NUMERICAL TECHNIQUES FOR TRAPATT CIRCUIT ANALYSIS AND DESIGN

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Abstract

Four numerical techniques used in conjunction with a simple diode model are described for the analysis of TRAPATT circuits. Some of these techniques require minimal computer time and hence appear promising for design purposes.

Introduction

At the present time, most if not all of the approaches to TRAPATT oscillator and amplifier circuit design have been of an experimental or empirical nature. One of the major reasons for the relative lack of analytic design procedures is the highly nonlinear nature of TRAPATT operation. This gross nonlinearity creates difficulties in characterizing the diode and circuit interaction in simple terms. Recently, an approximate diode model was proposed as a vehicle for so characterizing TRAPATT operation.[1] In this paper several numerical techniques for solving the diode-circuit interaction with this model are described and compared. Examples are given of TRAPATT circuits which are easily analyzed by these techniques.

The Diode Model

Because of the highly nonlinear nature of TRAPATT diode action, a time-domain model of the diode is utilized. This model, shown in Fig. 1, is derived from the theory of Clorfeine et al[2]. The momentary closing of the switch models the rapid voltage drop during avalanche shock front transit, and is consistent with the current pulse model proposed by Evans[3]. The nonlinear capacitance models both the plasma extraction and the passive diode depletion-layer capacitance.

Numerical Techniques

Four different numerical techniques were implemented to solve the diode-circuit interaction problem; these are listed in Table I. The impulse response technique is as reported by Evans and Scharfetter[4]. To utilize this technique, the TRAPATT circuit admittance must be known as a function of frequency. From this admittance function the circuit impulse response is obtained by computing its inverse Fourier transform, using the Fast Fourier Transform (FFT) algorithm. The circuit current is then obtained by convolving the impulse response with the voltage history of the diode. The simple differential equations describing the diode model of Fig. 1 are solved using a predictor-corrector method.

This numerical method is a very general approach, suitable for both lumped and distributed circuits; however, the large amount of computer time involved detracts from its usefulness as a tool for TRAPATT circuit design. For example, to accurately characterize a typical two-slug TRAPATT circuit would require about 12,000 values of the impulse response. Approximately 24 msec would then be required at each time step to evaluate the convolution integral using an assembler language subroutine optimized for fast execution on an IBM 360/75 computer. The total computation time required to solve such a circuit by this method would approach 10 minutes.

The reflected wave technique[5] (more precisely called the method of characteristics) is another approach to time domain simulation, and is one which requires substantially less computation time than the impulse response technique. This method is useful if the circuit contains transmission lines; however the technique can be implemented with a circuit containing some lumped elements. The admittance function of the network is not required in this approach. Instead, all voltage waves transmitted from all junctions of transmission line sections are stored in the computer to describe the state of the circuit. The circuit is, therefore, directly characterized in the time domain. The equations representing the diode model are again solved by means of the predictor-corrector technique.

As an example of the accuracy and utility of this approach to the analytic treatment of TRAPATT circuits, the conventional double-slug circuit described by Snapp[6] was simulated using the reflected wave technique and a simple diode model very similar to that shown in Fig. 1. A stable simulation was obtained which agrees quite well with results reported by Snapp; the results of this simulation are shown in Fig. 2. The computation time involved was only 1.5 msec per time step, yielding a total computation time of approximately 40 sec, compared to 10 min. for the same simulation using the impulse response approach.

The third numerical approach, the hybrid time-frequency domain technique, requires even less computation time. This approach is not a true time domain simulation, for strict periodicity is enforced a priori. However, its simplicity and rapidity made it attractive. The procedure is an iterative technique to find a set of waveforms which simultaneously satisfy the diode model equations in the time domain and the network equations in the frequency domain. For example, an estimate of the diode current waveform in the time domain is applied to the diode model, resulting in a diode voltage waveform in the time domain. The FFT is then used to determine the Fourier components of voltage, which are multiplied by the network admittance values at the harmonics to obtain Fourier components of network current. Again the FFT algorithm is used to obtain a time domain waveform of current, which is then used to update the previous diode current waveform. This procedure is repeated until convergence is obtained. For the two-slug circuit of Snapp mentioned above, the computer time required to reach a stable solution was about 8 sec.

The fourth numerical technique is the simplest approach, for the diode current waveform is specified a priori, instead of specifying the circuit a priori, and the FFT is used to obtain Fourier components of both current and voltage. The ratio of these components then yields the negative of the required circuit impedances at the various harmonic frequencies.

As a simple example of this fourth numerical technique, we can assume a diode current waveform which consists of the fundamental component and third harmonic component of a square wave; all other harmonics are assumed open-circuited. The diode current and voltage waveforms are shown in Fig. 3 for such a simulation based on the FD 300 diode. The calculated circuit impedances at f_o and $3f_o$ are 63 + j1 ohm and 45 - j28 ohm, respectively. The computed power output was 51 W at an efficiency of 54%; the time of computation was 0.1 sec. Using this numerical approach, a TRAPATT circuit could be designed by devising an iterative routine which varied the input current waveform until the desired circuit characteristics were achieved.

1. Impulse response 2. Reflected waves 3. Hybrid frequency-time domain	Circuit known, determine waveforms
4. Assumed waveform	Waveform known, determine circuit

Table I Numerical techniques

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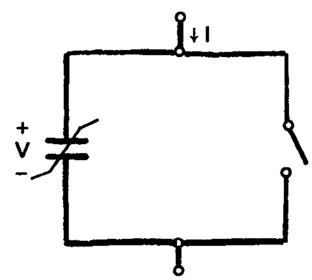

Fig. 1 Simple model of a TRAPATT diode

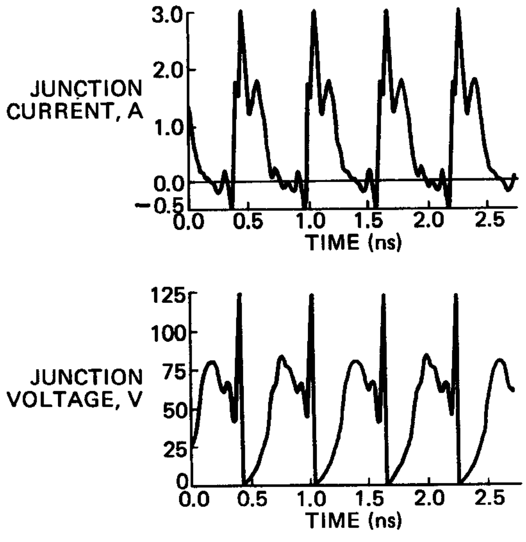

Fig. 2 Computer simulation of two-slug TRAPATT circuit using reflected wave numerical technique

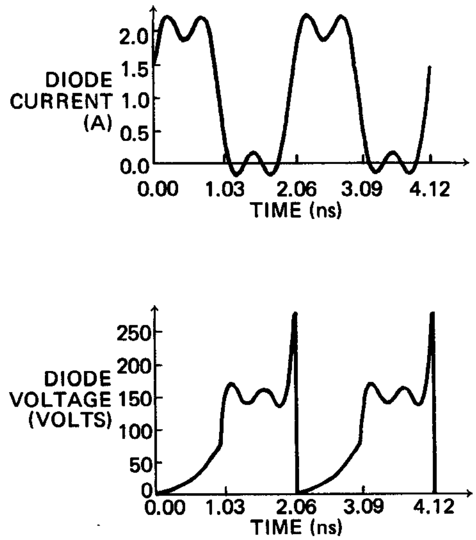

Fig. 3 TRAPATT current and voltage waveforms for two-harmonic approximation to square wave of current