IX. SOLID-STATE MICROWAVE ELECTRONICS*

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RESEARCH OBJECTIVES

Our research objectives include developing fundamental performance limits and designing optimum imbedding networks for diodes in high microwave applications such as mixers, frequency multipliers, parametric amplifiers, and avalanche transit-time devices. These aims form the background for extending communications research to higher and higher frequencies and involve diode functions that are not likely to be replaced by digital circuits in the foreseeable future.

During the coming year, we shall continue our low-noise solid-state millimeter-wave receiver development and our work on avalanche diode amplifiers. We also plan to investigate frequency modulation methods for avalanche oscillators and dynamic stability in broadband frequency multipliers.

Theoretical analysis (both analytic and numerical) of the anomalous avalanche oscillator will continue. Various modes of operation will be investigated and design criteria established.

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A. SMALL-SIGNAL AVALANCHE DIODE EQUIVALENT CIRCUIT MODEL

Small-signal, or "incremental," models for nonlinear devices aid in circuit design and provide a means for developing theoretical performance limits. We propose a four-element incremental model for the avalanche region of a microwave negative resistance diode and a simplified method of obtaining the element values.

The four-element model, which contains frequency-independent, bias-dependent elements, predicts the same frequency behavior as the Gilden-Hines[1] model if one degree of freedom is eliminated, and provides a better fit to measured incremental impedance data. It was derived initially by fitting a generalized admittance with four degrees of freedom to measured incremental admittance data taken on a microwave negative resistance diode over the frequency range 4-10 GHz and over the current

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range 0-80 mA. The incremental admittance of the diode junction was recovered by analytically "de-imbedding" the junction.

The proposed circuit model is shown in Fig. IX-1. If the time constants R/L and C/G are set equal to each other, thereby eliminating one degree of freedom, then the impedance of the circuit of Fig. IX-1 has the same frequency behavior as the Gilden-Hines model derived from consideration of the physical processes of avalanche breakdown and carrier drift. Equivalance of the two models then results in three equations

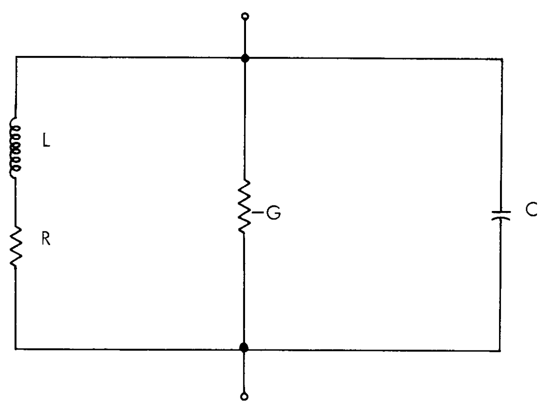

Fig. IX-1. Small-signal model for an avalanche diode.

relating the measured element values to the physical constants of the theoretical Gilden-Hines model. The most interesting relationship is that τ, the carrier transit time through the drift region, is equal to 2RC, although this relationship has not yet been verified experimentally. The assumption L/R = C/G is a good one, since the curve-fitting analysis retaining all four degrees of freedom shows that these two time constants are within 10% of each other for values of bias above 25 mA.

The proposed technique for characterization of the equivalent circuit consists in low-frequency measurement of C, possible low-frequency measurement of R, microwave measurement of the "avalanche frequency," and calculation of G from $G \approx \frac{RC}{L}$. Since C is very nearly the junction depletion layer capacitance at avalanche breakdown and is bias-independent, it can easily be measured on a capacitance bridge at 1 mHz. Similarly, the diode resistance was measured as a function of bias current at 10 mHz on an R-X bridge and found to be very close to the value of R in the equivalent circuit. The determination of the avalanche frequency $\omega_a \approx 1/\sqrt{LC}$ as a function of bias requires plots of impedance against bias at several microwave frequencies, but does not require de-imbedding. This task is particularly easy if one has a network analyzer at his disposal. With the use of this characterization technique it will probably be discovered that L and G are strongly bias-dependent, while R and C are not.

The model presented here permits use of existing computer-aided circuit design programs that assume frequency-independent circuit elements.

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References

1. M. Gilden and M. E. Hines, "Electronic Tuning Effects in the Read Microwave Avalanche Diode," IEEE Trans., Vol. ED-13, No. 1, pp. 169-175, January 1966.