I-6. PERFORMANCE CHARACTERISTICS OF CW SILICON AND GaAs AVALANCHE DIODE OSCILLATORS

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Recently there have been numerous reports of coherent microwave generation from p-n junction structures when biased into the avalanche region and situated in a suitable circuit environment. However, little quantitative data on the performance of these devices in various circuit configurations have been available. Further, nothing has been presented concerning their application to specific system problems; nor has any data regarding their reliability been documented to date.

The present paper reports on the important performance characteristics of both silicon and gallium arsenide CW avalanche diode oscillators. Power output, frequency stability, dc to rf efficiency, tunability, spurious signal content, and other important device parameters are discussed. In addition, operating life data are presented together with the results of some systems experiments which clearly demonstrate the practical values and limitations of these new devices.

Using modified tunable waveguide crystal detector mounts, CW power outputs of 30 mW at 5 per cent dc to rf efficiency at 13 - 14 GHz have been obtained consistently from epitaxial gallium arsenide diodes mounted in the double-ended pill structures. To achieve this performance, typical input currents ranged between 9 and 10 mA with corresponding breakdown voltages of 25 - 40 volts. Typical threshold currents for these diodes are about 2 - 4 mA and output power increases rapidly with increasing avalanche current or power until a saturation effect is noted (see Fig. 1). Similarly, the dc to rf efficiency, shown in Fig. 2, exhibits the same dependence on bias current. Measurement of output power and hence efficiency has been carefully analyzed to make certain that only single frequencies are studied. Swept local oscillators and signal substitution techniques are employed for this purpose.

It has been our experience that silicon avalanche oscillators characteristically exhibit a noisier spectrum than that obtainable with gallium arsenide diodes.

Another interesting and important feature of these avalanche diode oscillators is the ability to tune them over wide frequency ranges by very simple means. Adjustment of a sliding short can provide at least 10% tuning range and electric tuning by YIG spheres is also possible over ranges of at least 5% of the center frequency. These results are based on fairly crude, non-optimized experiments. Since these structures exhibit negative resistances over wide frequency ranges, ease of tuning must be considered one of their advantages.

Figure 3 illustrates the tuning achieved using a simple sliding short in an X-band crystal detector mount. In a number of application-oriented experiments, avalanche diode oscillators have been evaluated with respect to their practical and immediate utility in systems. The most obvious use for these structures clearly falls into the local oscillator area and here one is concerned with their high noise level and potential spurious behavior. Ku-band receiver noise figure measurements have been made using both balanced and unbalanced mixers. Broadband gas discharge noise sources as well as signal generators have been used as noise sources (gas discharge lamps cannot provide sufficient noise to make accurate Y-factor measurements with unbalanced mixers). Alternatively, diode oscillators have been replaced with klystron sources and receiver noise figure measurements repeated.

As might be anticipated, diode local oscillators appear to be just as good as klystron local oscillators when used with carefully balanced mixers. Literally, hundreds of comparative measurements reveal that there is no essential difference in receiver noise figures when using either a klystron or diode local oscillator. These comments do not apply to FM noise for which no satisfactory data yet exist.

It should be noted that the diodes used in these studies have been epitaxial gallium arsenide mesa diodes, designed for varactor applications. It has been interesting to observe that receiver noise figure shows a significant dependence on local oscillator drive when using diodes. In fact, 0.5 mW per diode was found to be optimum in the balanced mixer case. Local oscillator drive is not so critical when klystrons are employed. The reasons for this dependence are quite clear, relating to the dependence of balance on local oscillator drive. The lack of criticality in the case of the klystron only serves to point up its inherent cleaner spectrum.

In the case of the unbalanced receiver, the inherent "noisiness" of the avalanche oscillator was readily apparent. On the average, receiver noise figures were 10 to 20 dB higher for diode oscillators when compared with klystrons for the same high-level local oscillator drive. It was interesting to note that optimum local oscillator drive for minimum receiver noise was quite low for the diode oscillator (30 - 50 microwatts). For the klystron local oscillator, optimum drive was found to be approximately 150 - 500 microwatts. When both oscillators were adjusted to give minimum noise figure, the receiver noise figure averaged 6 - 10 dB better for the klystron under optimum conditions. These results are felt to be consistent with first principles of crystal mixer performance and local oscillator noise. Data similar to that shown in Fig. 4 have been analyzed to determine the excess noise temperature ratio of diode oscillators assuming that the balanced mixer measurements eliminated all local oscillator noise, and, therefore, represented the ideal. The oscillator noise temperature ratio t' can be found from the expression:

$$F' = 10 \log \left[1 + \frac{t'}{N_{if} + t - 1} \right]$$

where F' = excess receiver noise figure due to local oscillator noise

N_{if} = if amplifier noise ratio

t = mixer crystal noise temperature ratio

Under these conditions, F' is found to be the difference between the receiver noise figure using a balanced mixer (7 dB) and the receiver noise figure using an unbalanced mixer and a diode oscillator (15 - 30 dB). Because the receiver noise figure suffers through increasing crystal mixer conversion loss when low local oscillator drive is employed, the determination of excess noise from the diode oscillators must take into account this additional dependence. The rapid increase in receiver noise figure with the klystron local oscillator at low levels is a manifestation of the crystal conversion loss degradation. Considering the excess noise temperature at a local oscillator drive of 0.5 mW, one obtains a value of t' = 1200 times. This may be interpreted that the noise output at this level is more than 30 dB above thermal noise. The situation can be improved somewhat rather simply by noting (Fig. 4) noise figure need not degrade at a local oscillator level as low as 65 microwatts. At this point the effective excess noise from the diode oscillator is down to 15.3 dB; which would still be unreasonable.

As a general observation, gallium arsenide avalanche diode oscillators exhibit good long-term frequency stability ($< 10^{-5}$). Preliminary measurements also reveal that substantial changes in ambient temperature do not seriously influence the stability of these devices.

Preliminary and limited operating life test on one unit has yielded over 800 hours with no degradation in output power and no perceptible change in frequency as determined by a precision wavemeter which can be used to read 1 MHz. Several thousand total hours have been accumulated on these devices and it is concluded that good life can be obtained providing the dc power dissipation does not exceed 0.4 watts.

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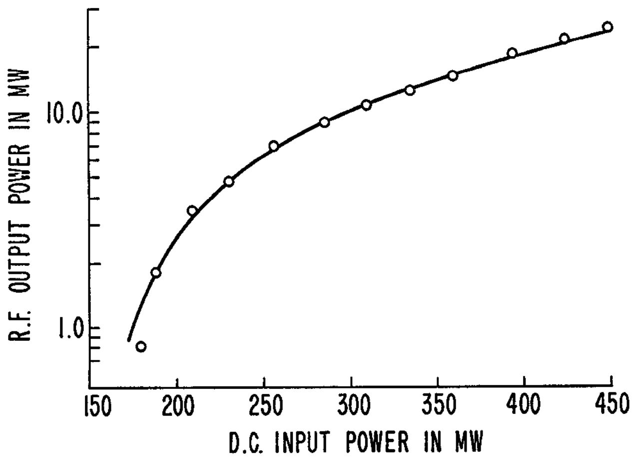

Figure 1. Output Power at 13.6 GHz vs. DC Input Power for GaAs Avalanche Diode Oscillator

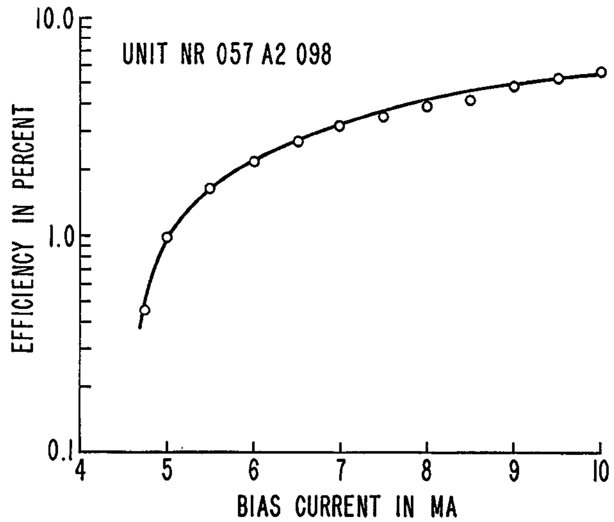

Figure 2. DC to RF Efficiency for GaAs Avalanche Diode Oscillator at 13.6 GHz, Plotted vs. Input Current

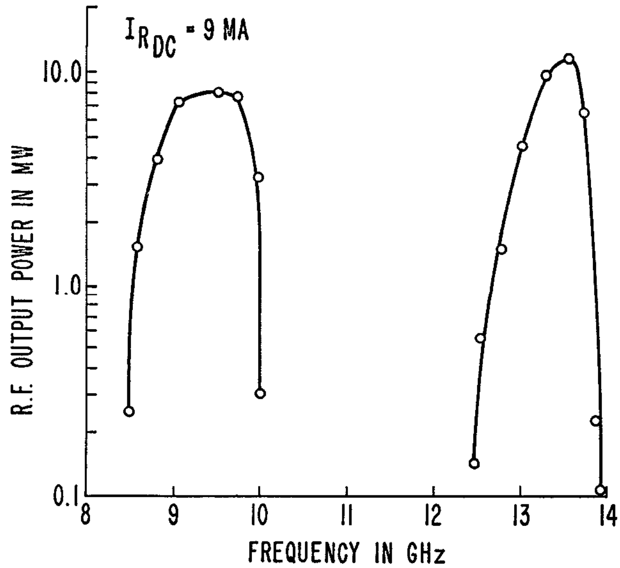

Figure 3. Tuning Range for GaAs Avalanche Diode Oscillator at a Fixed Bias Current of 9 mA

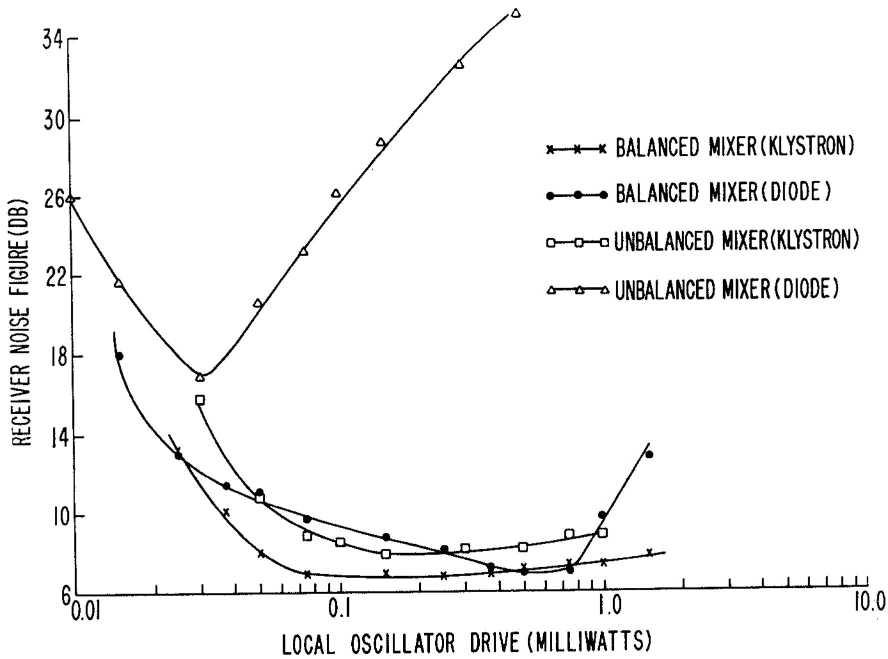

Figure 4. Receiver Noise Figure vs. Local Oscillator Power