AMPLITUDE AND FREQUENCY MODULATION OF CW GUNN OSCILLATORS

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The use of Gunn oscillators in CW Doppler radar, as local oscillators, and in other system applications often requires automatic frequency and/or phase control, frequency modulation or amplitude modulation. The frequency modulation of CW Gunn oscillators by simultaneously applying ac and dc bias voltages has been described by King and Wasse,[1] who discussed possible modulation mechanisms. Hobson[2] has reported an experimental study of voltage tuning using a biconical cavity.

In this paper we present the results of a theoretical and experimental study of AM, FM and AFC of wide-band tunable Gunn oscillators operating in the X-band. The oscillators consist of a Gunn diode mounted on a post in rectangular waveguide. The circuit is loaded with an iris and is tuned over the band with a sliding short located behind the post. The output power as a function of frequency is shown in Fig. 1 for a typical oscillator.

The devices used were epitaxial sandwich structures with an active layer length of $L = 10$ microns (nominal) and a doping density-length product $nL \simeq 8 \times 10^{14}$ cm^{-2}. When biased at 2-3 times threshold their transit time frequency is calculated to be approximately 12 GHz. From this result and from the experimental tuning characteristics it was concluded that the devices were operating in the delayed domain mode.[3,4] The device negative resistance matches itself to the positive load resistance of the microwave circuit while the device reactance is tuned out by the circuit reactance, thus establishing the oscillation frequency.

The device reactance has three components; the package capacitance and lead inductance; the domain capacitance; and the reactance due to the non-linear current-voltage characteristic. The package reactance is independent of bias voltage. The domain capacitance will be a minor contribution to the total reactance if the period T of the oscillation frequency is much larger than the dielectric relaxation time constant τ, i.e. $T >> \tau \simeq 4 \times 10^{-12}$ sec. This condition also implies that the static i-v characteristic can be used to calculate both the negative resistance and the reactance. It is this bias voltage controlled reactance which is responsible for voltage tuning of the oscillation frequency.

Since the device is situated in a resonant circuit the amount of voltage tuning obtained will depend on the circuit impedance and its loaded Q. For a fixed tuned circuit if the device suscep-

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tance changes by an amount ΔB, a frequency shift Δf will occur in order to maintain the resonance condition. This frequency shift is given by

$$\Delta f = \frac{-f}{2Q_L} \frac{\Delta B}{G} \qquad (1)$$

where f is the original oscillation frequency, Q_L is the circuit loaded Q and G is the load conductance seen by the device. For the X-band circuit previously described, the frequency and power deviation per volt change in bias voltage are plotted in Fig. 2 as a function of oscillation frequency. Also plotted in this figure is the reciprocal of the loaded Q as determined by measuring the maximum injection phase-locking bandwidth[5].

The loaded Q is a significant factor in both the AM and FM characteristics of the oscillator. Notice in Fig. 2 that the modulation sensitivity $\Delta f/\Delta v$ increases with increasing Q_L^{-1}. However, the power deviation per volt which is a measure of amplitude modulation decreases with increasing Q_L^{-1}. Thus in specific applications such as FM transmission, a heavily loaded circuit should be used to obtain high modulation sensitivity. Furthermore, when the oscillator is operated with an imperfect bias supply (dc with ripple and random noise), more AM noise will be generated in lightly loaded circuits and more FM noise in heavily loaded circuits. The scattering in the experimental points is due to parasitic resonances which are also apparent in Fig. 1.

As a first approximation, in order to obtain quantitative results, the effect of the iris is neglected and the real part of the load is taken as proportional to Y_O, the characteristic admittance of the matched waveguide. The factor f/Y_OQ_L of Eq. (1) is plotted in Fig. 3, normalized to the experimental modulation sensitivity of Fig. 2, at the point f = 9.4 GHz. At the lower frequencies f/Y_OQ_L seems to govern the sensitivity. However, at the higher frequencies this is not the case. The large difference in slope occurs because the device susceptance is frequency dependent.

Figure 4 shows the oscillation frequency plotted as a function of sliding short position. Also shown is the resonant frequency of the circuit when an empty device package is used as well as the theoretical result for the resonant frequency of a rectangular waveguide cavity operating in the TE_{102} with dimensions a = 0.9 inches and d = length. This frequency is given by

$$f = c \left[\left(\frac{1}{d}\right)^2 + \left(\frac{1}{2a}\right)^2\right]^{1/2} \qquad (2)$$

where c is the speed of light. At the lower frequencies (large d) the oscillation frequency is offset by a difference Δf from the empty device package plus circuit resonance. From Eq. (1) this would require a device electronic capacitance of approximately 0.15 pf. This value is in reasonable agreement with theoretical calculations based on a physical model for the Gunn effect. At the higher frequencies the oscillator deviates from the empty package results because of the additional series inductance present when an actual device is used.

At the higher frequencies less voltage is required to drive the device to obtain a given deviation ratio, $\delta = f_d\ (max)/f_m$ where f_d is the frequency deviation and f_m is the modulation frequency. Thus the linearity of frequency modulation should be better in the more heavily loaded circuit. This is demonstrated experimentally in Fig. 5. Generally, these devices show higher frequency deviation per volt at lower values of bias voltage.

The frequency sensitivity to voltage noted in Fig. 2 can be used for AFC of the Gunn oscillator. An AFC loop consisting of a crystal controlled oscillator and multiplier chain, a mixer, IF amplifier, limiter, discriminator and an error signal current amplifier was constructed. With the loop closed the long term thermal drift of the oscillator was reduced to the same order of magnitude as the stability of the crystal oscillator. The short term random noise was greatly reduced. Figure 6 compares the oscillator spectrum with the loop opened and closed. The photos were taken with 5kc/cm dispersion and a 5 second exposure time. The oscillation frequency was 9.701 GHz.

ACKNOWLEDGEMENT

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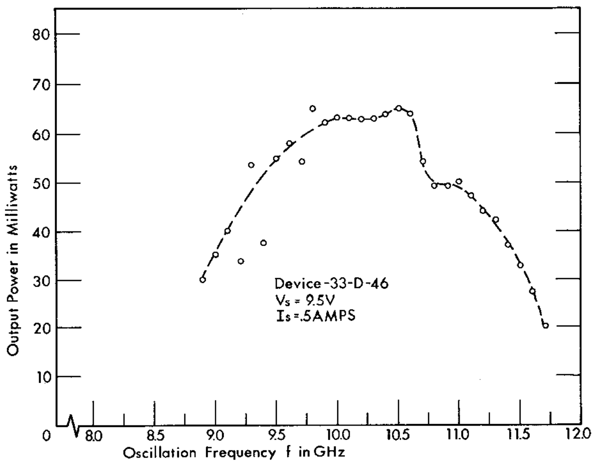


Fig. 1 - Output power as a function of frequency for X-band tunable oscillator.

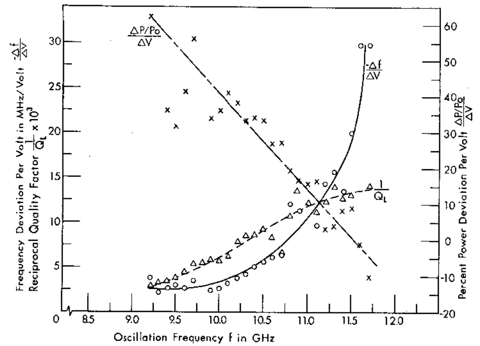


Fig. 2 - Modulation sensitivity, reciprocal loaded Q, and percent power deviation as a function of frequency.

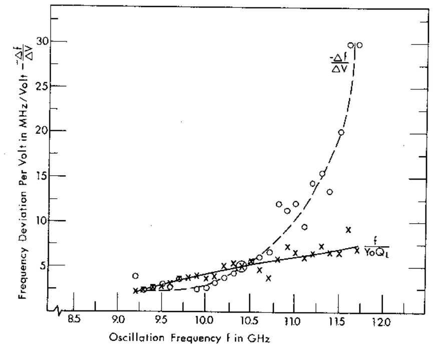


Fig. 3 - Frequency dependence of modulation sensitivity and normized factor f/Y_oQ_L.

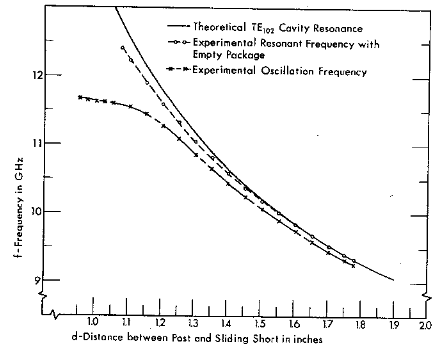


Fig. 4 - Oscillation frequency and circuit resonant frequency with empty device package as a function of cavity length.

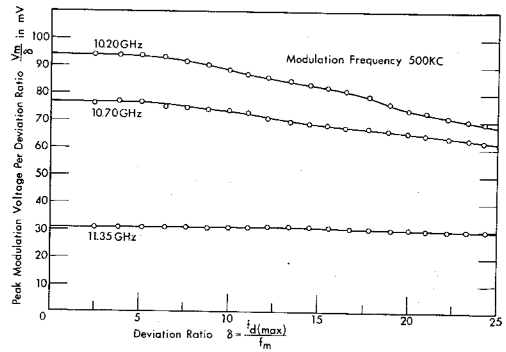
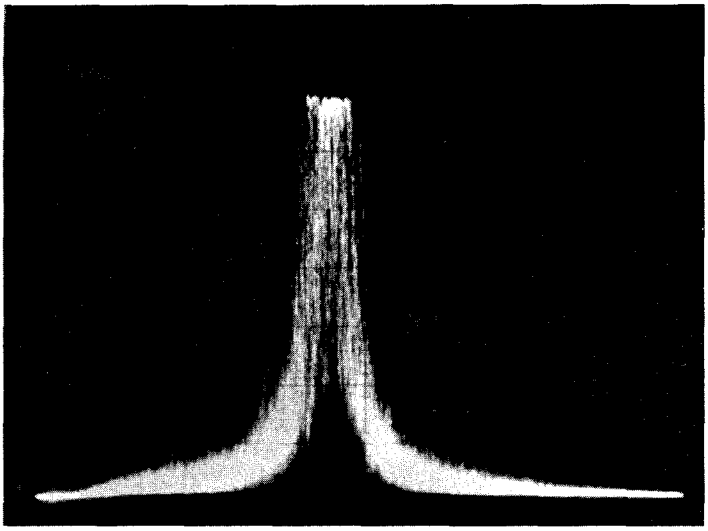
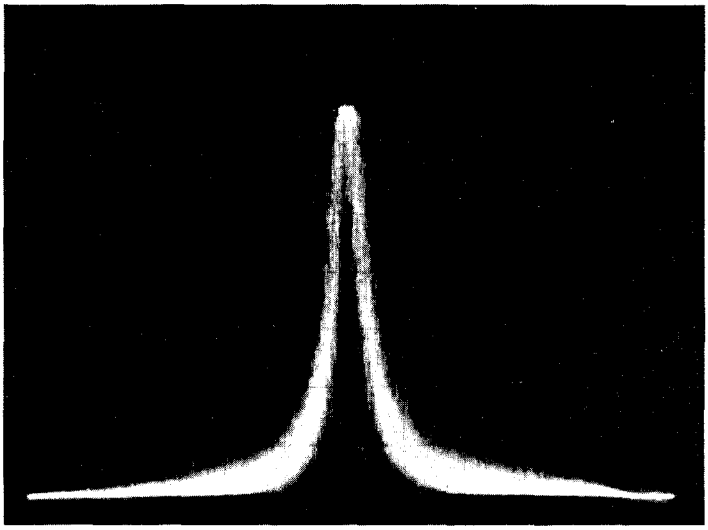


Fig. 5 - FM Linearity.



(a) Free running spectrum



(b) Spectrum with AFC on

Fig. 6 - Spectrum of Gunn Oscillator. Disperision: 5 kc/cm.