.

Frequency Selectivity

Theory

The principle of frequency selectivity in YIG limiters is explained as follows. A sample of YIG is biased by an external static magnetic field to subsidiary resonance. If an external RF magnetic field is applied, spinwaves will be induced in the YIG. Above a critical level called the limiting threshold, the coupling to the spinwaves becomes nonlinear, and the RF field couples to spinwaves at one half the signal frequency. The excess power is coupled through these spinwaves to lattice vibrations, which convert the power to heat.[1] If another signal whose level is below the limiting threshold is present simultaneously but offset in frequency by several spinwave linewidths, the spinwave spectra of the two signals do not interact significantly and the weak signal suffers little additional attenuation.[2]

Design

Previous frequency-selective limiters have been either single stage[3] or multiple stage devices using large numbers of identical cascaded resonators.[4]. In either design, dynamic range is limited and selectivity is not particularly sharp. If a YIG limiter stage is driven more than about 10 to 15 dB above threshold, the loss mechanism deteriorates and attenuation begins to decrease.[5]. It is also observed that, as the above-threshold power level is increased, below-threshold signals close in frequency to the above-threshold signal suffer greater attenuation.

These shortcomings are alleviated in the present device by using a graded threshold approach in a multiple-stage limiter. In this design, the limiting threshold of each stage is successively lower than that of the preceding stage.

Investigation

We have carried out a theoretical investigation[2,6] which shows that selectivity is greatly improved if each stage of a multiple-stage limiter is operated at the same number of dB above threshold. The theoretical 2.2 dB bandwidth of an N-stage limiter operating at a power level P_T above threshold P_{th} is $\Delta f_{2.2\,dB} = 5.56 \Delta H_k N^{1/2} [(P_T/P_{th})^{1/N} - 1]$ MHz, where ΔH_k is the spinwave linewidth in oersteds.

This dependence of selectivity on overall isolation P_T/P_{th} and number of stages N is illustrated in figure 1. The N = 1 curve applies to single stage limiters and multiple stage limiters wherein the threshold is the same in all stages. The N = ∞ curve applies to limiters in which the threshold decreases continuously from input to output. For example, the present three-stage graded threshold limiter operating 27 dB above threshold has a selectivity bandwidth nearly five times sharper than a single-stage limiter operating at the same level.

Enhancement of Limiting Threshold

The limiting threshold of each stage is controlled by the coefficient of coupling between the YIG sphere and the circuit, and also by the circuit bandwidth. Increasing the coupling, or lowering the bandwidth, or doing both, decreases the threshold power. Narrow bandwidth is achieved through the use of direct coupled resonators. Each resonator consists of two sectoral radial striplines connected by a short length of uniform-width stripline. The RF magnetic field is thereby concentrated largely in the uniform-width stripline section where the YIG sphere is placed. This resonator structure is illustrated in figure 2.

Coupling to the YIG sphere is enhanced by forming a loop around the sphere. A half loop is fabricated by machining a semicircular groove in the ground plane. This machined groove is considerably easier to fabricate and consistently reproduce than is a loop in the stripline. The direct contact between the sphere and the ground plane groove also aids removal of heat from the sphere. Even tighter coupling is obtained by also forming a circular bend in the uniform-width stripline section of the resonator, as shown in figure 2b. This is done only in the second and third stages of the present device to obtain the lowest limiting threshold.

Part of the problem with conventional limiters is that limiting action begins to deteriorate only a few dB above threshold. In lowering the limiting threshold through tighter coupling to a given size sphere, the dynamic range is increased by nearly the same amount as the decrease in threshold level.

The absolute power handling capacity is increased by using larger spheres. From experiments with spheres ranging in diameter from 0.015 inch to 0.1 inch, we find the power handling capacity varies approximately as the square of the diameter. In figure 3 we have plotted the power level at which CW limiting begins to deteriorate. The power handling capacity of a stage is nearly doubled by using two YIG spheres coupled to the same resonator. A second groove is machined in the top ground plane and a second sphere is placed directly above the first sphere on the opposite side

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of the resonator. If a thick resonator is used, grooves can be machined in opposite sides of it to give the tight coupling effect of the wraparound conductor.

Three-Stage X-Band Limiter Results

The present device comprises an input stage containing two 0.1-inch diameter YIG spheres and two following stages containing an 0.05-inch and an 0.025-inch diameter YIG sphere, respectively. Figure 4 is a photograph of the internal arrangement of the pseudoradial stripline resonators and transverse grooves. Overall length is 2 inches.

The three resonators are capacitively coupled to achieve a 200-MHz-wide, 1-dB passband centered at 9375 MHz. The measured below-threshold frequency response is shown in figure 5.

The CW limiting characteristic appears in figure 6. The leakage level is extremely flat, exhibiting less than a 1-dB variation over a 23-dB change in input level. Limiting is also very uniform across the passband.

The frequency selectivity is illustrated in figure 7. This shows the suppression of a below-threshold signal at frequency f_R due to a second, above-threshold signal at frequency f_T as a function of frequency difference $f_R - f_T$. This suppression refers to the additional attenuation of the small signal that occurs when the strong signal is present.

It is here reemphasized that selective limiting occurs at any frequency within the passband (and for several hundred megahertz beyond, although the cold loss becomes quite high). If an above-threshold signal (or any number of above-threshold signals) appears at any frequency, simultaneous limiting of below-threshold signals occurs only within a few megahertz of the strong signal.

The limiter is nonlinear, thus causing intermodulation product frequencies to appear in the output. Figure 8 shows the limiter output power levels of the strongest IM product, $2f_T - f_R$, as well as the level of the weak signal as functions of transmitter power for 5, 10 and 20 MHz frequency separations when $f_R < f_T$. Relative IM product levels are slightly higher for $f_R > f_T$ due to asymmetry of the frequency selectivity. The relative strengths of the IM products was observed to be independent of the weak signal power provided it was less than the threshold level.

Conclusions

The graded threshold approach applied to YIG frequency-selective limiters results in increased dynamic range and sharper frequency selectivity for a given number of spheres. Power handling ability of YIG limiters is a direct function of sphere size.

Coupling to YIG spheres may be greatly enhanced by using a grooved ground plane configuration.

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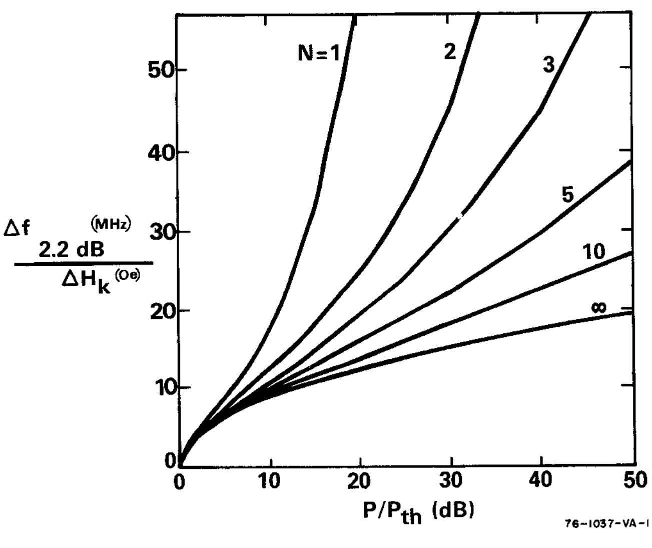

Figure 1. Frequency Selectivity in Multiple-Stage Limiters

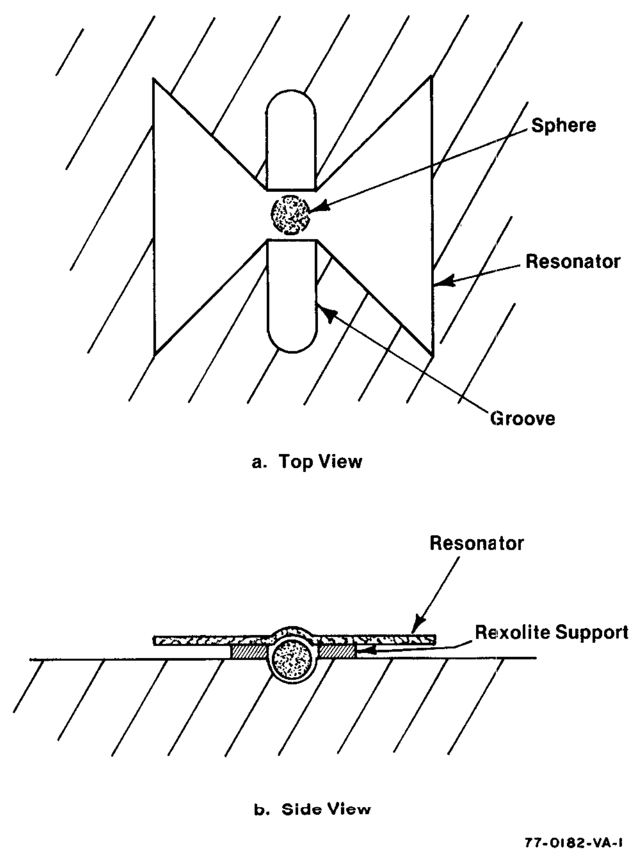

Figure 2. Pseudoradial Resonator Grooved-Ground-Plane Configuration

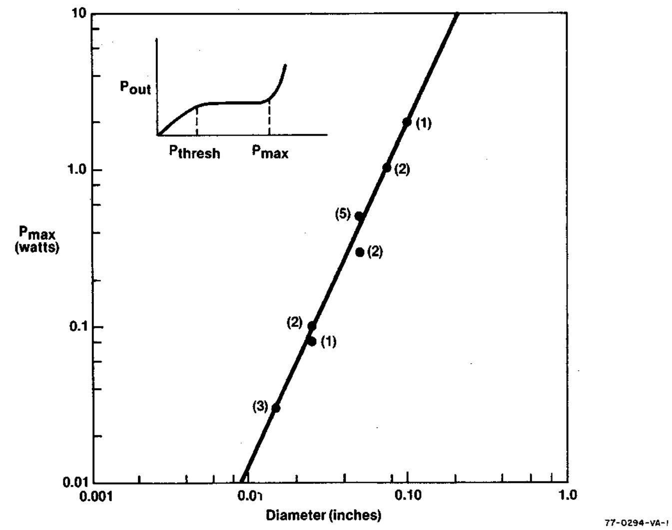

Figure 3. Power Handling Capacity of YIG Spheres

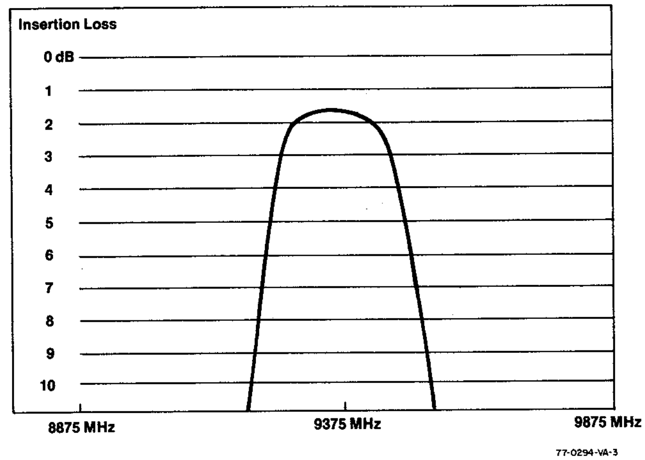

Figure 5. Below-Threshold Frequency Response

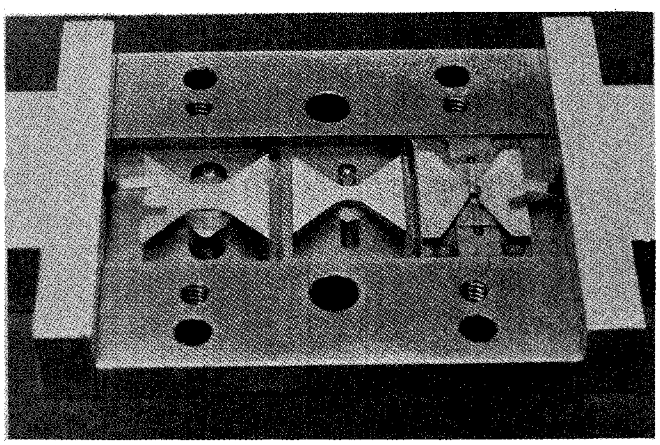

Figure 4. Three-Stage Limiter Construction

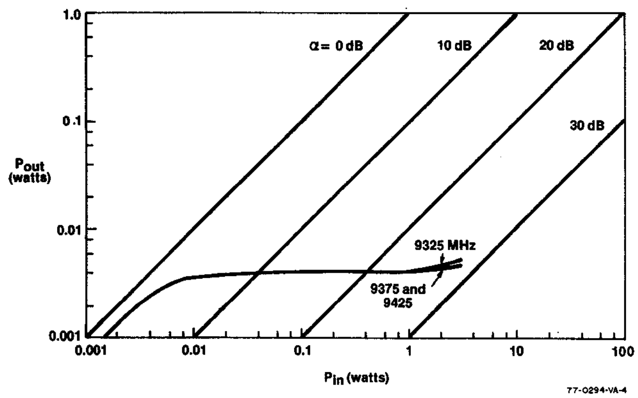

Figure 6. CW Limiting Characteristic

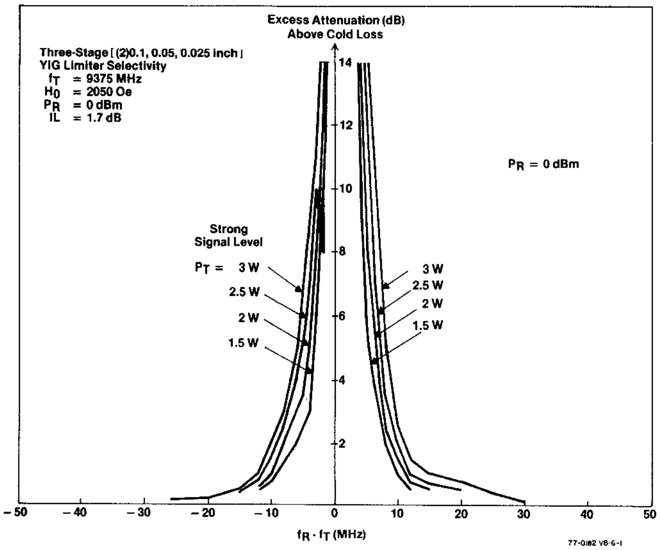

Figure 7. Frequency Selectivity

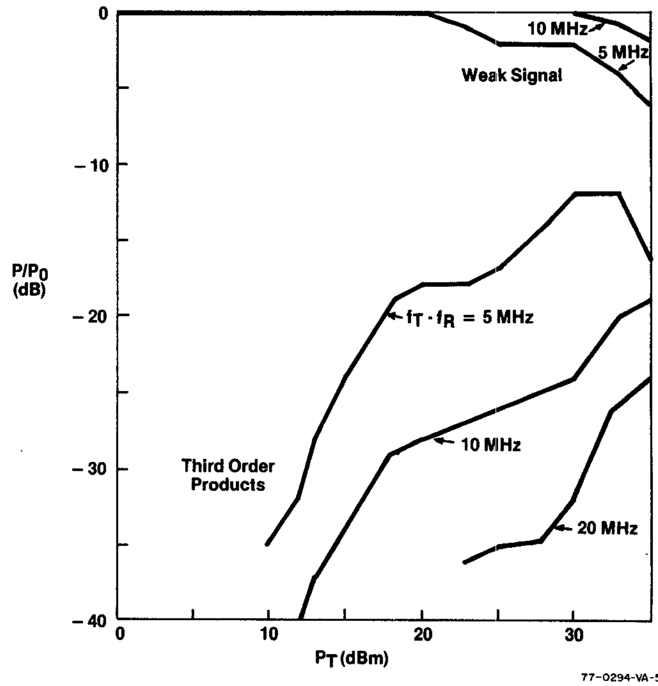

Figure 8. Intermodulation Products