VI-6. PREDICTION AND MEASUREMENT OF OSCILLATOR FREQUENCY MODULATION UNDER RANDOM VIBRATION

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Many microwave oscillators operate in a vibrating environment and the effect of this vibration on performance must be known. Test data have shown the vibration in missiles and jet aircraft is not sinusoidal, indeed, the spectrum analysis of vibration shown in Figure 1 indicates that the vibration is better simulated by band limited random noise than by sinusoidal vibration. Diagnosis of trouble is easier to perform and understand if sinusoidal vibration is used. Therefore, it is desirable to predict the frequency modulation of an oscillator operating under random vibration, on the basis of tests made with sinusoidal vibration.

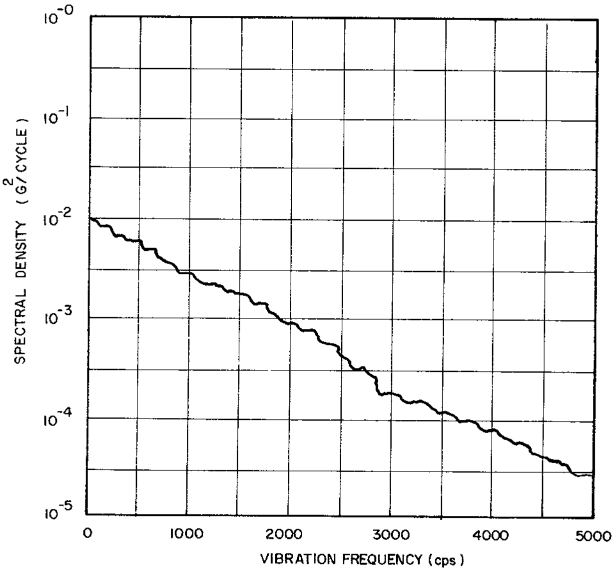


Figure 1. Typical Spectral Density Curve for Missile Vibration

If the sine wave response of a system is known, it is possible to predict the random noise response if the system is relatively simple. Practically, this means that the mechanical behavior must be relatively uniform as a function of frequency with no high Q resonances, and even more important, the system must be linear. Recently developed klystron oscillators possess these properties and measurements on these oscillators have shown that F.M. under random vibration can be predicted with good accuracy.

Mechanical Modulation Coefficient. The first step in the procedure is to measure the mechanical modulation coefficient as a function of vibration frequency. This is done by applying a sinusoidal vibration to the oscillator and measuring the frequency deviation coherent with the vibration frequency. The mechanical modulation coefficient is defined as

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

where

μ is the vibration frequency

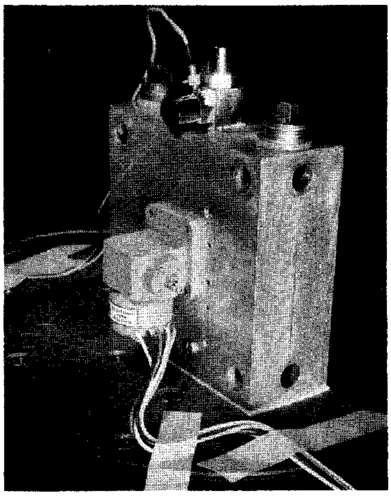
Δf is the frequency deviation (cycles, peak)

A is the acceleration amplitude (gravity units, peak).

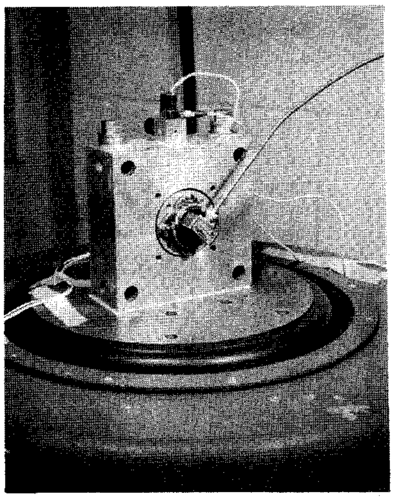
Usually, an acceleration of 1g is applied and varied over a frequency range at least one-half octave above and below the band of interest. The deviation is measured with some type of microwave discriminator.

Measurement Precautions. In measuring the mechanical modulation coefficient, it is useful to have accelerometers monitoring vibration along and perpendicular to the intended axis of vibration.

The oscillator r.f. load reflection coefficient must not be a function of vibration frequency. This test condition is difficult to satisfy since it is also necessary that the oscillator output be connected to the discriminator. The method illustrated in Figure 2 has worked well on klystrons operating as high as 31 gc. The tube is bolted to either a rugged ferrite isolator or fixed attenuator which is made as much a part of the vibration fixture as possible. The semi-rigid coaxial cable with solid polytetrafluoroethylene dielectric has proved an excellent means of getting the signal off of the vibration table without pulling the oscillator.



Tube Side of Fixture



Output Side of Fixture

Figure 2. Vibration Mounting of Tube Showing the Method of Taking the RF Signal from the Tube to the Measuring Equipment

The equipment for both the mechanical modulation coefficient measurement and the F.M. under random vibration measurement is shown in Figure 3. The only measurement difference is in the type vibration used.

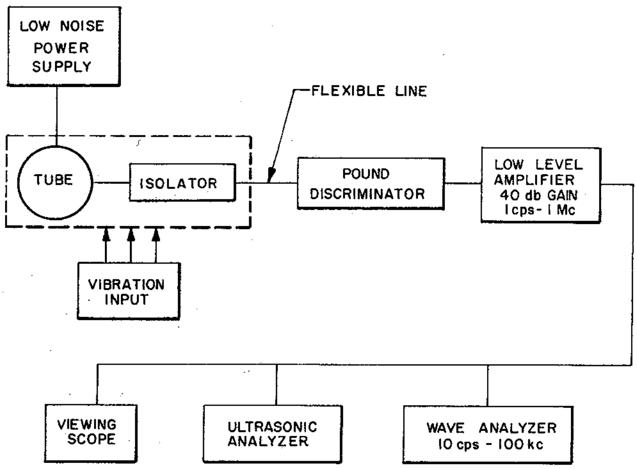


Figure 3. Noise Measurement Block Diagram

Prediction of FM Under Random Vibration. If a plot of the mechanical modulation coefficient is relatively independent of frequency (say flat within 6 db and with no sharp resonances) it is then worthwhile to check for linearity. The vibration amplitude to use is determined by the amplitude of the random vibration. An upper limit is three times the rms value of the band limited random vibration. In practice, a level of about one-tenth this amount has proved to be sufficient.

Computation of the F.M. caused by random vibration is simply a matter of evaluating

$$m = \left[\int_{\mu_1}^{\mu_2} [M(\mu)]^2 \, \sigma(\mu) \, d\mu \right]^{\frac{1}{2}} , \qquad (2)$$

where

m = rms frequency deviation in the band μ_1 to μ_2

$\sigma(\mu)$ = amplitude of the acceleration density spectrum (in units of g^2/cycle).

Note that μ_1 and μ_2 are usually set in the wave analyzer following the discriminator. If neither $M(\mu)$ nor $\sigma(\mu)$ vary appreciably between μ_1 and μ_2, then

$$m = M(\mu) [B\sigma(\mu)]^{\frac{1}{2}} , \qquad (3)$$

where the bandwidth

$$B = \mu_2 - \mu \qquad (4)$$

is usually the noise bandwidth of the wave analyzer.

Experimental Results. This procedure has been carried out on a reflex klystron. The measured mechanical modulation coefficient is plotted in Figure 4. The klystron was then subjected to the random vibration shown in Figure 5. This plot gives $[\sigma(\mu)]^{\frac{1}{2}}$ which is the quantity actually measured. Notice that the slope of the band edges is high (but not infinite as specifications are often written).

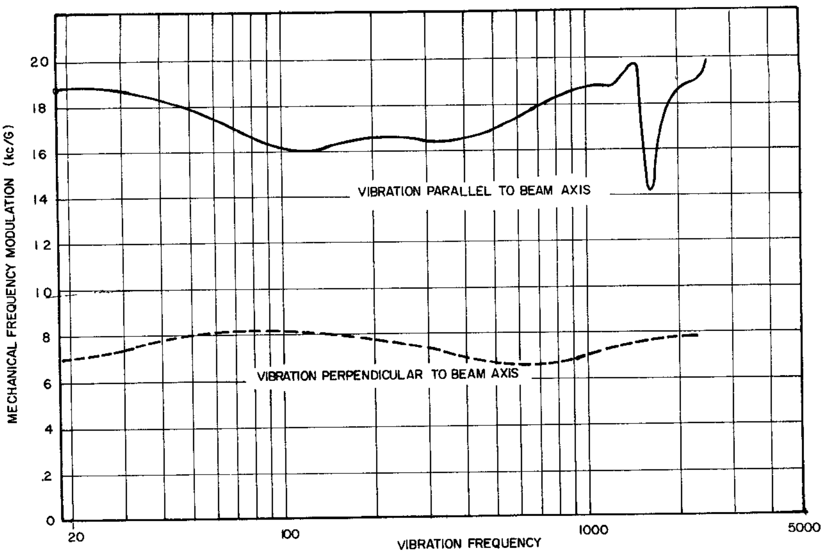


Figure 4. Mechanical Modulation of a Reflex Klystron

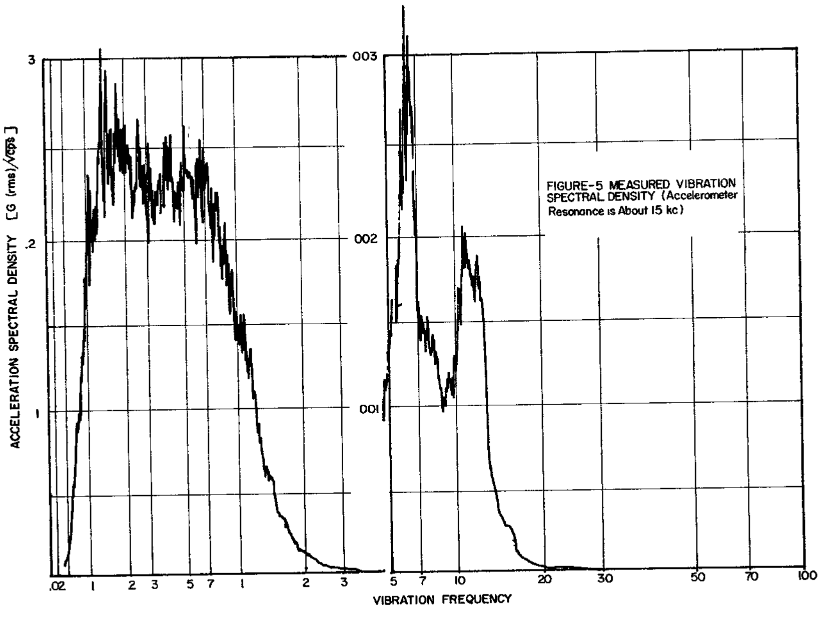


Figure 5. Measured Vibration Spectral Density (Accelerometer Resonance is About 15 kc)

The plot above 5 kc is above the calibrated range of the accelerometer and is intended to show that vibration is present at frequencies above the band of interest.

The measured frequency deviation for this oscillator is plotted in Figure 6. For comparison, Equation (3) has been used to compute the circled points. The data above 5 kc confirm that the tube responds to vibration which is present in this range.

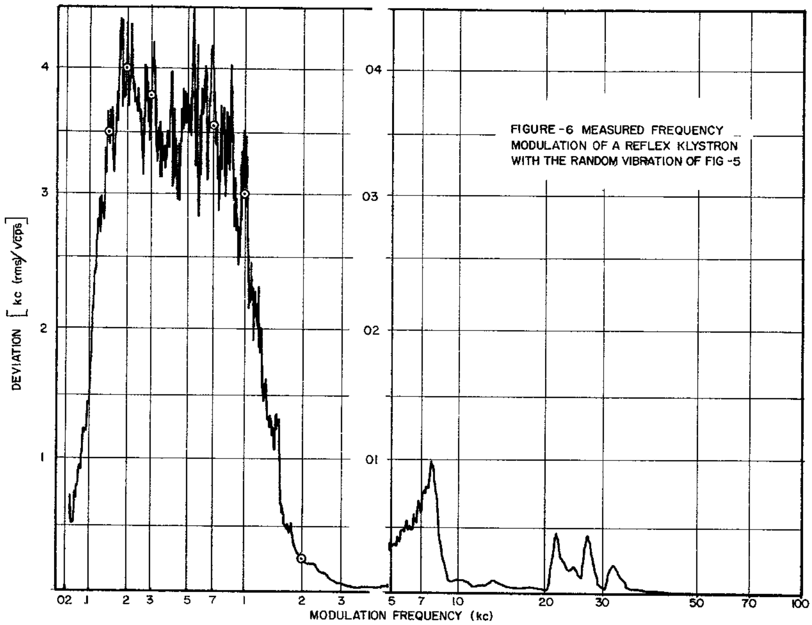


Figure 6. Measured Frequency Modulation of a Reflex Klystron with the Random Vibration of Figure 5

Conclusions.

1. For oscillators with simple mechanical structure, it is possible to predict F.M. under random vibration on the basis of sinusoidal vibration measurements.
2. A sinusoidal vibration of 0.3 times the rms value of the random vibration is sufficient to prove linearity.
3. Most vibration equipment has output at frequencies up to 50 kc which cannot be neglected.