Diode Characterization in a Microstrip Measurement System for High Power Microwave Power Transmission

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Abstract

A method has been devised to experimentally characterize a packaged diode by inserting in a microstrip test mount. The diode is shunt mounted to the ground plane where a network analyzer measures the scattering parameters from the two-port test fixture. The equivalent circuit parameters are extracted from the measured data. A large signal measurement using the same test mount has also been configured to determine the power conversion efficiency from RF to DC as well as determining the embedded network impedance of the diode. Experimental characterization, conversion efficiencies, and input impedance of a GaAs Schottky barrier diode are presented. The method is quite general and can be used for characterizing solid-state devices for other applications.

I. Introduction

Diode characterization has been determined in coaxial-line [1]-[4] and waveguide measurement systems [5],[6]. Coaxial-line and waveguide measurement systems are hampered by the complexities of achieving proper calibration and the parasitics of the mounting structures. In this study a microstrip test mount is used to analyze the characteristics of a GaAs Schottky barrier diode at 2.45 GHz. Previous work has been published on a microstrip test mount where the diode was shunted to the ground plane at the end of an open-ended microstrip line [3]. The microstrip test mount presented in this paper is a 2-port device which allows the measurement of the four scattering parameters. The diode is tested at small signal levels for determining the circuit model and tested at large signal levels for determining the RF to DC power conversion efficiency as well as the diode input impedance. For microwave power transmission, the diode conversion efficiency is a key element for implementing successful systems [7]. The receiving rectifying antenna (rectenna) incorporates this type of GaAs Schottky barrier diode to convert the received beam into useful DC power. Computer programs can be used to predict rectenna performance by including accurate diode parameters. The ability to experimentally characterize the diode operating under high power conditions enables efficient design of the rectenna circuitry. The microstrip test mount allows the diode to be measured in both small and large signal conditions. Although the method was developed for measuring diodes in microwave power transmission applications, the method should have many applications in measuring solid-state devices for other uses.

II. Microstrip Test Mount Design

The height of the ceramic or glass wall on the screw-type diode determines the appropriate thickness of substrate to use. The Through-Reflect-Line (TRL) calibration used by the HP8510 network analyzer is required for proper calibration. As shown in Figure 1, a 50 ohm microstrip line has a hole drilled at the center of the board. The diameter of the hole is the same diameter of the diode. The quasi-TEM reference plane is located at the center of this hole. Due to the large height of the diode ceramic wall, the substrate is made of 60 mil RT/duroid with a dielectric constant of 2.2. Open, through and delay boards as shown in Figure 2 were constructed for the TRL calibration using the same type of substrate.

III. Experimental Setup

The experimental setup for the small signal testing is shown in Figure 3. Bias tees are added to provide different bias locations while measuring the scattering parameters and to provide DC signal isolation from the HP8510. Due to the frequency restriction of TRL calibration, the testing frequencies ranged from 600 MHz to 4.2 GHz.

The large signal test setup is shown in Figure 4. The input and reflected power on the source side of the mount are measured to determine the overall input power. A low pass filter is added to prevent the harmonics produced by the source from being mea-

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sured as input power. The double stub tuners are used to maximize the output DC power. Bias tees are also added to the setup for measuring the DC voltage across a known resistive load and to provide DC isolation from the rest of the setup. A short is placed at the end to reflect the RF power. After achieving over 70% conversion efficiency, the through board replaces the diode test mount for measuring the optimum input and output impedance of the diode under the large signal condition as shown in Figure 5. The setup is calibrated by the TRL method which locates the reference plane at the center of the through board where the diode would be located. Because the frequency span does not cover the higher order harmonic frequencies, a second calibration technique is employed for measuring the scattering parameters from 2 to 8 GHz. Port 1 of the HP8510 is calibrated by open, short, and load terminations. The impedance measured is modified by an extra delay from the calibrated reference plane to the end of the open microstrip board. The end of the open microstrip board is the location of the diode center.

IV. Measurement

For the small signal testing of the GaAs Schottky diode, the scattering parameters for the frequency range (600 MHz - 4.2 GHz) were measured at eight different bias locations (4 reverse bias, 1 zero bias, and 3 forward bias). The use of different bias voltages characterizes the non-linear effect of the diode. Touchstone was then used to determine the diode circuit parameters by the optimizer command that curve fits the diode circuit model to the measured scattering data. From the scattering parameter measurement and the Touchstone optimizer, one can determine the lead inductance L_p, the package capacitance C_p, the series resistance R_s, the junction resistance $R_j(V)$, and the junction capacitance $C_j(V)$.

For the large signal testing, 1.2 watts was used as the operating power level. The stub tuners maximized the output DC voltage or achieved over 70% conversion efficiency while also minimizing the reflected power. The tuners were then removed from the test setup shown in Figure 4 and connected to the HP8510 as shown in Figure 5. The input impedance of the tuners were measured separately by the HP8510 and the overall circuit impedance was found by adding the two measured values in parallel. The second harmonic circuit impedance at 4.9 GHz was also determined with the tuners by using the second calibration method mentioned previously.

V. Small Signal Results

The small signal circuit results are shown in Figures 6, 7 and 8. After the initial optimization of the eight circuit files by Touchstone was completed, the assumed bias independent parameters (L_p, R_S, and C_p) were selected, based on the result and data given by the manufacturer [8], [9]. The circuit model was solved as shown in Figure 6. Figure 7 shows the *CV* characteristic curves from the calculated and measured data. The calculated curve is based on the equation given by the manufacturer for these particular diodes [8]:

$$C_j = C_o\sqrt{\frac{0.8}{0.8 - V}}$$

C_O is the zero bias junction capacitance (3.55 pF) and V is the bias voltage. Figure 8 shows the measured junction resistance as a function of bias.

VI. Large Signal Results

An RF to DC conversion efficiency of 85% has been achieved in the large signal test setup. The conversion efficiency was calculated by

$$\text{Conversion Efficiency} = \frac{\frac{V_{DC}^2}{R_{load}}}{P_{in} - P_{reflected}}$$

where the load was 202 ohms. A system error of 4% in the measured conversion efficiency is based on the variance of loss through the experimental setup (Figure 4). The measured impedances at the fundamental and second harmonic frequencies at various efficiency locations are shown in Figure 9. The various impedances at the fundamental frequency demonstrate a trend as the efficiency is increased. These points are the circuit impedances as seen by the diode. Taking the complex conjugate of the circuit impedance points determines the diode impedance. Therefore, a simple diode model of a resistor and capacitor in series is realized. The second harmonic impedance points lie near the short position which is expected for diodes in an efficient rectenna. Ten diodes were tested and the typical maximum conversion efficiency was 80%. The circuit impedance as seen by the diode was approximately 6 + j29 ohms at 2.45 GHz. Based on the trend of the impedances of the fundamental frequency and the approximate short location of the second harmonic impedances, this method appears sound for determining the input impedance of the Schottky barrier diode for the rectenna application.

VII. Conclusions

A microstrip measurement system has been developed to analyze packaged GaAs Schottky barrier diodes under small and large signal conditions. The equivalent circuit model was characterized, an RF to DC conversion efficiency of 85% has been witnessed, and the diode input impedance has been determined under high power operation. The method is quite general and can be used for characterizing solid-state devices for other applications.

VIII. Acknowledgements

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REFERENCES

[1] J.W. Bandler, "Precision Microwave Measurement of the Internal Parasitics of Tunnel-Diodes," *IEEE Trans. Electron Devices*, vol. ED-15, no. 5, pp. 275-282, May 1968.

[2] R.P. Owens and D. Cawsey, "Microwave Equivalent-Circuit Parameters of Gunn-Effect-Device Packages," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, no. 11, pp. 790-798, Nov. 1970.

[3] P.T. Greiling and R.W. Laton, "Determination of Semiconductor Junction Device Package Networks," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, no. 12, pp. 1140-1145, Dec. 1974.

[4] M.B. Steer and R.G. Hicks, "Characterization of Diodes in a Coaxial Measurement System," *IEEE MTT-S Digest*, pp. 173-176, 1991.

[5] J.M. Roe and F.J. Rosenbaum, "Characterization of Packaged Microwave Diodes in Reduced-Height Waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, no. 9, pp. 638-642, Sept. 1970.

[6] B.D. Bates and A. Ko, "Modal Analysis of Radial-Resonator Waveguide Diode Mounts," *IEEE Trans. Microwave Theory Tech.*, vol. 38, no. 8, pp. 1037-1045, Aug. 1990.

[7] W.C. Brown, "The History of Power Transmission by Radio Waves," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, no. 9, pp. 1230-1242, Sept. 1984.

[8] W.C. Brown, "Free-Space Microwave Power Transmission Study, Combined Phase III and Final Report," Raytheon Report no. PT-4601 covering from Dec. 9, 1969 to July 31, 1974, NASA Contract no. NAS-8-25374, pp 5-23 - 5-46.

[9] "Reception-Conversion Subsystem (RXCV) for Microwave Power Transmission System, Final Report", prepared by Raytheon Company for JPL, JPL Contract no. 953968, NASA Contract no. NAS 7-100, pp. 2-21 - 2-30, Sept. 1, 1975.

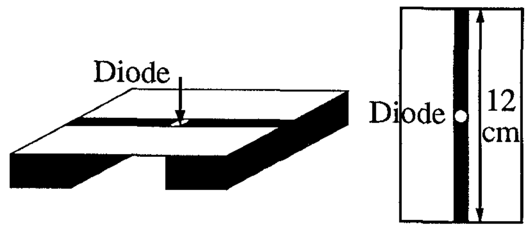

Figure 1. Microstrip diode test mount

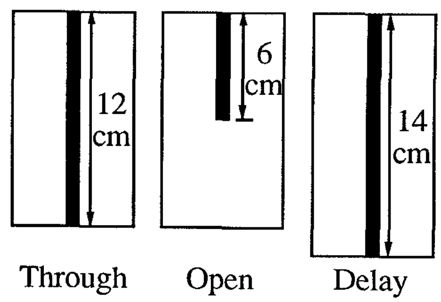

Figure 2. Microstrip TRL calibration boards

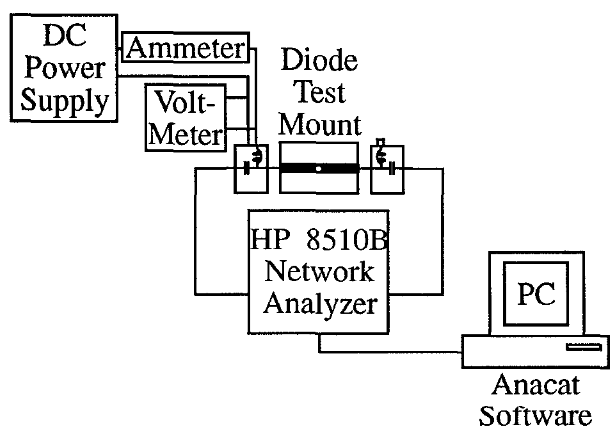

Figure 3. Small signal test setup
600 MHz - 4.2 GHz

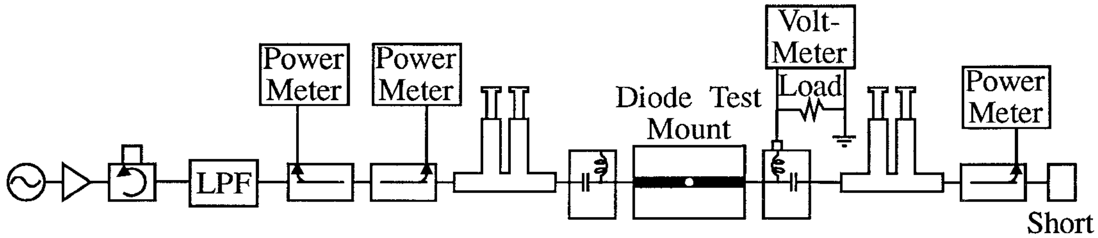

Figure 4. Large signal test setup, 2.45 GHz

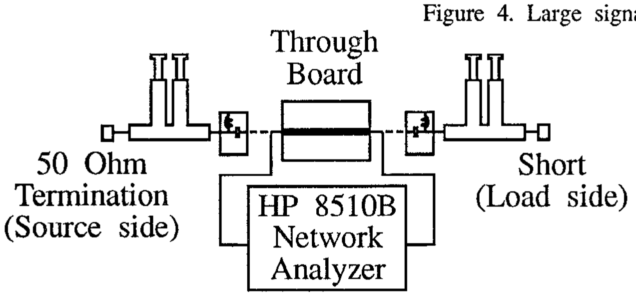

Figure 5. Circuit impedance measurement as seen by the diode under large signal testing

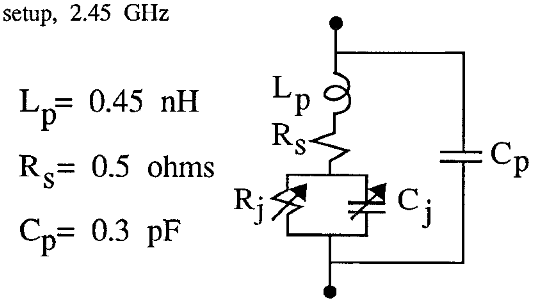

Figure 6. Small signal equivalent circuit of GaAs diode and experimental results

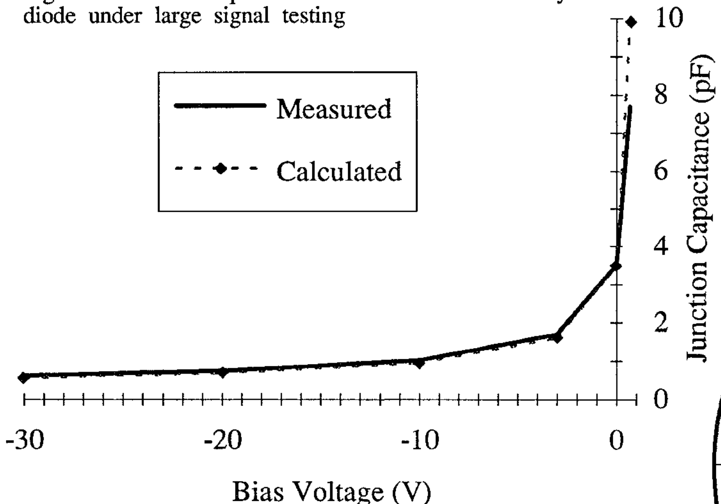

Figure 7. Junction Capacitance vs. Bias Voltage

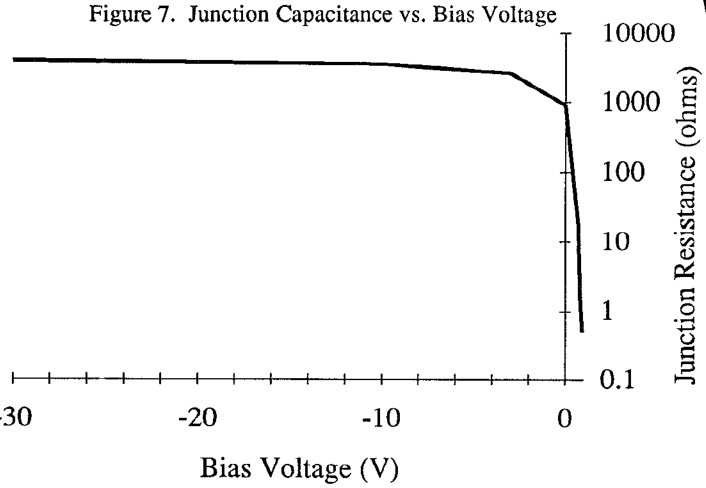

Figure 8. Junction Resistance vs. Bias Voltage

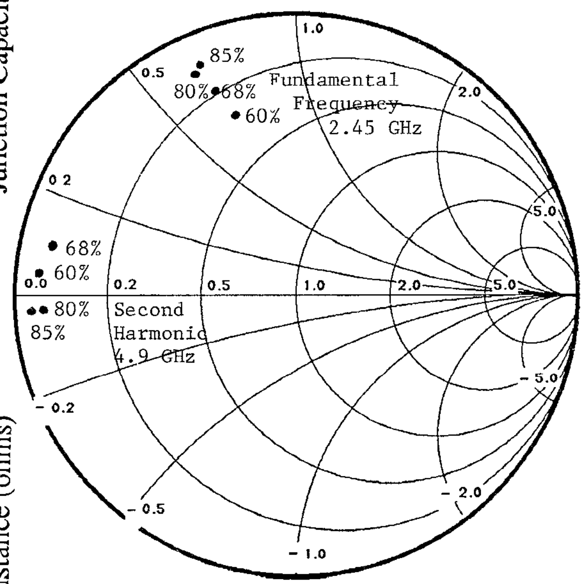

Figure 9. Circuit impedances as seen by the diode under large signal measurements