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.

E. WANTUCH[1]
Fairleigh Dickinson University
Teaneck, N. J.
M. KING
Airtron Div.
Litton Precision Products, Inc.
Morris Plains, N. J.

[1] Formerly with Airtron Div., Litton Precision Products, Inc., Morris Plains, N. J.

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 sinuosidal 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

$$M(\mu) = \frac{\Delta_f}{A} \quad (1)$$

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.

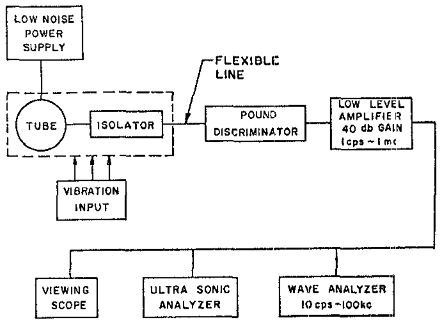

Fig. 1. Noise measurement block diagram.

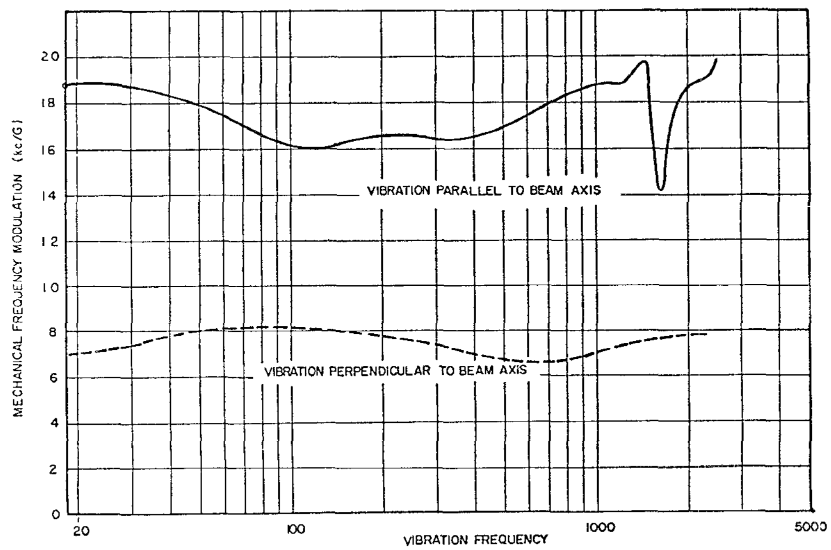

Fig. 2. Mechanical modulation of a reflex klystron.

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We have found that if sinusoidal acceleration of $\frac{1}{4}$ to $\frac{1}{3}$ the rms value of the desired random vibration causes no noticeable distortion of the discriminator output, then the mechanical behavior is sufficiently linear for an accurate prediction of the frequency modulation which will result from a given random vibration.

The prediction of the frequency modulation caused by random vibration is simply a matter of evaluating

$$m = \left[\int_{\mu_1}^{\mu_2} [M(\mu)]^2 \psi(\mu) d\mu \right]^{1/2} \quad (2)$$

where

m = rms frequency deviation in the band μ_1 to μ_2
$M(\mu)$ = mechanical modulation coefficient
$\psi(\mu)$ = magnitude of the random acceleration density spectrum (in terms of g^2/cycle).

If neither $M(\mu)$ nor $\psi(\mu)$ vary appreciably between μ_1 and μ_2, then

$$m = M(\mu)[B\psi(\mu)]^{1/2} \quad (3)$$

where the bandwidth B is usually the bandwidth of the wave analyzer.

Figure 2 is a plot of the mechanical frequency modulation coefficient measured on one of these reflex klystrons. Note that this coefficient is less for vibration perpendicular to the beam axis than for vibration along the beam axis, as would be expected from a mechanical analysis of a cross-section view of a typical reflex klystron. This klystron was then operated under random vibration having the acceleration spectral density shown in Fig. 3. Note that the spectral density is given in terms of $[\psi(\mu)]^{1/2}$. The plot above 5 Kc/s is beyond the calibrated range of the accelerometer, and is included to show that vibration is present well beyond the cutoff point of the band-limiting filters used in the vibration gear.

Figure 4 is a plot of the frequency modulation measured under the random vibration of Fig. 3. For comparison, Fig. 2 and (2) were used to compute the circled points. Note that the data above 5 kc/s confirms that the tube responds to vibrations at ultrasonic frequencies. It can be seen that very accurate predictions of performance are possible. Care must be taken to ensure that the vibration input to the device under test is linear, and that distortion within the vibration equipment, both mechanical and electrical, do not introduce frequency compnents well outside the desired vibration range.

J. R. Ashley
C. B. Searles
Sperry Electronic Tube Division
Gainesville, Fla.

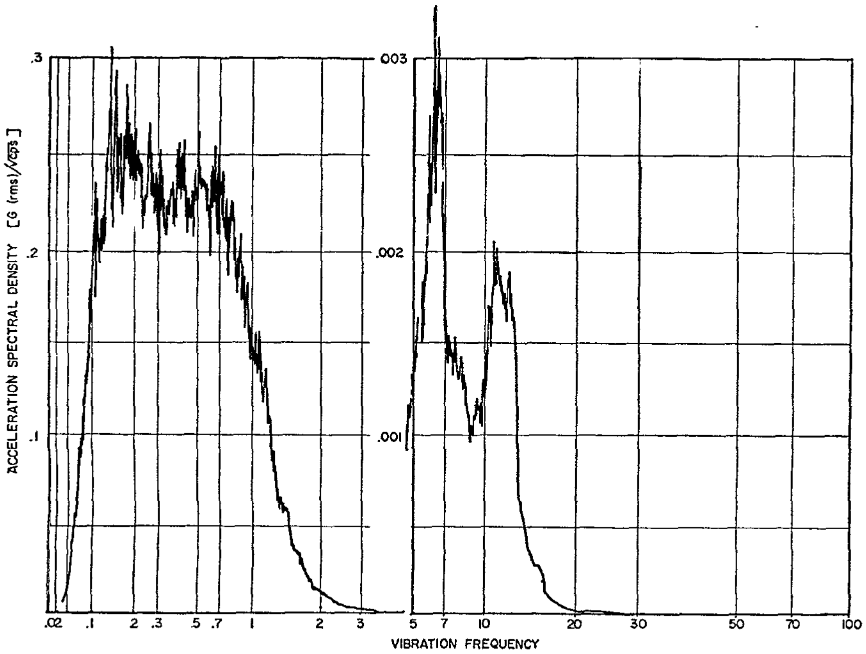

Fig. 3. Measured vibration spectral density (accelerometer resonance is about 15 kc/s).

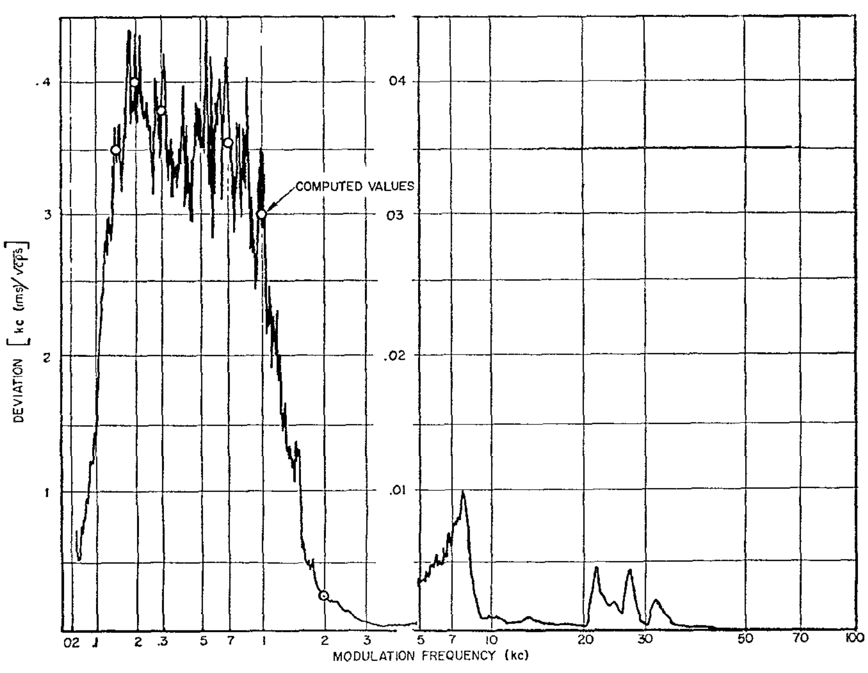

Fig. 4. Measured frequency modulation of a reflex klystron with the random vibration of Fig. 3.

Relative to Microwave Power Engineering

Recent erroneous reporting[1] of a facet of the proceedings of a microwave power engineering symposium has left the impression that microwave CW power transmission is limited, without qualification, by heating of the waveguide before the electric breakdown limit is reached. Consequently, a partial purpose of this correspondence is to show that microwave CW power transmission via re-entrant waveguide need not be limited by heat dissipation in the waveguide nor by electric breakdown even beyond the equivalent CW power capacity of high voltage (i.e., 132 to 750 kV) classical (i.e., 60 c/s) transmission lines. On the contrary, the feasibility of microwave power transmission is dependent on resolving the following.

1) The problems (e.g., spurious mode conversion, resonances, tolerances, etc.) associated with maintenance of the presently desired (e.g., circular electric) mode purity in sufficiently large oversized circular re-entrant waveguide so as to realize the required total (ohmic) attenuation and

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[1] For example, R. Henkel, "Believe power transmission via microwave now in sight," see, *Electronic News*, p. 28, April 19, 1965.