MAGNETOSTATIC SURFACE WAVE SIGNAL-TO-NOISE ENHANCER‡

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Abstract

Utilizing saturation of magnetostatic surface waves propagating in thin YIG films, the signal-to-noise enhancer (or power expander) performs the opposite function from that of the power limiter; weak signals suffer up to 20 to 30 dB greater attenuation than do strong signals. This discrimination takes place on a frequency selective basis over an instantaneous bandwidth of one-third octave or more. Basic principles, construction methods, and experimental results are discussed.

Introduction

The signal-to-noise enhancer[1] is a passive two-port device which performs the function opposite that of the frequency selective microwave ferrite power limiter[2]. Incoming signals falling below some threshold power level suffer insertion loss of up to 30 dB or more. Signals exceeding the threshold, which is typically on the order of 0 dBm, are attenuated by a significantly smaller amount. The difference in insertion loss can be more than 25 dB for signals 20 dB above threshold.

The term "signal-to-noise" enhancer comes about because the device operates on a frequency selective basis. While the transmission coefficient is enhanced around the frequency of a strong signal, below-threshold signals present simultaneously at frequencies separated by more than a few spinwave linewidths from the strong signal still suffer high attenuation. Figure 1 is a representative plot of insertion loss versus frequency in the presence of several signals at various power levels. Frequency selective enhancement takes place at any in-band frequency or multiple number of frequencies at which above-threshold signals happen to arrive. No apriori knowledge of the signal frequencies is needed.

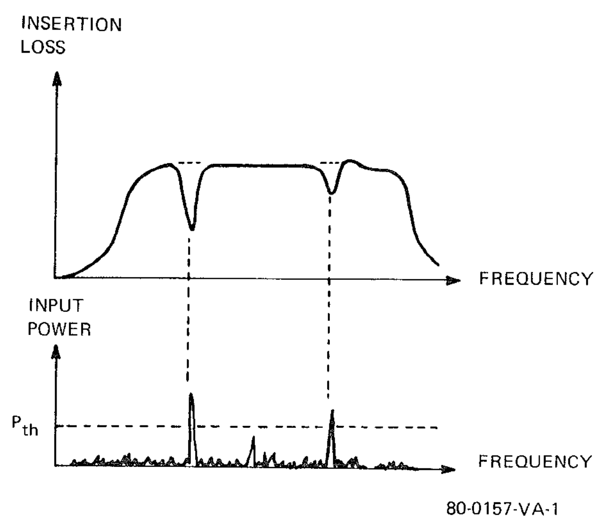

Figure 1. Enhancer insertion loss versus frequency in the presence of several coherent signals at various power levels. The dashed segments in the upper curve show the insertion loss in the absence of above-threshold signals.

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Magnetostatic Surface Wave Signal-to-Noise Enhancer

A schematic drawing of the enhancer is shown in figure 2. A straight-through microstrip transmission line directly connects the input and output ports. A thin film of single crystal YIG (grown on a GGG substrate) is placed above the microstrip, in direct contact with it. The film is biased by an external static magnetic field in the plane of the film, oriented parallel to the microstrip. With a suitably chosen bias field strength, magnetostatic surface waves (MSSW)[3] can be launched into the film by RF currents in the microstrip.[4,5]. At low RF current levels, the excitation of MSSW is linear. The MSSW propagate at right angles away from the microstrip and carry RF energy away from its vicinity, resulting in high insertion loss. Above some critical RF magnetic field strength, the spin wave amplitudes saturate, and the coupling between the microstrip and the MSSW decreases. A smaller proportion of the RF energy in the line is carried away, resulting in lower insertion loss. Figure 3 shows a typical measured loss vs input power characteristic for several values of the interaction length, or distance over which the line is coupled to the film.

If MSSW's reaching the edge of the film are allowed to reflect back toward the line, RF will be coupled back into the microstrip, with some time delay. The effect will be strong interference-fringe type ripple in the below-threshold frequency response curve. To prevent this, the edges of the film were originally ground at a shallow (1 degree) angle to act as a MSSW absorber. More recently, we have

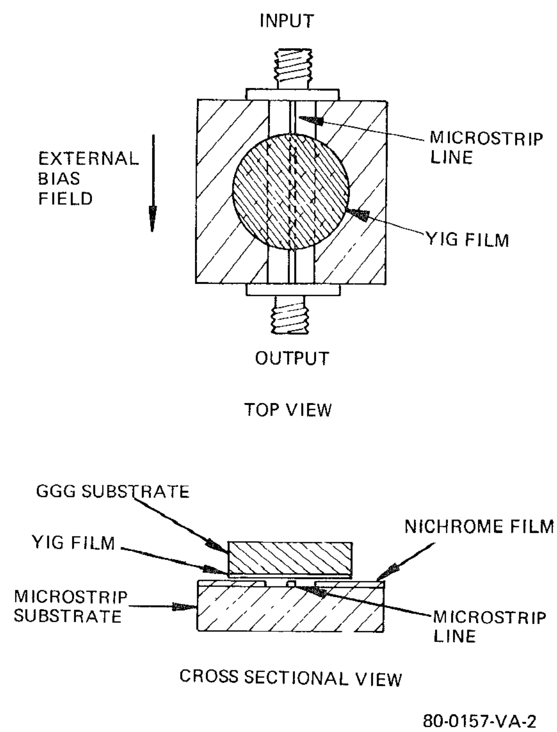

Figure 2. Magnetosatic Surface Wave Signal-to-Noise Enhancer. The YIG film is grown by liquid phase epitaxy on a gadolinium - gallium - garnet (GGG) substrate. The film is placed face down in direct contact with the microstrip line and nichrome film, which are deposited on the microstrip dielectric substrate. Top and bottom ground planes are not shown.

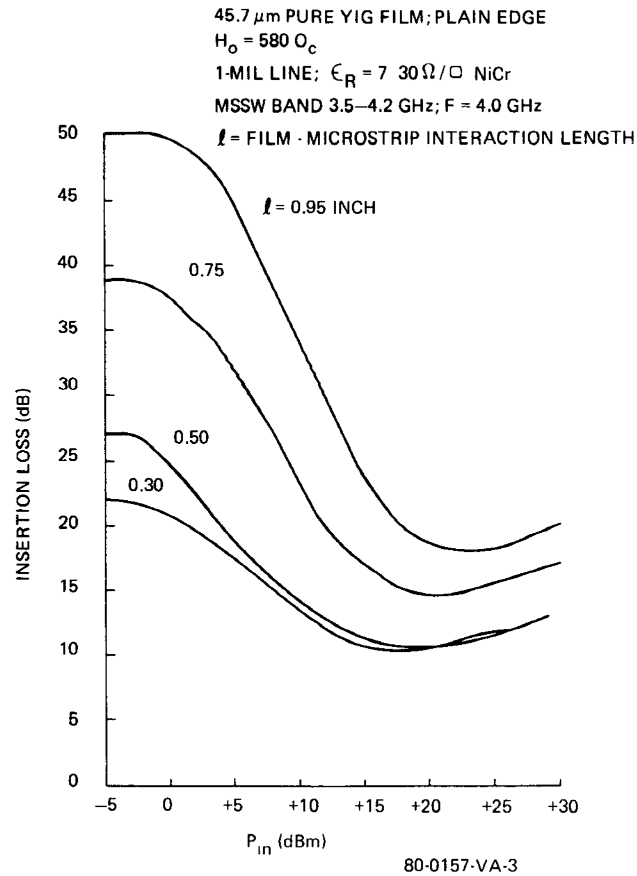

Figure 3. Measured insertion loss as a function of input signal level. The interaction length ℓ is the length of microstrip coupled to the film.

found that very thin films of aluminum (600 Å) or nichrome (10-100 Ω/□) deposited on the microstrip substrate under the edges of the YIG film, as shown in figure 2, perform this function without danger of breaking the YIG/GGG during grinding.

The ultimate bandwidth of the enhancer is controlled by the MSSW band. In an isolated film, the MSSW can propagate at frequencies f between f_{LO} and f_{HI}:

$$f_{LO} = \gamma(H_o^2 + H_o 4\pi M_s)^{1/2} \leqslant f \leqslant f_{HI} = \gamma(H_o + 2\pi M_s) \quad (1)$$

where H_o is the bias field strength, $4\pi M_s$ is the saturation magnetization of the ferrimagnetic material, and γ is the gyromagnetic ratio, 2.8 MHz/Oe. If low threshold power is to be achieved, half-frequency spin waves must be allowed to exist as well. This implies the further constraint:

$$f > 2\gamma H_o \quad (2)$$

Swept frequency response curves are shown in figure 4, which shows insertion loss at several different input power levels. The below-threshold absorption band agrees well with that predicted by equations (1) and (2).

Using pure YIG, a maximum of about 1/3 octave can be obtained in the 3-4 GHz region. For operation above 4.9 GHz, half-frequency spin waves do not coexist with the surface waves, and material with higher $4\pi M_s$ must be used. Alternatively, one surface of the film can be metallized. The latter technique extends the upper frequency limit

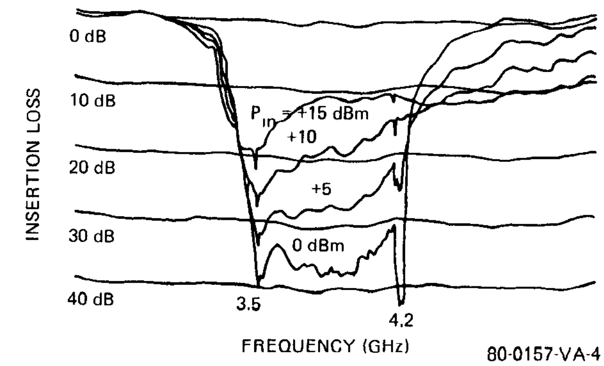

Figure 4. Swept insertion loss at four different input power levels. YIG film thickness 36 μm, biased for MSSW in the 3.5 - 4.2 GHz band. Transducer is 1-mil line on ε_r = 70 substrate. Interaction length ℓ approximately 0.5 inch. Notice conventional power limiting appears above top of MSSW band.

to $f_{HI} = \gamma(H_o + 4\pi M_s)$. In experiments with a coplanar waveguide transducer having 1-mil gaps between the center conductor and the ground planes we have obtained enhancement over the 4.2 - 5.2 GHz band.

The width of the microstrip transducer must be small compared to the shortest MSSW to be excited. Since the MSSW wavelength approaches zero at f_{HI}, microstrip lines as narrow as 1-mil are used to maximize the bandwidth. We used high dielectric constant materials (ε_r = 70) for the microstrip substrate in some of our experiments. This gives greater below-threshold absorption, according to[5]

$$L(\text{dB/cm}) = 0.08686 \frac{\omega}{c} \varepsilon_{eff} \, \text{Im}(1 + j\mathcal{R}/\omega\mathcal{L})^{1/2} \quad (3)$$

where ε_{eff} is the effective dielectric constant of the microstrip substrate, (including the effect of the nearby YIG/GGG film), $\mathcal{R}$ is the radiation resistance per unit length, and $\mathcal{L}$ is the inductance per unit length of the microstrip line. An added advantage of using high dielectric constant material for the substrate is that a 1-mil wide line on a 0.025-inch thick substrate of ε_r = 70 has an impedance near 50 ohms, eliminating the need for impedance transformers at the input and output ports.

Threshold and Enhancement

An approximate expression for the enhancement threshold, which probably only applies to the long wavelength end of the MSSW band, is[6]

$$P_{th} = Z(\Delta H_k d)^2 \frac{4(\Omega_H^2 + 1/2 - \Omega)^2}{(1 + 2/\Omega)^2 \sin^2\theta \cos^2\theta} \quad (4)$$

where Z is the microstrip impedance, ΔH_k is the spin wave line width, d is the film thickness, $\sin^2\theta = (\Omega^2/4\Omega_H) - \Omega_H$, $\Omega = f/\gamma 4\pi M_s$ and $\Omega_H = H_o/4\pi M_s$. Although equation (4) suggests very thin films should be used for low threshold power, we have found that better enhancement (ratio of above/below threshold insertion loss) occurs when relatively thick (20-50 μm) films are used.

The decrease in RF power along the line due to radiation of MSSW energy into the film can be expressed as $dP/dx = -C\,P(x)$ at points x along the line where the power is below threshold and $dP/dx = -C\,P_{th}$ where P(x) exceeds P_{th}, with C a constant. Below threshold, the output power is $P_{out} = P_{in}\exp(-C\ell)$, where ℓ is the interaction length. Above threshold, the power drops according to P(x) = $- C P_{th} x$ until P(x) falls below P_{th} or the output port is reached. From this, we have the following phenomenological expressions for the enhancement factor E defined as $Loss_{below\ threshold} - Loss_{above\ threshold}$: (E in dB)

$$E = 0 \qquad P_{in} < P_{th}$$
$$E = 4.34(P_{in}/P_{th} - 1) - 10\log(P_{in}/P_{th}) \qquad P_{th} \leq P_{in} \leq (1+C\ell)P_{th} \quad (5)$$
$$E = 10\log(1 - C\ell P_{th}/P_{th}) + 4.34C\ell \qquad P_{in} \geq (1+C\ell)P_{th}$$

This is illustrated in figure 5 for several values of $C\ell$.

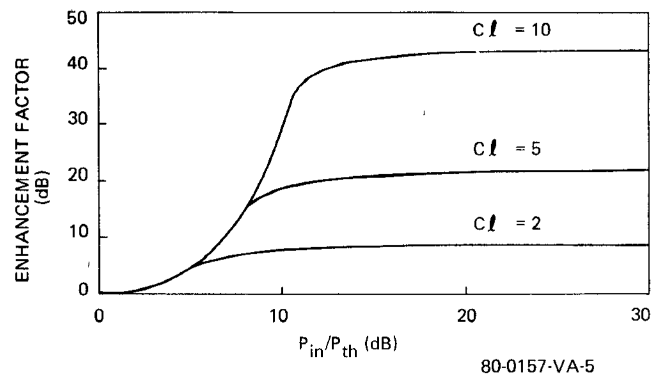

Figure 5. Theoretical enhancement factor as a function of input power level for several values of absorption parameter C times interaction length ℓ.

Frequency Selectivity

Frequency selectivity is observed in the enhancer by measuring the change in output amplitude of a weak signal in the presence of an above-threshold signal as the strong signal level and frequency separation are varied.

Figure 6 shows the output power level of a below-threshold signal in the presence of an above-threshold signal. In the absence of the strong signal, the weak signal is attenuated about 32 dB. As the frequency separation between the two signals decreases, the weak signal experiences a decrease in insertion loss. This effect is more pronounced as the strong signal level is raised. This frequency selectivity effect is similar to that observed in YIG power limiters[2] and is in general not symmetrical with respect to the frequency separation. This asymmetry seems to be more pronounced near the edges of the MSSW band.

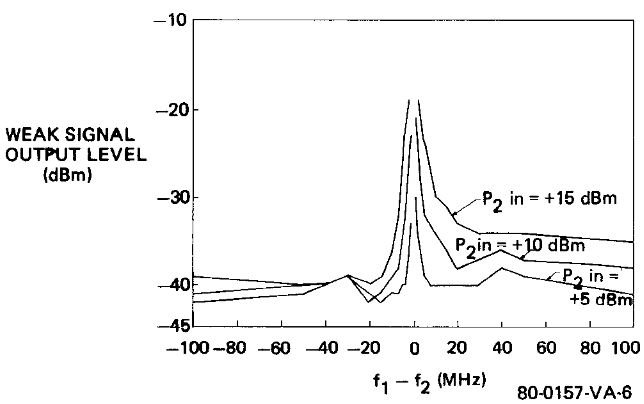

Figure 6. Amplitude of weak signal at $f_1 = 4100$ MHz, measured at enhancer output, in the presence of a strong signal at f_2, versus the frequency separation. Weak signal input level = −10 dBm. Weak signal attenuation = 32 dB in absence of strong signal. 45.7 μm pure YIG film biased at 610 Oe.

Conclusion

The signal-to-noise enhancer provides the unique function of discriminating between strong signals and weak signals (such as thermal noise) over broad instantaneous bandwidth, on a frequency selective basis. Weak signals are attenuated as much as 20 dB or more while strong signals present simultaneously suffer as little as 5 dB loss. No external controls are required. Potential applications include extracting narrow-band signals from wide-band circuits in communications, radar, and ECM systems and suppressing thermal noise in broadband circuits.

References

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