IMPEDANCE CHARACTERISTICS OF TRAPATT OSCILLATOR CIRCUITS

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Abstract

An accurate, closed-form analysis has been developed for calculating the harmonic matching impedance required for a time-delay-triggered TRAPATT oscillator. Quantitative agreement was obtained with experimental impedance measurements on an S-Band oscillator.

Introduction

The most commonly used TRAPATT oscillator is the time-delay-triggered[1] (TDT) circuit. A procedure has been developed for calculating the broad-band matching impedance required for a TRAPATT diode oscillating in the TDT mode. The results of this analysis have been experimentally verified for an S-Band TRAPATT diode in a TDT circuit. This analysis should enable the circuit designer to devise improved realizations for high-efficiency avalanche oscillators.

In a non-sinusoidal oscillator the terminating impedances must be controlled at each harmonic of the oscillation frequency to assure that the current and voltage waveforms at the diode terminals are consistent with the dynamics of the device. Previous TRAPATT analyses[2,3] calculated circuit harmonic impedances for only a single oscillating frequency, whereas experiment has indicated[1,4] that TRAPATT oscillators may be tuned over wide frequency ranges.

Analysis

This analysis predicts the harmonic impedances required to terminate a TRAPATT diode for high-frequency oscillations over a broad band of frequencies. The analysis is in closed form and accounts for the diode parameters and the characteristics of the package and circuit in which the diode is mounted. The current waveform in the model is a pulse with three distinct constant-amplitude segments plus a linear fall, as shown in Fig. 1. The amplitudes and durations of the three constant-current segments are influenced by both the diode properties and the amplitude and rate of change of the voltage transient reflected from the low-pass filter terminating the TDT cavity.

The first segment of the current pulse coincides with the diode charging and avalanche breakdown process. For a given diode and circuit, the time-delay-triggering mechanism results in a feedback process which constrains the initial constant-current segment of the diode current waveform to a single equilibrium value. This equilibrium value is calculated by an iterative technique combining a transient analysis of the diode package parasitics with the diode voltage response calculation. The voltage response during this phase of the oscillation cycle is calculated based on the method of Clorfeine[2]. After the avalanche breakdown and the formation of a low-resistance plasma, the current increases to a higher value. This high-current phase lasts until the available lumped-circuit capacitance in the vicinity of the diode is completely discharged. Then the current drops to the third level which is supported by the discharge of the distributed capacitance of the transmission line. The current remains at this level until the last of the remaining carriers is removed from the unsaturated velocity state. As this occurs, the voltage rises gradually towards breakdown, simultaneously causing the diode current to decrease. This model approximates the current fall with a linear ramp. As the current reaches zero, the voltage stops rising and remains constant until the reflected pulse from the previous breakdown transient triggers the diode into a new breakdown cycle. The transit time of this pulse determines the oscillator frequency.

The diode current and voltage waveforms are Fourier analyzed to obtain the complex impedance of the oscillator circuit at each harmonic. The parasitic reactances of the diode package and mount are included in the analysis to predict the impedance looking into the circuit from the diode reference plane. The fundamental frequency is varied in the calculation simply by changing the duration of the holding period. The complex circuit impedance of the harmonics is obtained directly from the frequency-dependent fundamental impedance without further calculation. This result holds for any oscillator in which the fundamental frequency f is varied only by changing the duration of a holding interval and not the shape of the voltage and current waveforms. It can be shown that in this case the impedance Z_n at the n^{th} harmonic of f is simply the fundamental impedance Z_1 evaluated at nf. That is,

$$Z_n(f) = Z_1(nf).$$

Thus, a single plot can contain the entire impedance information for a given TDT oscillator.

Figures 2 and 3 show calculated impedance curves for a hypothetical S-Band TRAPATT diode with a depletion-layer doping density of $2. \times 10^{15}$ cm^{-3} and a width of 2.2×10^{-4} cm and a junction area of 10^{-4} cm^2. The diode is assumed to be mounted in a 7-mm coaxial cavity with 50-ohm characteristic impedance. The resistive and reactive components of the circuit impedance are calculated as a function of frequency for three different values of package capacitance and also for the ideal case in which no package parasitics are present. These results are typical of most cases run: the reactance of the circuit at the diode terminals is capacitive at low frequencies; the circuit reactance remains capacitive through several harmonics (depending on the choice of fundamental) and reverses sign at a resonance determined by the package parasitics. The total circuit impedance is influenced more by the parasitic reactance of the package and mount than by the properties of the diode chip itself. The real part of the calculated circuit impedance remains positive over nearly the entire frequency range of these plots. A negative real part implies harmonic pumping and is thus not realizable with a passive load.

Experiment

Experimental results were obtained to validate the predictions of the analysis. A 50-ohm TDT oscillator circuit was constructed which was tunable from 2 to 3 GHz.

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The circuit was tuned to support high-efficiency oscillations at discrete frequencies in this band. For each oscillator frequency the circuit impedance as seen from the diode terminals was measured at all harmonics up to 12.4 GHz. The result is plotted in Fig. 4. Also plotted is a calculated reactance curve based on a characterization of the experimental diode, package and mount. The diode* doping density was 2.6×10^{15} cm^{-3}, the width was 2.7×10^{-4} cm, and the area was 1.24×10^{-4} cm^2. It is seen that the load impedance of the oscillator varied smoothly, as predicted, and that relatively good experimental agreement was obtained between the measured and calculated impedances. The results verify the basic TDT oscillator hypothesis that the shape of the diode voltage and current pulses can remain invariant when the cavity is retuned to change the duration of the holding portion of the cycle. The measured and calculated reactances tracked up to about 10 GHz. A resonance occurred at this frequency in both the measured and calculated cases. The measured real part of the impedance was within a few percent of the predicted value from 2 to 2.5 GHz.

Conclusions

A new calculation of the dynamics of the TRAPATT oscillation has provided the first closed-form impedance calculations in quantitative agreement with experimental impedance measurements for a TDT oscillator. The analysis is relatively simple and should have significant impact on the design of practical TRAPATT oscillator circuits by allowing the circuit impedance to be matched directly to the diode and its package parasitics.

*The diode was generously provided by Sperry Rand Research Center, Sudbury, Massachusetts.

References

1. W. J. Evans, "Circuits for High-Efficiency Avalanche Diode Oscillators", IEEE Trans. Microwave Theory Tech., vol. MTT-17, Dec. 1969, pp. 1060-1067.

2. A. S. Clorfeine, R. J. Ikola, and L. S. Napoli, "A Theory for the High-Efficiency Mode of Oscillation in Avalanche Diodes , RCA Rev., Sept. 1969, pp. 397-421.

3. B. C. DeLoach, Jr., and D. L. Scharfetter, "Device Physics of TRAPATT Oscillators", IEEE Trans. Electron Devices, vol. ED-17, Jan. 1970, pp. 9-21.

4. C. P. Snapp, "External Current-Waveform Measurements of High-Effiency Oscillations in Silicon Avalanche Diodes", Electron Lett., vol. 6, March 1970, pp. 145-147.

Acknowledgement

This work was sponsored by the Department of the Air Force.

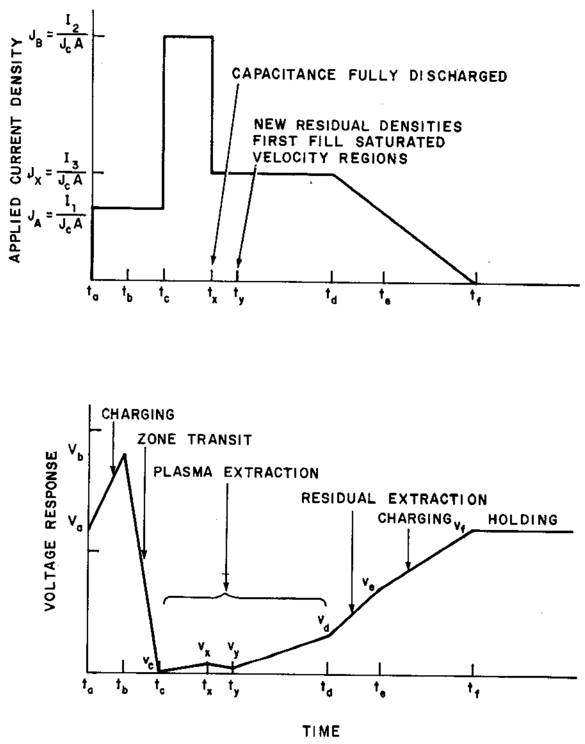

Fig. 1 Piecewise-linear approximations to TRAPATT current density and voltage waveforms.

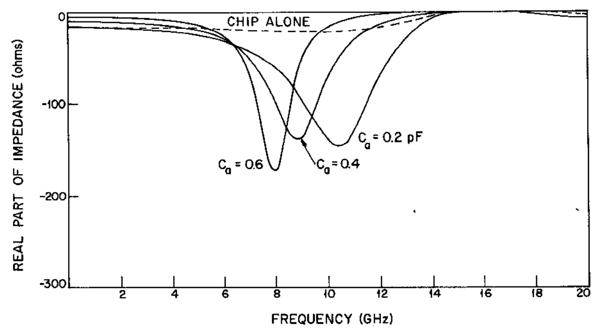

Fig. 2 Calculated resistance of TRAPATT diode circuit vs. frequency with package capacitance as a parameter.

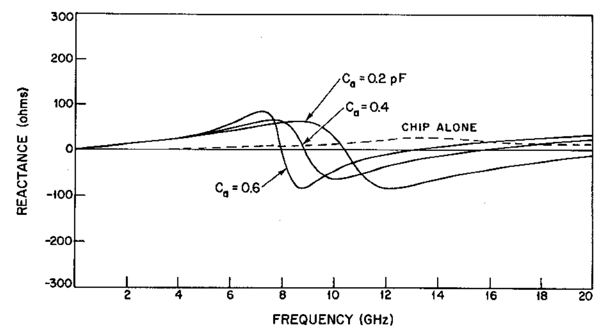

Fig. 3 Calculated reactance of TRAPATT diode circuit vs. frequency with package capacitance as parameter.

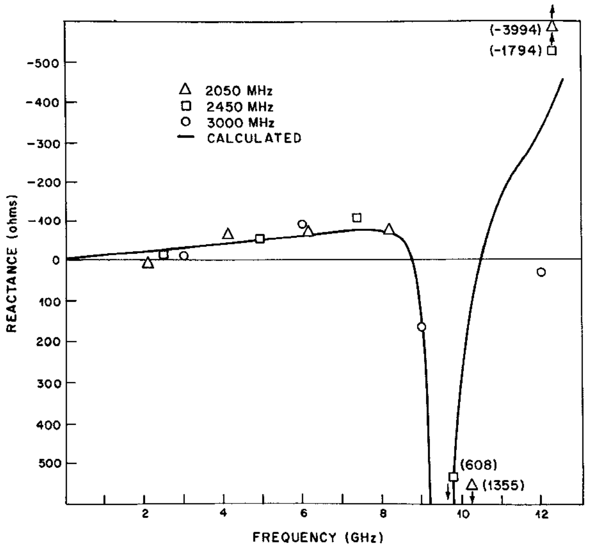

Fig. 4 Measured reactance of TRAPATT oscillator tuned to 2050, 2450, and 3000 MHz, and calculated reactance for experimental diode vs. frequency.