CIRCUIT OPTIMIZATION OF S-BAND TRAPATT OSCILLATORS*

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Abstract

Improved performance of S-band TRAPATT oscillators has been obtained by circuit optimization techniques. Experimental conversion efficiencies approaching the theoretical predictions have been obtained for n^+pp^+ oscillators. Significant improvement has also been obtained in the operation of p^+nn^+ diodes.

Introduction

In a recent report[1] it was shown that the dc-to-RF conversion efficiency of TRAPATT oscillators is dependent upon the extent of the voltage collapse experienced by the diode. It was also observed that the dc operating voltage and therefore the percentage of voltage collapse is determined primarily by the RF circuit. According to these observations, diodes with higher breakdown voltages should produce greater conversion efficiencies than diodes with low breakdown voltages when the diodes are operated in the same oscillator circuit. This behavior is related to the diode doping level in the depletion region and the experimental results agree well with the theoretical predictions. Based upon these conclusions it should be possible to optimize the TRAPATT oscillator performance by two methods: for operation in a given circuit a diode with an optimum structure can be selected, and for operation with a given diode an optimum oscillator circuit can be selected. This paper is concerned with the latter approach.

The circuit utilized in these experiments is a conventional slug-tuned coaxial circuit that selects the operating frequency by a low-pass filter located approximately a half-wavelength away from the diode. The RF circuit was modified by changing the characteristic impedance of the first slug in the low-pass filter and the coaxial line immediately adjacent to the diode. Tests were conducted to determine the optimum circuit configuration and the optimum circuit oscillator results were compared to the nonoptimum results.

Charging Capacitance Behavior

Evans[2] has shown that it is sometimes necessary to include extra charging capacitance in the immediate vicinity of the diode in order to get efficient oscillator performance. The extra capacitance is required since the 50-Ω line is not able to supply the large conduction current required when the diode voltage collapses.

To investigate this behavior the oscillator was operated with a series of slugs located directly over the diode. The characteristic impedances of the slugs were selected so that the extra charging capacitor had values ranging from 0 pF (i.e., the 50-Ω line) to approximately 9 pF. The results obtained for an n^+pp^+ diode are shown in Fig. 1. The 50-Ω line allows TRAPATT performance but since there is not enough charging capacitance the oscillator performance is degraded. An optimum performance condition occurs at approximately 1 to 2 pF. For capacitor values above 2 pF the RC time constant for the oscillator is too great and the diode voltage cannot collapse fast enough thereby degrading the oscillator performance. Increasing the size of the diode (Fig. 2) increases the amount of charge required. In this instance the 50-Ω line is less able to sustain TRAPATT oscillations than the previous example and even poorer performance results. Since the diode requires more conduction current the optimum performance point is shifted to a larger capacitance value (approximately 4.5 pF). Increasing the capacitor above approximately 5 pF again results in too great an RC time constant.

Low-Pass Filter Capacitance Behavior

Extending these experiments to the first slug in the low-pass filter provides the results shown in Fig. 3. If the capacitance is too small the reflection coefficient is too small and some of the harmonics of the fundamental are passed on to the microwave load, thereby degrading the oscillator performance. Similar results have been obtained and discussed by Evans[2] for TRAPATT oscillators operating at frequencies slightly below 1.0 GHz. If the first slug is too capacitive most of the microwave power is trapped in the cavity and very little power is passed on to the load. This type of behavior probably results in the most efficient voltage-current waveforms appearing across the diode since the higher harmonics of the fundamental are all trapped in the microwave cavity. However, since very little power is passed on to the load the measured efficiency is low. The optimum capacitor value is approximately 4.5 pF. As might be expected, the optimum capacitor value remains constant independent of the particular diode tested.

Comparison of Optimized and Nonoptimized Results

When the optimized oscillator results are compared to the nonoptimized behavior significant improvement is observed to exist (Fig. 4). At 2.2 GHz the maximum output power was increased from 16 W to 17.8 W and the maximum efficiency was increased from approximately 36 percent to 44 percent. The experimentally obtained efficiency is observed to approach the theoretical efficiency curve predicted from the computer results obtained by Lee et al.[3] for a 2-μm abrupt-junction Si n^+pp^+ diode. At a frequency of 3.5 GHz the results are even closer to the theoretical predictions (Fig. 5). At this frequency the RF power was increased from 13 W to 14 W and the maximum efficiency was increased from 30 percent to 37.5 percent. When these experiments were performed on a p^+nn^+ diode the results shown in Fig. 6 were obtained. At 2.2 GHz the RF power was increased from 9.6 W to 10.8 W and the efficiency was increased from 23 percent to 28 percent. In all of these measurements the pulse width was 1 μs and the duty cycle was 0.1 percent.

Conclusions

The use of a relatively straightforward optimization approach has resulted in significant improvement in the operation of S-band TRAPATT oscillators. By adjusting the critical values of the charging and filter

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capacitors it has been possible to obtain between 5 to 8 percent additional percentage points of efficiency, an increase of approximately 20 percent. The experimental results are observed to approach the theoretical limits obtained from detailed computer simulations.

References

1. Trew, R. J., Masnari, N. A. and Haddad, G. I., "Comparison of S-Band Silicon n^+pp^+ and p^+nn^+ TRAPATT Oscillators," Presented at the Cornell Conf. on Microwave Semiconductor Devices, Circuits, and Applications, Ithaca, N. Y., August 1973.

2. Evans, W. J., "Circuits for High-Efficiency Avalanche-Diode Oscillators," IEEE Trans. on Microwave Theory and Techniques, vol. MTT-17, No. 12, pp. 1060-1067, December 1969.

3. Lee, C. M., Haddad, G. I. and Lomax, R. J., "Computer Simulation of TRAPATT Oscillations in Si n^+pp^+ and p^+nn^+ Diodes," Presented at the Cornell Conf. on Microwave Semiconductor Devices, Circuits, and Applications, Ithaca, N. Y., August 1973.

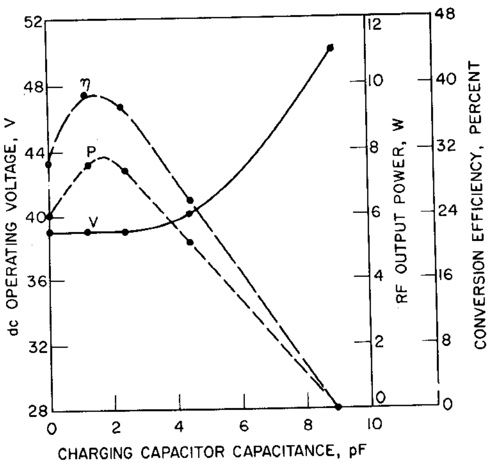

Fig. 1
Charging capacitor characteristics of the TRAPATT oscillator with an n^+pp^+ diode. (I_{dc} = 0.5 A, f = 2.1 GHz, diameter = 0.00476 inch)

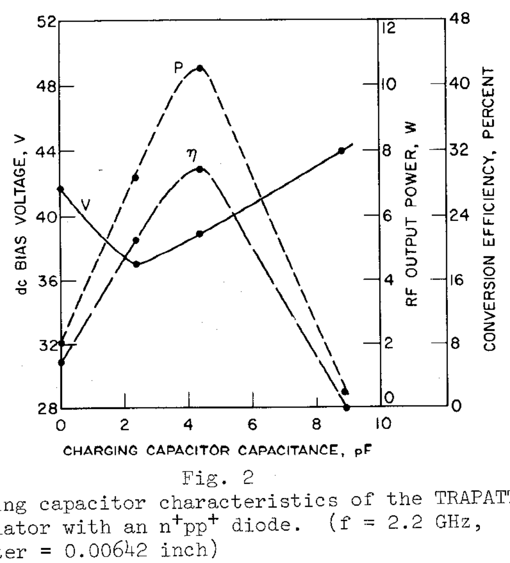

Fig. 2
Charging capacitor characteristics of the TRAPATT oscillator with an n^+pp^+ diode. (f = 2.2 GHz, diameter = 0.00642 inch)

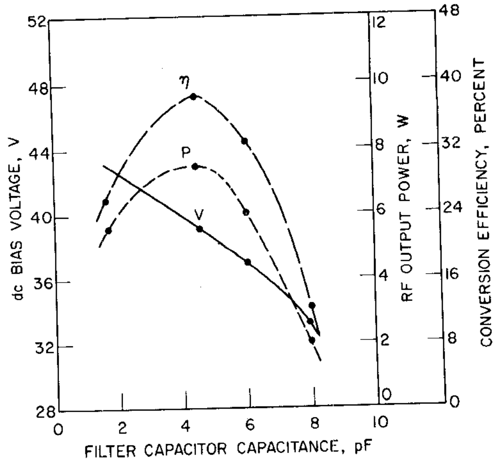

Fig. 3
Filter capacitor characteristics of the TRAPATT oscillator with an n^+pp^+ diode. (I_{dc} = 0.5 A, f = 2.2 GHz, diameter = 0.00476 inch)

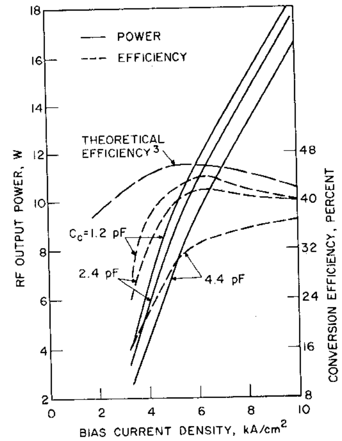

Fig. 4
TRAPATT oscillator power efficiency characteristics for an n^+pp^+ diode. (f = 2.2 GHz)

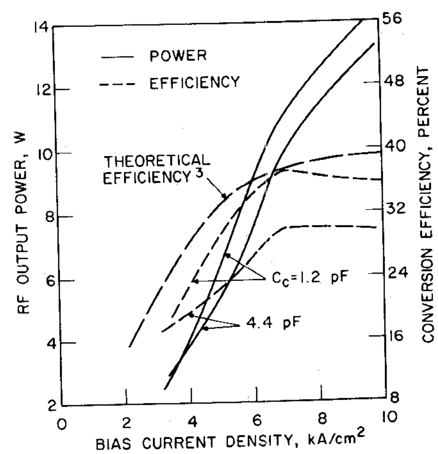

Fig. 5
TRAPATT oscillator power efficiency characteristics for an n^+pp^+ diode. (f = 3.5 GHz)

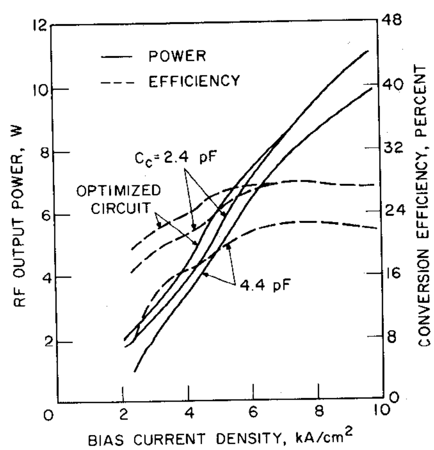

Fig. 6
TRAPATT oscillator power efficiency characteristics for a p^+nn^+ diode. (f = 2.2 GHz)