A High Power *X*-Band Limiter

The narrow ferrimagnetic linewidth exhibited by single crystal yttrium iron garnet forms the basis for several novel microwave devices. These may be divided into two main categories, namely, magnetically tunable filters and microwave limiters. Single crystal YIG spheres may be associated with additional microwave resonators to enhance one of these desired characteristics and to suppress the other.

In the present program, our task was to design a high power *X*-band limiter with the following characteristics:

Center frequency: 9600 Mc/s
Instantaneous bandwidth: 100 Mc/s
Insertion loss: 0.5 ± 0.2 dB for low-level signals
Power handling capability: 50-kW peak; no catastrophic failure up to 250-kW peak at a 0.0013 duty cycle
Power output: Shall be sufficiently low so that a diode switch can provide the additional protection required in a typical radar system (less than 100-watt peak).

A three-resonator configuration was chosen. The configuration originally proposed by DeGrasse, in a strip-line version, seemed the best starting point. The two outer cavities consist of conventional microwave resonators which are made a full wavelength long so that the YIG sphere may be placed at a convenient position of maximum RF magnetic field. The two cavities are oriented at right angles to each other, with the YIG sphere located in a coupling hole; it thereby provides the required mutual coupling when it is biased to gyromagnetic resonance.

The filter may be considered a three-cavity direct coupled configuration. In order to obtain a maximumly flat design, all the external Q's may be computed. In the case of the outer two resonators, a loaded Q of approximately 75 is required. For the middle resonator, which consists of the YIG sphere, the loaded Q was determined empirically by observing the overall band-pass filter characteristics on a microwave sweeper.

The relatively wide bandwidth requires a rather large YIG sphere. The problem of avoiding spurious responses is rather serious. Some improvement may be obtained by reducing the waveguide height of the auxiliary resonators to obtain a larger filling factor for a given size sphere. In our initial experiments, the auxiliary resonators were constructed of 0.100- by 0.900-inch ID waveguide. Subsequently, comparisons were made with 0.150- by 0.900-inch ID resonators. A 0.3-dB reduction in overall insertion loss was noted with the higher waveguide resonators.

The common wall between the crossed resonators was 0.010-inch. The diameter of the coupling hole was chosen about 1.5 times the sphere diameter.

A second important consideration con-

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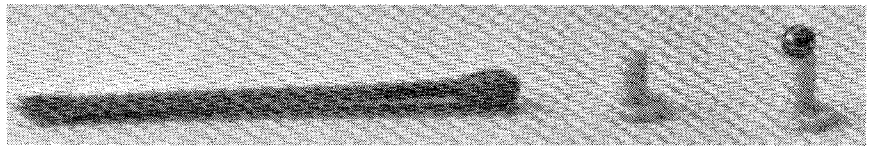

Fig. 1. Beryllium oxide supports for YIG sphere.

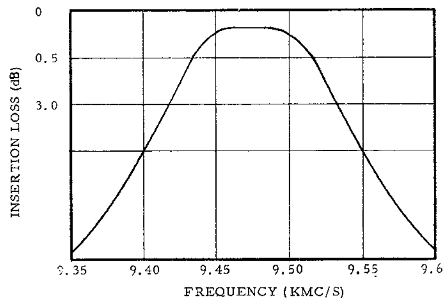

Fig. 2. Low power response curve.

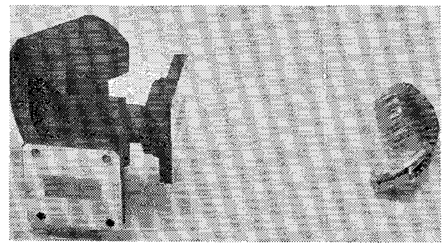

Fig. 3. Prototype YIG limiter.

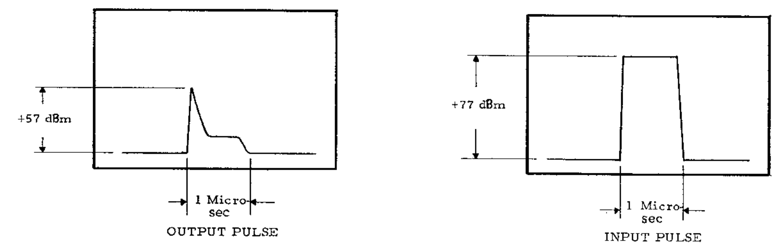

Fig. 4. Detected RF envelope (20-Mc/s bandwidth oscilloscope).

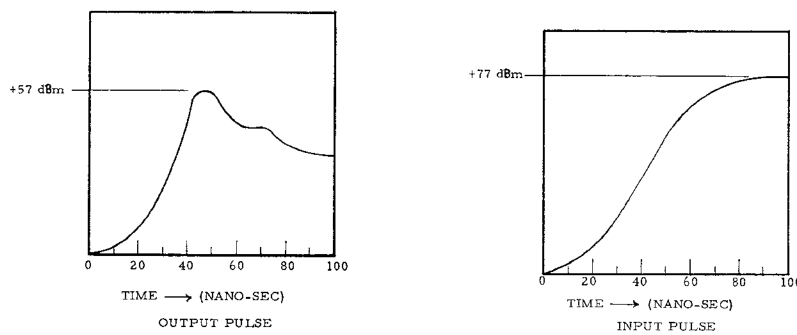

Fig. 5. Detected RF envelope (1000-Mc/s bandwidth oscilloscope).

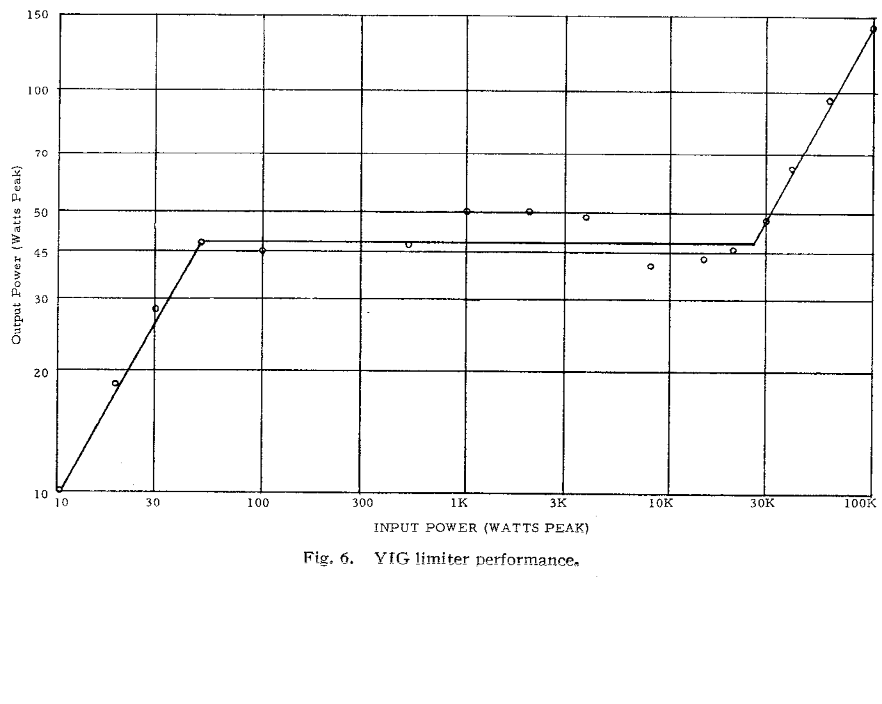

Fig. 6. YIG limiter performance.

cerns the heat transfer from the YIG sphere to the waveguide wall. The YIG sphere was supported on beryllium oxide posts equal to the full height of both resonators. These components are shown in Fig. 1.

A third important consideration concerns the quality of the yttrium iron crystal available. The resonance linewidth of typical crystals used in this program is less than 0.25 oersted when measured at 5000 Mc/s. This linewidth may be related to the unloaded Q of the YIG sphere and it assumes a value of approximately 6000. These measurements are based on a configuration where the sphere represents a slight perturbation of a microwave cavity, whereas in a limiter, a tightly coupled configuration is required. The effective Q of the YIG sphere is thereby reduced by a factor of 2. With a loaded Q of approximately 50 it contributes approximately 0.2-dB insertion loss.

A narrow linewidth lithium ferrite sphere was substituted for the YIG sphere It raised the overall device insertion loss to 3 dB, in agreement with its relatively broader resonance linewidth.

The overall insertion loss, with a YIG sphere 0.090-inch diameter, is shown in Fig. 2. It was 0.3 dB at the band center, and 0.5 dB at the edges of a 75-Mc/s band.

The assembled device, including the biasing magnet, is shown in Fig. 3.

Figure 4 shows a typical high power response curve. The lower trace represents a 50-kW peak pulse with one microsecond duration. The upper trace is taken under 100 times higher sensitivity. One may observe a short duration spike at the leading edge of the RF pulse with flat leakage following during the RF pulse interval.

Figure 5 shows the spike leakage measured on a sampling oscilloscope of 1000-Mc/s bandwidth. Due to the short duration of this spike, wider bandwidth is required to obtain a true picture of the spike leakage. The lower trace represents the leading edge of a 50-kW input pulse. The upper trace, displayed at 100 times higher sensitivity, represents the spike leakage through the device. Total horizontal sweep time is 100 ns. The peak amplitude of the spike is approximately 500 watts.

Figure 6 shows a graph of output peak power vs. input peak power. It may be seen that limiting occurs at approximately 50-watts peak. The slope of the output power curve is less than 2 dB for a 30-dB range of input power.

The leakage by the device has been reduced sufficiently to be handled by a semiconductor or switch to provide the total receiver protection required in a typical radar system.

This work therefore represents a substantial advancement in the state of the art of solid-state receiver protectors.

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Prediction and Measurement of Oscillator Frequency Modulation under Random Vibration

Electronic equipment used in jet aircraft or in a missile environment must operate under broadband random mechanical and acoustic vibration. Individual component performance is tested by subjecting the operating component to band limited random noise vibration rather than to sinusoidal vibration. The analysis of component performance, particularly the problem of pinpointing the source of spurious responses resulting from such random vibration testing is often not available.

The output of any microwave oscillator, whether a multicavity klystron oscillator, a reflex klystron, or a solid state multiplier will contain a certain amount of spurious amplitude and frequency modulation (AM and FM noise) when operated under environmental vibration. We have been able to accurately predict the noise performance of a reflex klystron when subjected to random vibration, on the basis of tests made using sinusoidal vibration.

When the sine wave response to a device is known, the response to random vibration can be predicted, if the device meets the following requirements:

1. The mechanical behavior is relatively uniform with frequency, with no high Q resonances in the vibration frequency range.
2. The mechanical behavior is linear over the vibration amplitude.

Several series of Sperry developed reflex klystrons in X band, Ku band and K band meet these criteria, and as a result, their FM performance under any given vibration input can be accurately predicted.

The first step is to determine the mechanical modulation coefficient, $M(\mu)$, defined as

$$M(\mu) = \frac{\Delta f}{A} \qquad (1)$$

where

μ = vibration frequency
Δf = frequency deviation (cycles, peak)
A = acceleration amplitude (gravity units, peak).

The mechanical modulation coefficient is measured by subjecting the operating tube to a sinusoidal acceleration of one or two g, and varying the vibration frequency over a range at least one-half octave above and below the random vibration band. Deviation of the oscillator frequency is measured at each vibration frequency, using a microwave discriminator fed through a semirigid coaxial line. A wave analyzer is used for taking detailed data on the output of the discriminator with the analyzer bandwidth set sufficiently narrow to select only the deviation coherent with the vibration frequency. The effects of 60 cycle power supply frequency components can thus be minimized.

A block diagram of the measurement gear is shown in Fig. 1. The viewing scope is most useful for observing saturation effects and other nonlinearities, while the ultrasonic analyzer provides a continuous display of the modulation spectrum from 1 to 100 Kc and is very valuable in detecting harmonics and in spotting trouble areas.

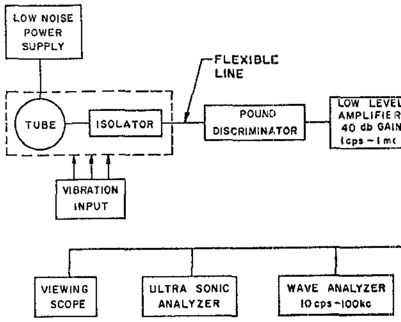

Fig. 1. Noise measurement block diagram.

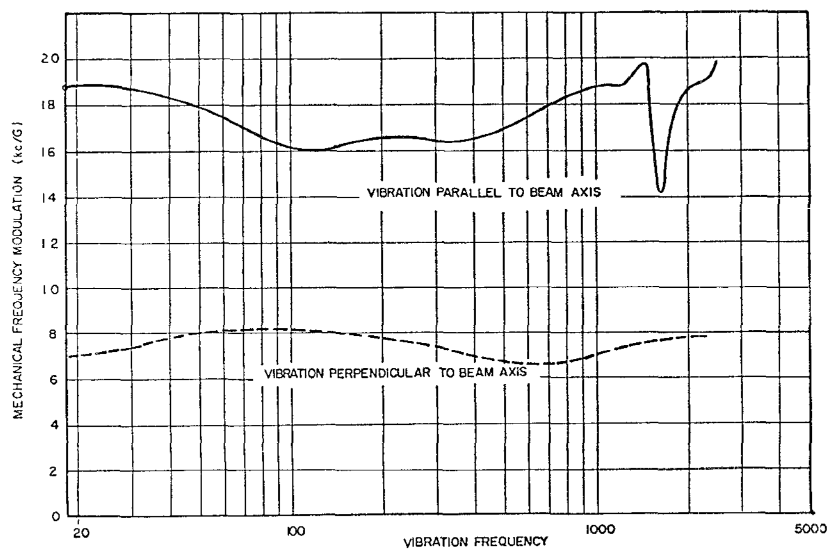

Fig. 2. Mechanical modulation of a reflex klystron.

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