POWER AND EFFICIENCY OF IMPATT OSCILLATORS*

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SUMMARY

This paper presents results on r-f power output and efficiency of IMPATT oscillators obtained from a large-signal model of these devices. The Large-signal model is obtained by solving the nonlinear equations which relate the current and voltage in a Read-type[1] IMPATT diode subject to the assumption that the transit time of the carriers through the drift region is small compared to the r-f period. The solution gives the current injected by the avalanche into the drift region as a function of the r-f voltage across the diode. From this result the external circuit current at the fundamental frequency of oscillation is found and is used to calculate the diode impedance. The results and conclusions which can be drawn from this analysis are summarized below.

Figure 1 is a plot for a typical diode of the resistance and reactance as a function of frequency for several values of r-f oscillator voltage. As expected, the large-signal impedance reduces to that obtained by Gilden and Hines[2] at small values of the r-f voltage. Figure 2 shows the dependence of diode resistance and power output as a function of the r-f voltage for several values of bias current. As the r-f voltage is increased the negative resistance of the diode decreases leading to a condition of stable oscillation for a fixed load resistance. Small-signal theories of IMPATT diodes predict that the impedance curves should shift up in frequency as $I_d^{1/2}$ where I_d is the bias current. However, as the bias current is increased the r-f voltage grows and therefore the impedance does not change as predicted by small-signal theory. This results in a marked change in the tuning behavior predicted from small-signal theory and has been discussed elsewhere[3].

The power and efficiency (for V_B = 30 volts) vs. frequency for an IMPATT diode are shown in Fig. 3, for several values of load resistance. Notice that for a fixed bias current the power output

* This work is being supported by the Rome Air Development Command under Contract F30602-68-C-0043. It was initiated under a grant from Omni Spectra, Inc., Farmington, Michigan.

is not a maximum at the avalanche frequency[2]. This occurs because of the increase in transit angle as the frequency is increased. On the other hand, as the frequency is increased the shunting effect of the depletion layer capacitance reduces the power output. Figure 4 shows the power output as a function of the bias current for several values of load resistance. From these curves it can be seen that the power output is a maximum, for a given frequency, when the avalanche frequency equals the operating frequency.

From Figs. 3 and 4 it is apparent that the power output is strongly dependent on the series load resistance. Figure 5 shows this relation explicitly for several values of the bias current. The small transit angle approximation is made in obtaining the avalanche injected current but not in calculating the phase delay of the external circuit current which is caused by carrier propagation through the drift region. Therefore, these results give at least a qualitative estimate of the behavior of diodes with a longer transit angle. For example, for a diode with a transit angle of 0.5π radians, a depletion layer capacitance of 1.0 pf, and an avalanche frequency of 5 GHz at a current density of 300 amps/cm^2, the negative resistance is found to be somewhat smaller than that given in Fig. 1. Under these circumstances a change in the series load resistance of 1-2 ohms has a significant effect on the power output as predicted by a plot similar to Fig. 5. Thus, the series bulk resistance of the diode can substantially reduce the power output of an IMPATT diode. Moreover, since this bulk resistance is a significant part of the load seen by the active part of the diode, the available power is further reduced. For the diode considered here with a load resistance of 0.5 ohms and a parasitic resistance of 2.5 or 0.5 ohms, the available power increases by a factor of 10, to about 1.0 watt for the latter case. These conclusions are consistent with the experimental results given by Kovel and Gibbons[4].

Under the conditions of fixed load resistance and increasing bias current it is interesting to plot the diode reactance. Figure 6 shows that a high value of series resistance results in a large change in diode reactance. Thus, if the diode is placed in a low Q circuit, low power output and substantial current tuning would be expected. Whereas in a high Q circuit, high power and little frequency tuning would be obtained. This behavior is observed experimentally.

LIST OF REFERENCES

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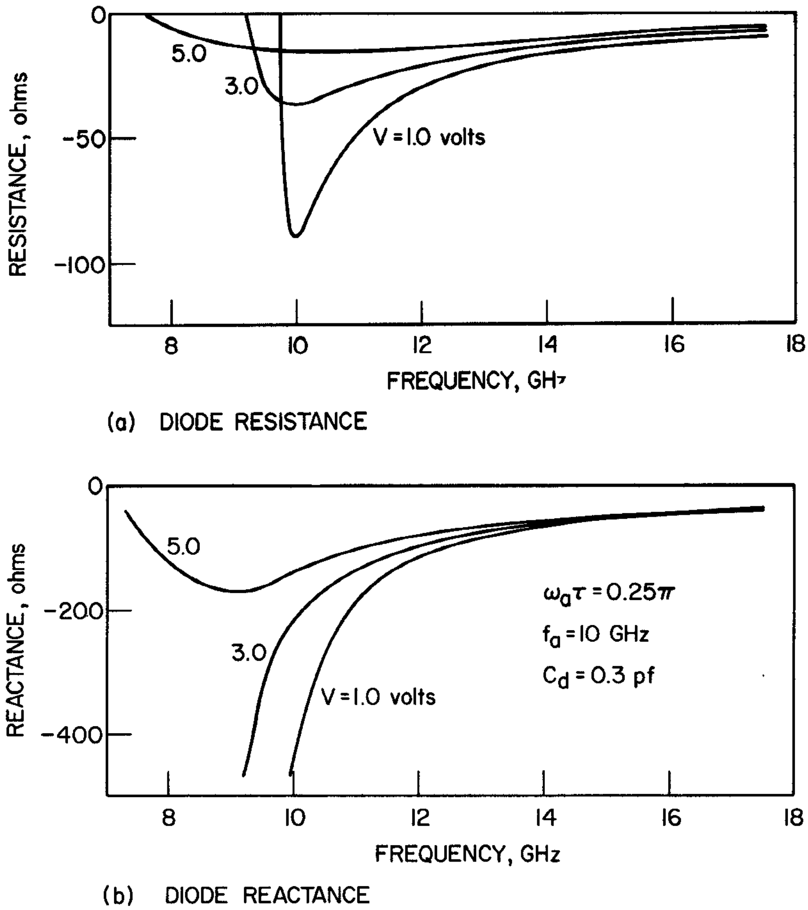

FIG. 1 DIODE IMPEDANCE VS. FREQUENCY FOR A BIAS CURRENT DENSITY OF 1200 AMPS/CM^2.

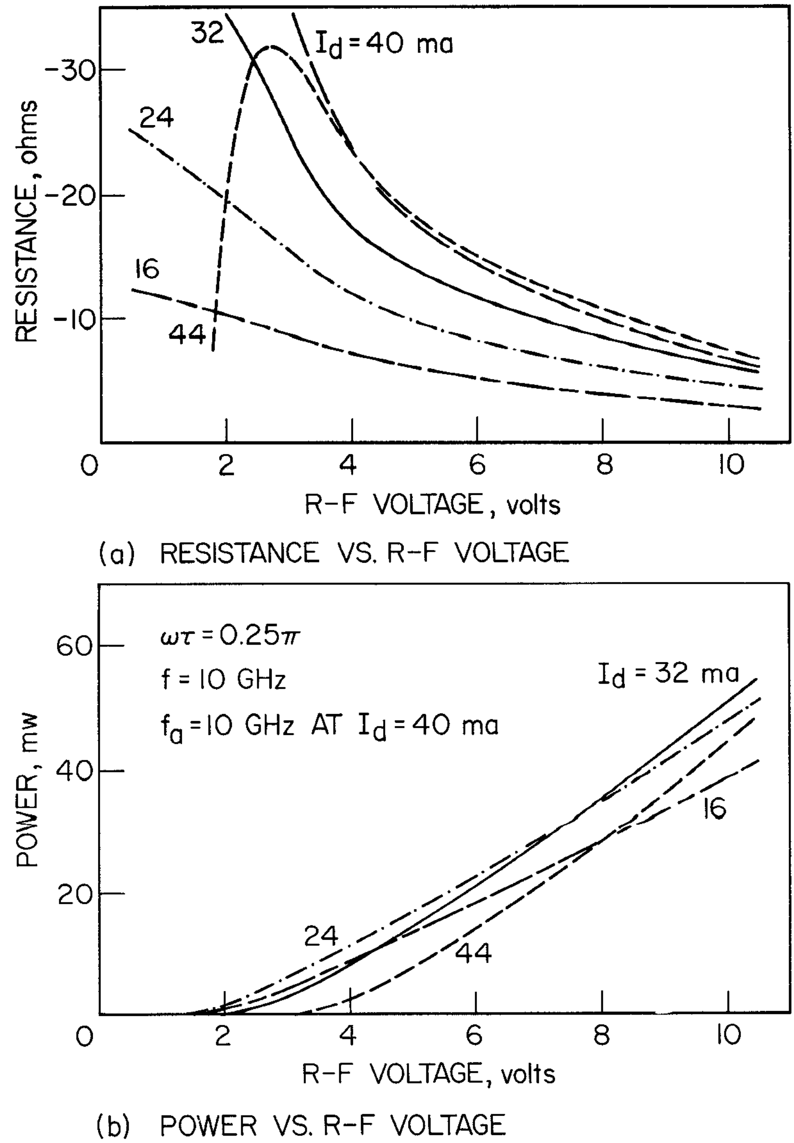

FIG. 2 RESISTANCE AND POWER VS. R-F VOLTAGE.

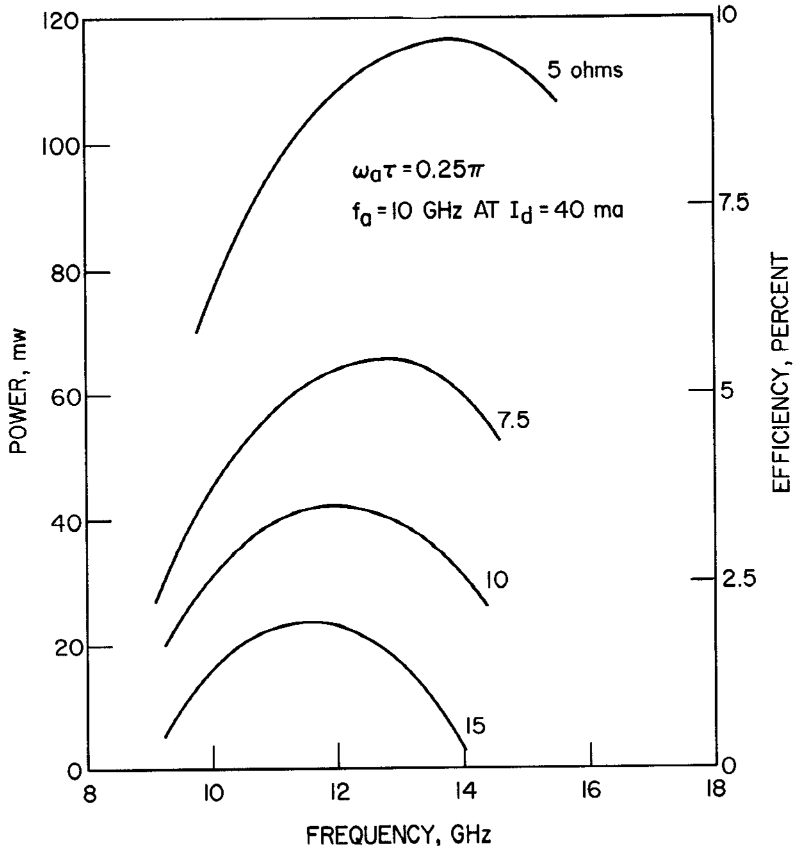

FIG. 3 POWER VS. FREQUENCY FOR FIXED LOAD RESISTANCE.

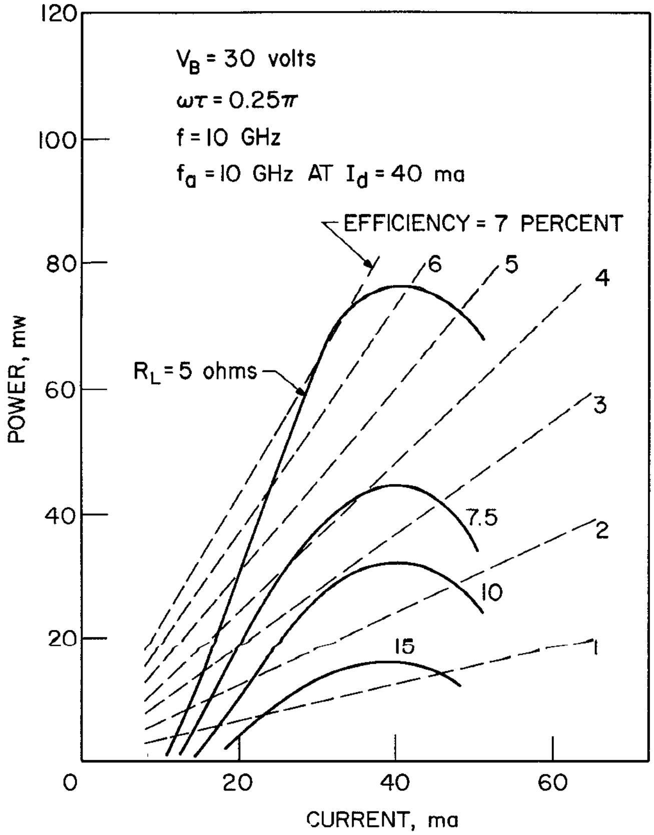

FIG. 4 POWER VS. BIAS CURRENT FOR FIXED LOAD RESISTANCES.

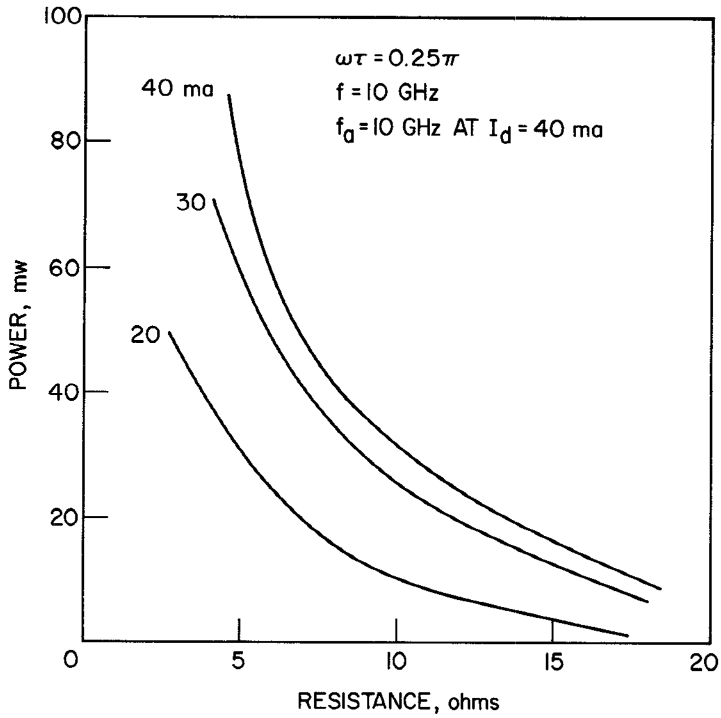

FIG. 5 POWER VS. LOAD RESISTANCE FOR FIXED BIAS CURRENTS.

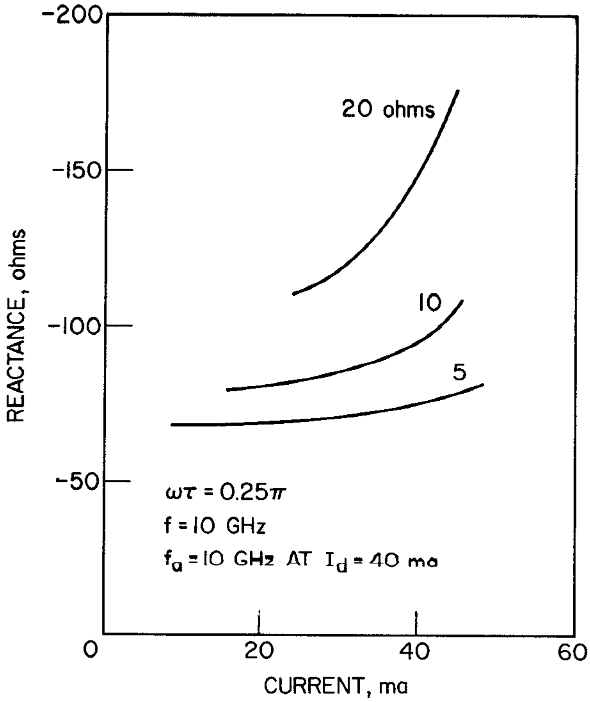

FIG. 6 REACTANCE VS. BIAS CURRENT FOR FIXED LOAD RESISTANCE.