CIRCUITS FOR HIGH EFFICIENCY AVALANCHE DIODE OSCILLATORS

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SUMMARY

The purpose of this paper is to describe the characteristics of the circuits used to obtain the high efficiency TRAPATT* mode[1] of operation in avalanche diodes. A number of interesting facts about the nature of the TRAPATT mode can be inferred from the circuit analysis. The circuit analysis has also been used for the simulation of a complete 500 MHz TRAPATT oscillator on the computer. A computer-generated movie has been made which shows the operation of the simulated TRAPATT oscillator.

The simulation of the complete oscillator is very helpful in identifying the physical phenomena which lead to the TRAPATT mode of oscillation. Unfortunately, obtaining the complete solution of all pertinent equations is not practical for many parameter studies. However, a good deal of information about this mode of operation can be obtained by analyzing the circuit and using the results in connection with experimental measurements.

The oscillators to be considered here have been realized in coaxial form, similar to the 500 MHz TRAPATT oscillator shown in figure 1. Typically, the oscillator requires some impedance matching element near the diode (although this is not always necessary) and a bandpass filter

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*TRApped Plasma Avalanche Triggered Transit

NOTES

located about a half wavelength from the diode. The circuit shown in figure 1 can be disassembled at the point labeled A-A in the coaxial line. Thus, for a given operating point, the return loss looking into the filter formed by the four movable tuning sleeves can be measured. Figure 2 shows a comparison between the measured and calculated return loss for a particular set of tuner positions which cause the diode to operate in the TRAPATT mode. It is apparent that the filter couples the diode to the load very well at 500 MHz, whereas frequencies from 4 to 8 GHz are almost completely reflected. Since the coaxial filter does not reflect the 500 MHz oscillation, and calculations indicate the circuit Q to be very low at this frequency, the coaxial line cannot be considered a 500 MHz cavity. However, any high frequency (4-8 GHz) disturbance (such as an Impatt oscillation) is reflected with a transient delay equal to the period of the 500 MHz oscillation. These observations suggest that the TRAPATT oscillation is initiated by the build-up of large-signal Impatt oscillations.

In the case of the 500 MHz oscillator, the dc bias current density is typically less than 1000 A/cm^2. However, the current density required to achieve a trapped plasma state in these particular diodes is about 10^4 A/cm^2. Therefore, the high current, low voltage state can exist only for a small fraction of the 500 MHz period. The operation of the 500 MHz oscillator is thus expected to follow the following chain of events. A large voltage (e.g., twice the breakdown voltage) initiates a traveling avalanche which in turn leaves the diode in the trapped plasma state. This high current state lasts for a small fraction of the 500 MHz period and during this time the voltage drop across the diode is nearly zero. This drop in voltage (i.e., from the breakdown voltage to zero) propagates down the line and is reversed in sign by the high frequency short provided by the filter. Thus, a voltage pulse of approximately twice the breakdown voltage propagates back to the diode where the process repeats itself.

This description of the oscillator is easy to check by making probe measurements along the transmission line. A photograph of the voltage on the line, between the diode and the filter, is shown in figure 3. The sampling probe is located about 10 cm from the diode and 20 cm from the filter. The photograph shows that a large voltage pulse passes the probe, switches the diode into the high current (shorted) state, and returns to the probe as a drop in voltage.

The TEM structure used in these oscillator circuits is easily analyzed and as the data in figure 2 indicate give results which compare well with experimental measurements. Thus, it is possible to model the circuit down to the active region of the diode with a reasonable degree of accuracy. Then the driving point impedance at the TRAPATT frequency and its harmonics can be calculated. In addition, transmission loss, circuit Q, and transient response can be calculated. Thus, using the circuit analysis in conjunction with experimental measurements, the diode impedance and operating point can be studied as a function bias current or other diode parameters.

The complete oscillator has been simulated on a digital computer in order to identify the physical mechanisms which give rise to the TRAPATT mode of oscillation. The program which describes the nonlinear diode behavior was developed by D. L. Scharfetter and H. K. Gummel.[2] The circuit constraint for the time domain solution of the diode equations has been provided by characterizing the circuit seen by the diode in terms of an impulse response function. This technique allows one to use a very complete circuit model (15-25 circuit elements, including transmission line sections, were used for the simulation discussed here) with only a negligible increase in the computation time required to solve the diode equations alone.

ACKNOWLEDGMENTS

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REFERENCES

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2. D. L. Scharfetter and H. K. Gummel, "Large Signal Analysis of a Silicon Read Diode Oscillator", to be published, Trans. IEEE ED-16, Jan. 1969.

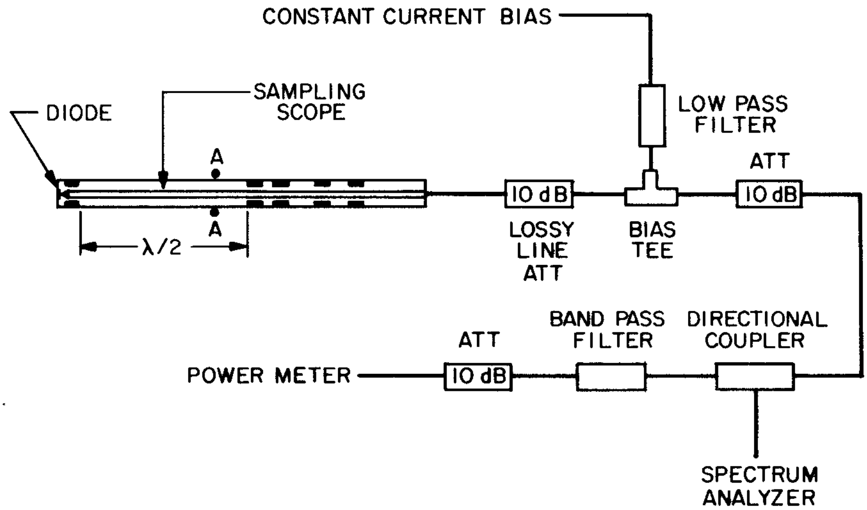

FIGURE 1

500 MHz OSCILLATOR

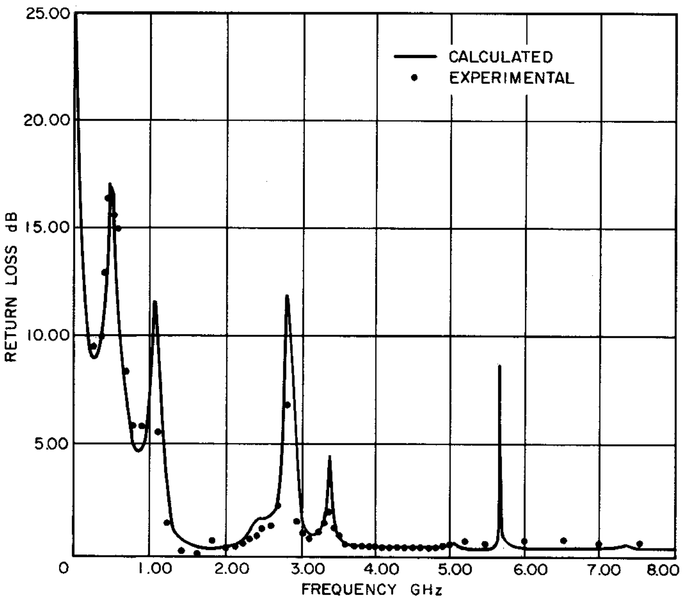

FIGURE 2

RETURN LOSS VS FREQUENCY - 4 SLUG TUNER

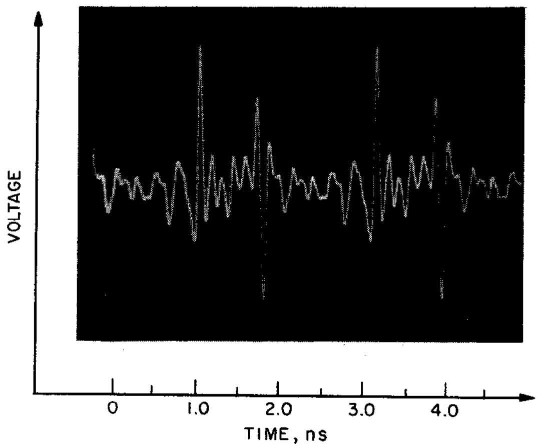

FIGURE 3

LINE VOLTAGE (PROBE 10 cm FROM DIODE)