THE DESIGN OF LUMPED-ELEMENT TRAPATT CIRCUITS

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Abstract

Using a simple diode model, computer simulations have been made which show that simple, all-lumped-element, high-efficiency TRAPATT circuits are feasible. Such circuits should possess greater bandwidth than conventional distributed TRAPATT circuits.

Most TRAPATT circuits which have been built to date have utilized distributed circuits, usually with approximately a half-wavelength of transmission line used between the diode and low-pass filter which passes the fundamental frequency but reflects higher harmonics. This type of circuit is simple to construct, is capable of high performance, and is satisfactorily explained to first order by the description first proposed by Evans[1]. On the other hand this type of circuit is inherently narrow band because of the closely spaced higher-order resonances which are present. In certain applications, such as in TRAPATT amplifiers, this characteristic is a significant liability, hence alternate circuit configurations are of interest.

Unfortunately, the simple description given by Evans to explain TRAPATT circuit operation does not offer much guidance in the search for alternate circuit configurations. Specifically, this approach does not facilitate the design of simple, all lumped-element high performance TRAPATT circuits. Such lumped-element circuits could have superior bandwidth capabilities and hence be of technological importance.

The question of whether or not a high-performance, all lumped-element TRAPATT circuit can be built has now been answered in the affirmative by the recent work of Clorfeine, Prager, and Hughes[2]. A remaining question is how may such a circuit be best analyzed and designed. In principle, this latter question could be answered by utilizing extensive computer programs describing large-signal TRAPATT diode behavior, such as described by Evans and Scharfetter[3]; however, the rather large computation time involved in these calculations makes their use for circuit design highly problematic. An alternate approach which appears promising is to use a simple approximate model of a TRAPATT diode[4] in conjunction with simple numerical techniques which model the diode-circuit interaction. In this fashion computation costs can be reduced to the point where it is feasible to implement search routines for circuit optimization similar to those now in common use in microwave transistor amplifier design.

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The simple diode model used, shown in Fig. 1, is derived from the theory of Clorfeine et al[5]. The momentary closing of the switch models the sudden voltage drop during avalanche shock front transit, and is analogous to the current impulse model proposed by Evans[1]. The nonlinear capacitance models both the plasma extraction and the passive diode depletion-layer capacitance.

One interesting lumped-element TRAPATT circuit that was designed with the aid of the simple diode model is shown in Fig. 2. The circuit consists of a dc biasing network and two series-resonant circuits connected in parallel. This circuit configuration allows the higher harmonics to be open-circuited, as required for the sudden voltage drop during avalanche shock front transit. The diode simulated was that used by Snapp[6] and reported previously in a distributed-circuit simulation[4].

The admittance of this circuit as a function of frequency is shown in Fig. 3a, while the impulse response is shown in Fig. 3b. It is of interest to note that the impulse response of this simple lumped circuit exhibits the strong periodic "reflections" normally associated with distributed TRAPATT circuits.

The computer simulation of the performance of this TRAPATT circuit is shown in Fig. 4. Note that the peak current obtained with this circuit is quite high, roughly four times the bias level, which experimentally is the case in many actual TRAPATT circuits. The computed power output of this oscillator is 22 w at an efficiency of 51%.

Our computer simulations indicate that other simple, lumped-element circuits are also capable of high performance. Shown in Fig. 5 is the result of a simulation based upon non-zero admittance at three frequencies. The diode modeled in this case is the Fairchild FD300. The circuit impedances at f_o, $2f_o$, and $3f_o$ are $51\Omega + j5.5\Omega$, $12\Omega - j15\Omega$, and $1\Omega + j1.6\Omega$, respectively; again higher harmonics are open-circuited. The computed power output is 7 w at an efficiency of 62%. This is a very interesting circuit because of its good match to 50Ω at the fundamental, and near short-circuit at the third harmonic. Also, in spite of a significant resistive component at the second harmonic, the efficiency is the highest of any we have achieved to date in our computer simulations.

In summary, we have shown by computer simulation that lumped-element TRAPATT circuits of high performance are possible. We have also shown that there does not appear to be a single, unique circuit configuration for such operation. One circuit which yielded high efficiency had the third harmonic (and all higher harmonics) open-circuited, while a second high-performance circuit had the third harmonic essentially short-circuited (with higher harmonics again open-circuited). Finally, we have shown that significant resistive loading of a harmonic is not necessarily incompatible with high efficiency operation.

References

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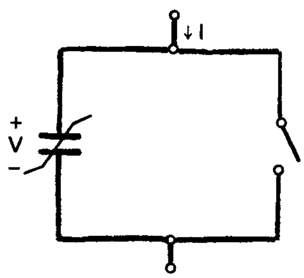
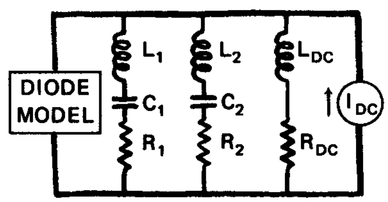


FIG. 1 SIMPLE MODEL OF TRAPATT DIODE



L_1 = 28.2 nH	L_2 = 17.4 nH	L_{DC} = 100 nH
C_1 = .326 pF	C_2 = .132 pF	R_{DC} = 1000 Ω
R_1 = 29.4 Ω	R_2 = 36.4 Ω	I_{DC} = .780 A

FIG. 2 A PROPOSED SIMPLE, LUMPED-ELEMENT TRAPATT CIRCUIT

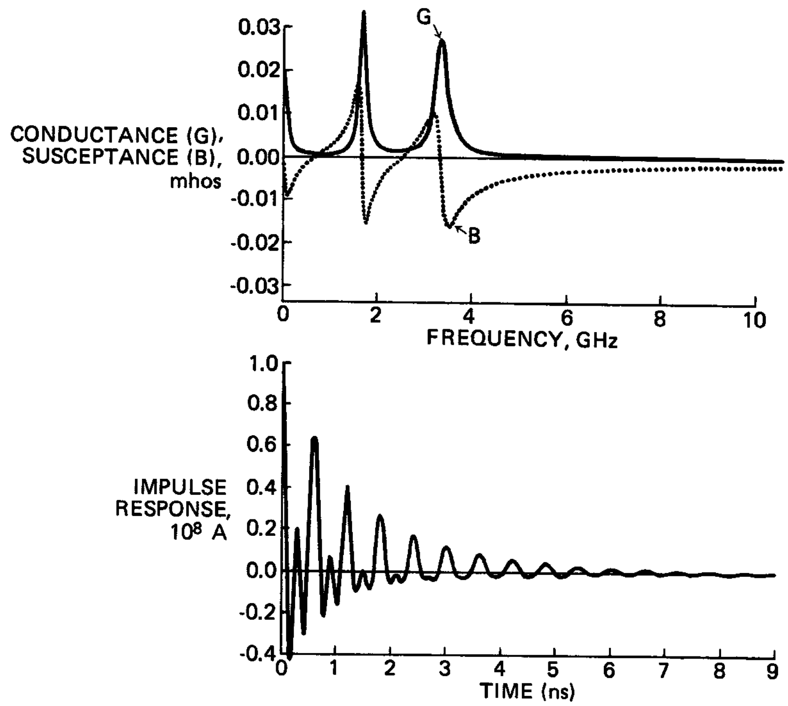


FIG. 3 ADMITTANCE FUNCTION AND IMPULSE RESPONSE OF THE CIRCUIT OF FIG. 2

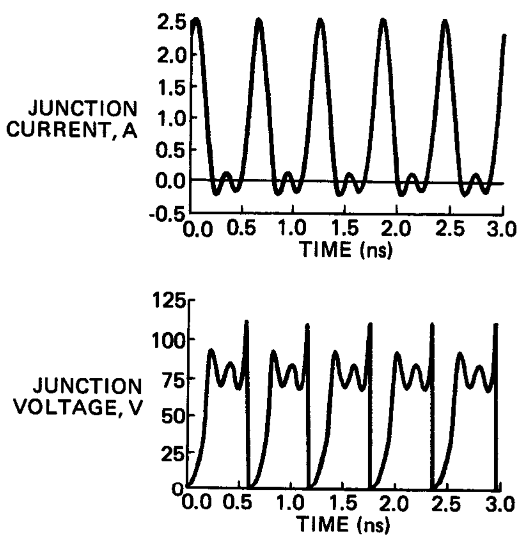


FIG. 4 CURRENT AND VOLTAGE WAVEFORMS FOR THE TRAPATT CIRCUIT OF FIG. 2

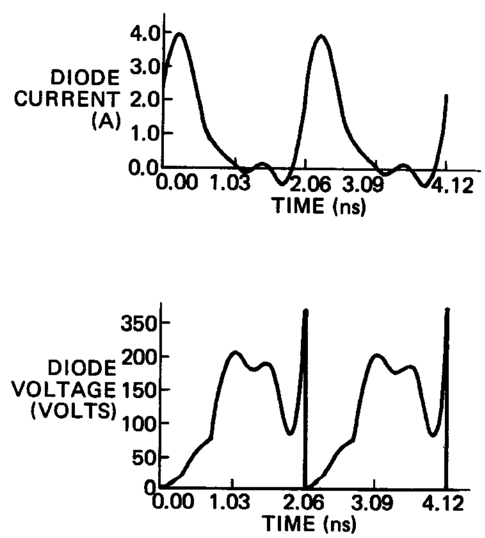


FIG. 5 CURRENT AND VOLTAGE WAVEFORMS FOR LUMPED-ELEMENT TRAPATT CIRCUIT WITH NEAR-SHORT-CIRCUIT AT THIRD HARMONIC