COMPUTER-AIDED SMALL-SIGNAL CHARACTERIZATION OF IMPATT DIODES

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INTRODUCTION The use of a general purpose digital computer to convert microwave impedance measurement data to useful forms and simultaneously correct for system errors was described in an earlier paper.[1] The method is applied to the small-signal characterization of germanium IMPATT diodes in the frequency range of 2.0 to 8.0 GHz in this paper. Since the equivalent circuit of the IMPATT diode is at least as complicated as equivalent circuits for other types of microwave diodes, the techniques demonstrated can easily be applied to other types of diodes.

DATA ACQUISITION AND REDUCTION The block diagram shown in Figure 1 represents the test set used. It consists of a network analyzer reflection test system and peripheral equipment used for biasing, readout, and diode mounting. The diode is mounted as a termination of a coaxial line for these small-signal tests. The diode holder thus consists primarily of two mating sections of 7-mm coaxial transmission-line. One section is a 10-cm air line which has a Rohde-Schwarz 7-mm connector on the diode end to provide a spring contact. The other section is a precision 7-mm connector which has been modified to hold the diode. Forced air on a finned heat sink provides cooling.

The IMPATT wafers being characterized in this fixture are mounted in a cylindrical microwave package which is 2.5 mm high and has a 2.5 mm diameter ceramic and cover mounted over a post on a 4.5 mm diameter base. The base is gold-plated copper. The reference impedances used to calibrate the test set and the diode mount consisted of (1) a silver short-circuit having the same dimensions as the diode package, (2) an empty diode package, and (3) a capacitor having the geometry of the diode package and formed by inserting a small ceramic disc between two gold plated pieces of brass. The silver short-circuit allows for the determination of the "excess" inductance.[2] The other two impedances are capacitors whose reference values are determined by measurement on a 30 MHz capacitance bridge. To calibrate the test set at a given frequency these reference impedances are placed sequentially into the diode holder at which time the test set is zeroed on the silver short and the values obtained from the capacitors are recorded for calibration input

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to the computer. A Z-matrix is then formed. Diode measurements under various bias conditions are made at this frequency by recording the concomitant phase and gain. The Z-matrix is used to find the diode terminal impedance.

DIODE MEASUREMENTS The small-signal equivalent circuit used by Misawa[3] and Gilden and Hines[4] is expanded to include package parasitics and is shown in Figure 2. This circuit shows the usual package capacitance, tape inductance, series resistance and junction capacitance of a packaged diode. To represent the avalanche process the two additional elements, the avalanche inductance and conductance, are necessary.[3,4] The values shown for the circuit elements are representative for a germanium IMPATT diode designed for oscillator service at 6.0 GHz. The package capacitance, C_{PK}, is the only element shown here that is not determined in the microwave test set. C_{PK} is determined by measurement on a 30 MHz capacitance bridge and its susceptance is subtracted from the terminal admittance before proceeding to find the other values of the circuit elements. Measurements at the various bias conditions will now be discussed.

Forward Bias Forward bias measurements are made at a current of 100 mA at which the junction capacitance, C_J, will have a negligible effect. The forward bias series resistance, R_{SF}, and L_C, the tape inductance, can be found from the real and imaginary parts of the impedance.

Reverse Bias ($V_R < BV$, $G_D \simeq o$, $L_D \simeq \infty$) With reverse bias voltages less than breakdown, the series resistance and junction capacitance both decrease in value as the voltage increases as is shown in Figures 3 and 4. These curves were obtained by averaging nine microwave measurements at each bias voltage. The nine measurements were spaced at 0.5 GHz intervals from 4.0 to 8.0 GHz. Within the spread of the measurements no frequency dependence was found. The solid line in Figure 3 shows the value of C_J as determined at 30 MHz, where the contributions of R_S and L_C are negligible. The error bars represent the one sigma limits on the microwave measurements across the band. The maximum value of sigma is 0.05 pF, demonstrating the validity of the test technique.

Figure 4 shows the microwave measurements of series resistance. It is in quadrature with the relatively high net reactance of L_C and C_J, so it is very difficult to measure accurately.

Thus the one sigma limits shown in Figure 4 for the series resistance are larger than those shown for C_J, but again the measurement accuracy is felt to be quite good since the maximum value of sigma is 0.2 ohms.

Reverse Bias ($V_R > BV$) With the diode biased into breakdown, the values of the avalanche inductance and conductance are found by making terminal admittance measurements for each bias current and frequency of interest. In order to extract the full equivalent circuit it is assumed that the values of R_S and C_J decrease by a negligible amount from their values at breakdown, R_{SB} and C_{JB} respectively.

For circuit design and diode evaluation purposes it is often convenient to consider the diode wafer admittance which includes the series resistance, junction capacitance, and the avalanche admittance. Values of wafer conductance and susceptance are plotted as a function of frequency in Figure 5 for a representative diode. Two current densities have been used and illustrate the variation of susceptance as a consequence of the avalanching inductance. In Figure 6 the avalanche inductance is plotted as a function of inverse current density for two different diodes at 6 GHz. The range of current density is from 100-350 A/cm^2. In a linear least squares fit the maximum deviation from a straight line is less than one percent. Analytically the avalanche inductance, L_D, is inversely proportional to current density.[4]

CONCLUSIONS Differences in diodes are evident from analysis of the computer output. Low efficiency performance can be anticipated by small values of negative conductance. More significantly, the relationships between current density, frequency, and maximum negative conductance are readily discernible. The wafer characteristics can be separated from parasitic elements and the external circuit. This helps to optimize and control the wafer geometry and the epitaxial material characteristics for operation in a specific frequency band.

Acknowledgements The authors wish to thank Mr. R. L. Frank and Mr. R. D. Mertz for assistance in numerous phases of this work. In addition, we thank our colleagues, Messrs. A. E. Bakanowski, H. M. Olson and D. R. Decker for their time in many valuable discussions.

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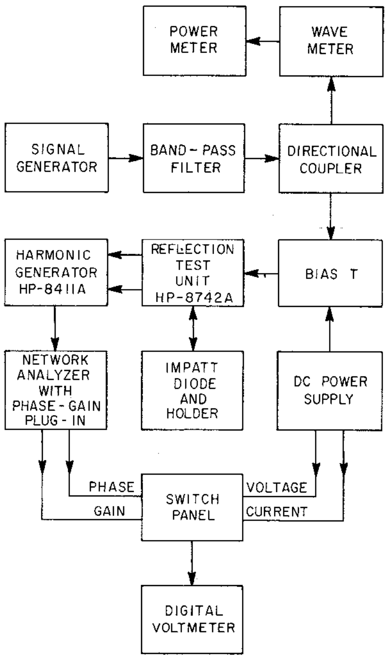

Figure 1. Block Diagram of Small Signal Characterization Test Set.

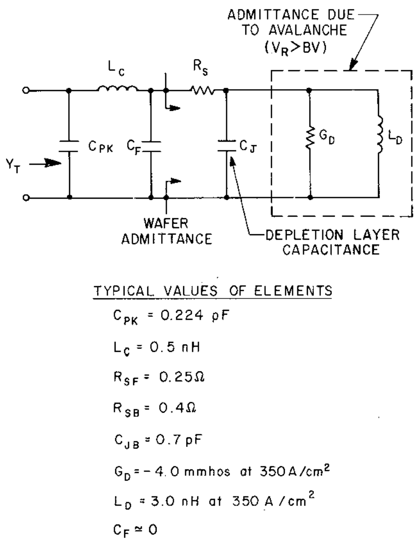

Figure 2. Equivalent Circuit of Germanium IMPATT Diode and Typical Values at 6.0 GHz.

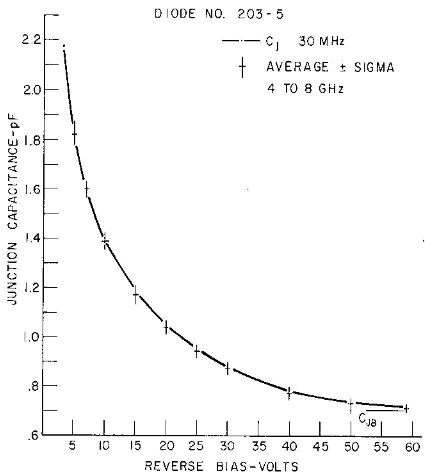

Figure 3. Junction Capacitance as a Function of Reverse Bias Voltage.

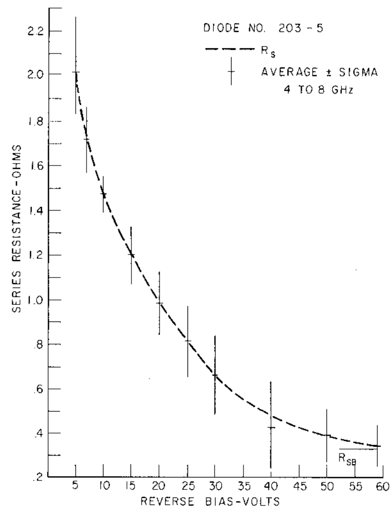

Figure 4. Series Resistance as a Function of Reverse Bias Voltage.

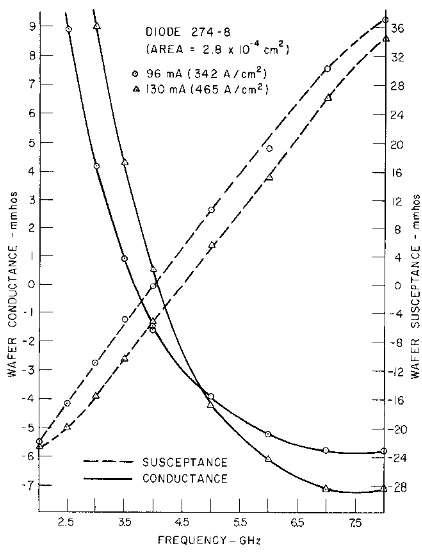

Figure 5. Diode Wafer Admittance as a Function of Frequency.

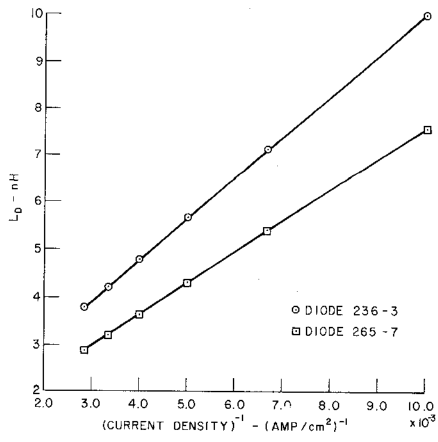

Figure 6. Avalanche Inductance as a Function of Reciprocal Current Density.