COMPUTER-AIDED TIME AND FREQUENCY DOMAIN MEASUREMENTS OF TRAPATT DIODE OSCILLATORS

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Introduction

Because of the multiple frequency nature of TRAPATT diode oscillator operation, circuit optimization is accomplished experimentally, and critical adjustments are usually required for high efficiency operation. In the study reported here, both experimentally-optimized high efficiency and deliberately mistuned TRAPATT circuits were measured in the time domain by a computer-aided time domain automatic network analyzer (TDANA) specifically designed for this application. Time domain reflectometer (TDR) data was used to obtain both the circuit impulse response and circuit admittance as referred to the diode chip. By comparing the results for both optimized and mistuned circuits, it is possible to obtain information on necessary circuit requirements for high efficiency operation.

TDANA

The block diagram of the TDANA[1,2] is shown in Fig. 1. The TDR used in the TDANA consists of the following commercially available items: Tektronix model 7S12 TDR/sampler plug-in, Tektronix model S-6 sampling head, Tektronix model S-52 pulse generator head, Tektronix model 7704 oscilloscope main-frame, semi-rigid transmission lines of T_1 = 25.35 nsec, and T_2 = 23.53 nsec. with a 0.635 cm. outer diameter, and a Microphase Corp. 6 GHz low pass filter.

The minicomputer used in the TDANA is the Data General Corporation's Nova system consisting of the model 1220 central processing unit, two tape units, two magnetic disks, a high-speed paper-tape reader, a 12 channel digital-to-analog converter (DAC) and an 8 channel analog-to-digital converter (ADC). Both converters are 12 bits over a plus to minus 5 volt range. The ADC conversion time is 24 microseconds with $\pm$0.015% $\pm$1/2 bit accuracy. The operating core memory size is 32K words. Also as a part of the total general purpose laboratory computing system is a teletype, Tektronix model 4013 CRT terminal, Tektronix type 611 storage display unit (used to display plots), Tektronix model 4601 hard-copy unit, and pulse generator that functions as an external clock for the ADC's and DAC's.

The minicomputer provides the capability of presenting the frequency domain data via the fast Fourier transform (FFT) as well as computing the necessary time and frequency domain corrections required to account for the TRAPATT diode package parasitic elements.

The TDANA specifications include a measuring time window of approximately 50 nanoseconds with a time resolution of 84 picoseconds, and a frequency range of 0 to 6 GHz with a frequency resolution of 23 MHz for 512 sample points. The paramenters computed included S_{11}, circuit admittance, and circuit impulse response of the admittance.

TRAPATT Oscillator Measurements

A simplified interpretation of the distributed TRAPATT oscillator circuit proposed by Evans[3] leads to the conclusion that the response of such a circuit to an impulse of voltage should be a series of positive going current spikes spaced by a time interval equal to the period of oscillation. One of the objectives of this investigation was to experimentally measure the impulse response of several optimally-tuned and deliberately-mistuned TRAPATT circuits and compare the results. Such information should be helpful in better understanding the circuit conditions that are necessary for high efficiency operation.

For convenience all experiments used the FD300 diode operating in the fundamental mode of power extraction. The average operating conditions of the diode were a pulsed bias of 0.7 ampere and 140 volts at a 0.1% duty cycle at an output frequency of 580 MHz. Efficiencies of up to 44% were obtained at peak RF output power levels of approximately 44 watts.

The TRAPATT circuit was of the Evans[3] type constructed in microstrip with either four or five tuning plates. For comparison purposes a TRAPATT circuit consisting of a commercial low-pass filter and line stretcher was also investigated.

Shown in Fig. 2 is an example of the reflected voltage in response to a step function, measured at the diode/circuit interface of a typical circuit that yields a stable TRAPATT oscillation. Three major capacitive discontinuities from the tuning plates are clearly in evidence. When this data is processed by the computer and referred to the diode junction through the inclusion of the diode package parasitics, the results as shown in Figs. 3, 4, and 5 are obtained. Figures 3 and 4 show the circuit admittance in the frequency domain while Fig. 5 shows the impulse response in the time domain. From the admittance plot we can observe that the fourth and higher harmonics are essentially open circuited, a condition that is consistant with the presence of a significant high-frequency content in the TRAPATT voltage waveform during plasma formation. The impulse response shows the expected periodic positive going spikes spaced at a time interval equal to the period of oscillation. Our studies have indicated that this is a necessary but not sufficient condition for high efficiency, stable TRAPATT operation; also of significance is the detailed variation of the impulse response between the major peaks. When different circuit configurations for both four and five tuners were adjusted for high efficiency operation, an impulse response very close to that shown in Fig. 5 was obtained in each case.

Figure 6 is the impulse response of the same circuit as in Fig. 5 except for a slight modification that produced a very noisey TRAPATT-like oscillation with a noise bandwidth of approximately 100 MHz. Both impulse responses exhibit the same periodic spikes and differ only in the fine structure between spikes. The frequency domain data for these two circuit conditions and two other similar unstable conditions are given in Table 1. Figure 7 gives a graphical presentation of the range of measured admittance values for several circuits which yielded stable TRAPATT oscillation. Only the fundamental, second and third harmonic frequencies are given since these three frequencies appear to have the most influence upon circuit performance[4]. For the third harmonic, only the phase of the admittance appears to be critical, which is in agreement with the results of Haddad et al.[5]

As a further comparaison, a TRAPATT-like circuit consisting of a commercial low-pass filter and line-stretcher was experimentally studied. When optimally adjusted, a poor quality oscillation was observed, with little voltage fall-back, and an efficiency of only 3.9%. The measured impulse response of this circuit is shown in Fig. 8. While this impulse response also exhibits positive spikes spaced in time by the period of oscillation, there are also two substantial negative spikes present, and the amplitude of the fourth "major" positive spike is smaller in amplitude than the adjacent positive spikes. To date, we have not observed high-efficiency oscillation from a circuit possessing these time domain characteristic.

Conclusion

Previous quantitative investigations of TRAPATT oscillator circuit requirements have focused primarily on frequency domain characteristics. These investigations have shown that a wide variety of circuit conditions can yield high-efficiency oscillation, and hence it has been difficult to specify quantitatively what are the minimum conditions for such operation. In this study an attempt was made experimentally to determine if the circuit problem could be simplified by viewing it in the time domain. Partial success was obtained in that for each case of high efficiency operation an impulse response was observed which consisted of a series of well-defined positive spikes spaced in time by the period of oscillation. It was also determined, however, that the fine structure of the impulse response between the major peaks was also of significance, and hence the circuit requirements as viewed in the time domain may not be simpler than those obtained in the frequency domain. The use of the TDANA approach for further comparisons of the impulse responses of a greater variety of TRAPATT circuits would shed more light on this problem and could ultimately lead to design criteria based predominantly on time domain considerations.

Acknowledgements

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References

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TABLE 1

Admittance (real part + imaginary part) in Millimhos for four different adjustments of a TRAPATT oscillator Circuit

Frequency - MHz	Stable Osc. Condition A	Noisey Osc. Condition B	Noisey Osc. Condition C	Noisey Osc. Condition D
Fundamental - 576	17.7-j9.47	12.0-j5.40	34.2+j18.3	14.7-j7.62
2nd Harmonic - 1152	39.5+j12.3	27.0+j31.0	32.4-j10.3	13.9+j24.0
3rd Harmonic - 1728	8.15+j15.5	6.74+j12.7	5.03+j9.22	20.2+j26.3
4th Harmonic - 2304	8.56+j12.4	5.67+j9.61	4.11+j6.64	5.03+j7.95
5th Harmonic - 2880	7.17+j11.3	3.91+j8.47	2.79+j5.38	3.49+j7.01
6th Harmonic - 3456	5.86+j7.69	3.80+j5.36	2.33+j3.22	2.91+j4.20
7th Harmonic - 4032	4.01+j4.28	2.50+j3.02	1.83+j1.35	2.09+j3.17
8th Harmonic - 4608	2.92+j5.07	2.07+j3.33	1.45+j1.50	4.02+j2.72

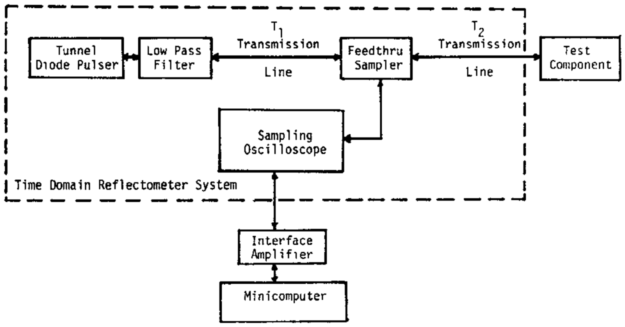

Fig. 1. TDANA basic block diagram.

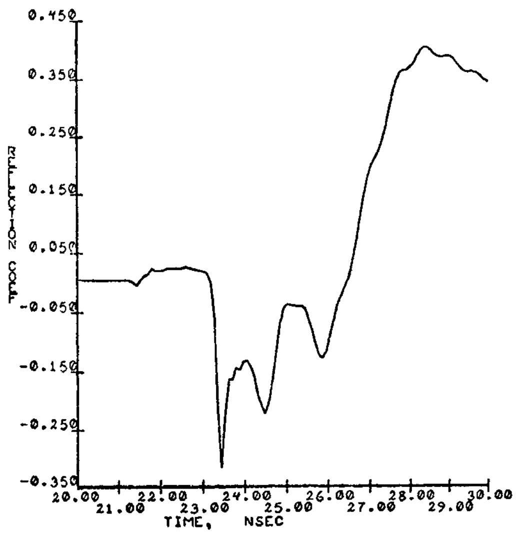

Fig. 2. Reflected voltage from TRAPATT diode oscillator circuit, Condition A.

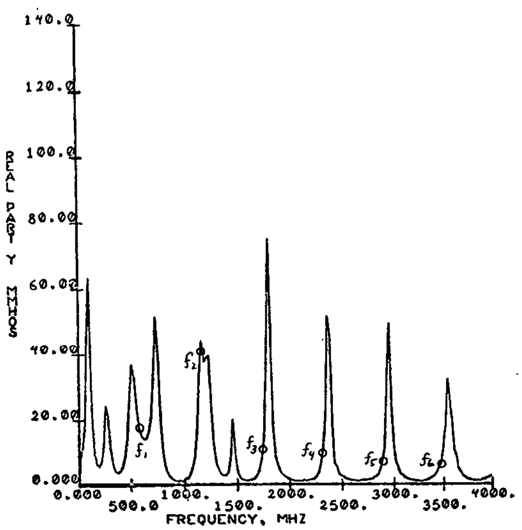

Fig. 3. Real part of the admittance at the diode junction for TRAPATT diode oscillator circuit, Condition A.

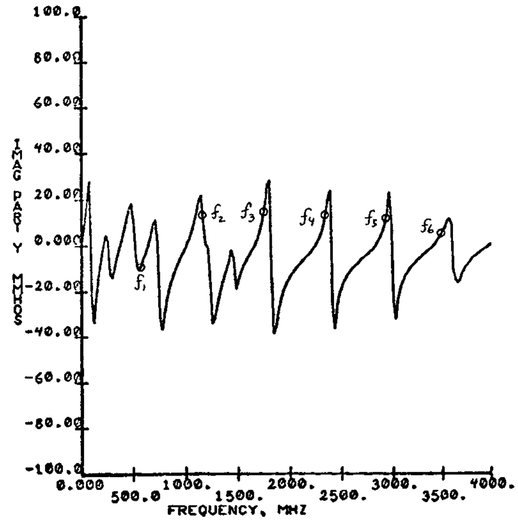

Fig. 4. Imaginary part of the admittance at the diode junction for TRAPATT diode oscillator circuit, Condition A.

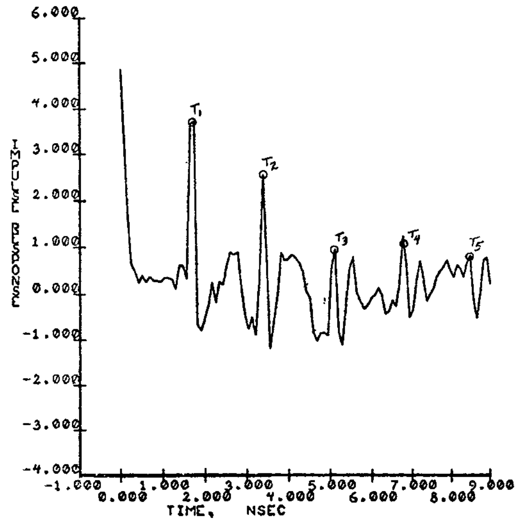

Fig. 5. Impulse response of the admittance at the diode junction for TRAPATT diode oscillator circuit, Condition A.

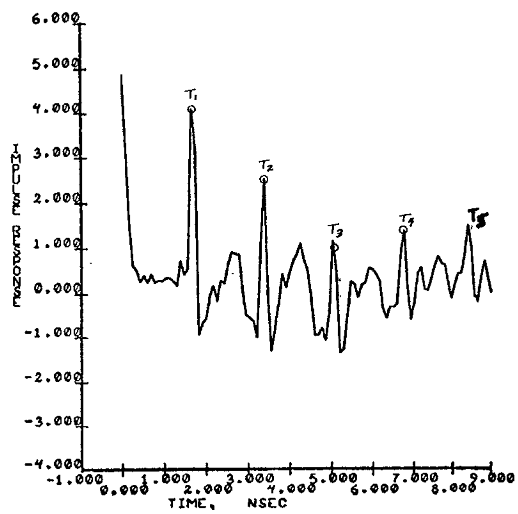

Fig. 6. Impulse response at the diode junction for a noisey TRAPATT diode oscillator circuit, Condition B.

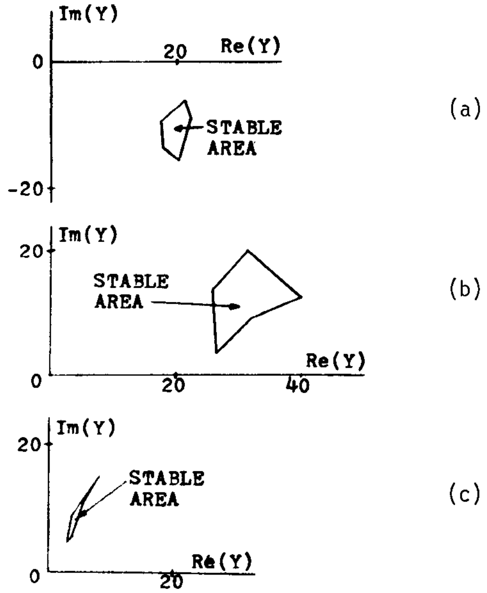

Fig. 7. Measured admittance range for stable oscillation at (a) fundamental and (b) second and (c) third harmonic frequencies. (All values are in millimhos.)

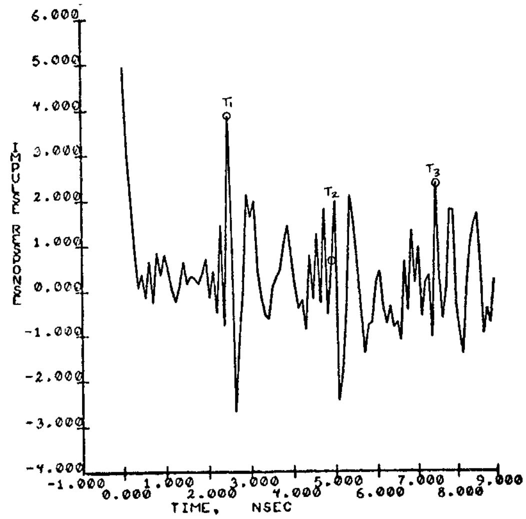

Fig. 8. Impulse response of the admittance at the diode junction for a low-pass filter/line stretcher circuit.