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VIDEO IMPEDANCE PROPERTIES OF PULSED X-BAND GaAs IMPATT DIODES

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Abstract

A pulsed impedance measurement system was developed to characterize the bias circuit of GaAs IMPATT diodes. Actual bias circuit data was obtained and used analytically to describe the interaction between Impatt diode bias input and modulator impedances.

Introduction

IMPATT diodes for pulsed solid state microwave sources require specialized electronic drive circuitry. For Raytheon X-band GaAs Double Drift diodes, high power modulators typically provide 2 amps of peak current over a variety of pulsewidth and duty cycle combinations. Present modulator designs have evolved through empirical techniques because of the unknown characteristics of the pulsed IMPATT diode's bias port broadband equivalent circuit. Gross characteristics were assumed and designs were developed accordingly. [1]

A more analytical design approach for developing modulator circuitry requires knowledge of the impedance of a GaAs Double Drift IMPATT Diode over the frequency of interest under pulsed (i.e. large signal) operating conditions. The measurement of this impedance and its use as a design tool is the focus of this paper.

Measurement Technique

Because pulsed, large signal diode impedance measurements cannot use conventional network analyzer methods, a new measurement technique had to be developed.

The pulsed impedance measurement system was derived from the familiar technique of matching a known impedance with an unknown impedance through some "matching network." The unknown impedance is then determined from the impedance of the matching network and measured reflections.

The pulsed impedance measurement system differs from this technique in that no "matching" network is involved. Instead, a measurement is made of the change in "mismatch" (reflection coefficient magnitude) when a known impedance element (perturbing impedance) is placed in series (or parallel) with the unknown impedance.

The method can best be understood by considering the following. The magnitude of an unknown impedance reflection coefficient, $|\Gamma_1|$, defines a circle whose radius (in Polar Coordinates) is given by

$$|\Gamma_1| = \frac{Z_u - Z_o}{Z_u + Z_o} \qquad (1)$$

where Z_o is the impedance of the measurement system and Z_u is the unknown impedance. The magnitude of the reflection coefficient of the unknown impedance plus a perturbing impedance $|\Gamma_2|$ is similarly defined by:

$$|\Gamma_2| = \frac{(Z_u + Z_p) - Z_o}{(Z_u + Z_p) + Z_o} \qquad (2)$$

where Z_p is the known perturbing impedance (which may be complex). Equations (1) and (2) may be solved simultaneously to produce values of the real and imaginary parts of the unknown impedance which are functions of the two measured reflection coefficient magnitudes $|\Gamma_1|$ and $|\Gamma_2|$, and the perturbing impedance only.

This method produces two unique complex-conjugate solutions for Z_u of which only one is correct. This ambiguity is resolved by replacing the original perturbing impedance with one which is specifically reactive. If the magnitude of the reflection coefficient of this combination increases over the magnitude of the unknown reflection coefficient, then the unknown has the same sign as the reactive perturbing impedance. If it decreases, the unknown has the opposite sign.

The entire measurement set-up has been connected via HP-IB to an HP9835 computer, and all measurements are performed with minimal operator interaction. A program has been written to perform the complicated mathematical manipulations involved in solving the simultaneous equations discussed earlier.

The computer program obtains power level information from the spectrum analyzer and computes the nodal impedance at the right of the isolation resistor (see Figure 1). The program calculates the IMPATT bias circuit impedance by de-embedding the known impedances of the modulator and isolation resistor. These impedances have been previously measured under CW conditions with a network analyzer and deposited in the program's data file.

Measurement Equipment

The block diagram of the pulsed impedance measurement system is shown in Figure 1. It has been configured to measure pulsed IMPATT diode bias circuit impedance. However, the system is capable of measuring other kinds of pulsed or non-pulsed impedance by substituting the unit under test for the microwave and video equipment to the left of the isolation resistor.

The measurement system contains a video signal source, reflection test set, accurate spectrum analyzer, and video pulse support equipment. The signal source supplies rf CW energy for the reflection test set (VSWR Bridge). The incident energy goes through the reflection test set and to the unit under test. The energy reflected from the unit under test travels back to the reflection test set. The rf energy out of the "reflected" port is proportional to the reflection coefficient of the unit under test in a 50 ohm system. The reflection coefficient is equal to the square root of the ratio of the reflected power from the unit under test to the reflected power when the test port of the test set is shorted (or open).*

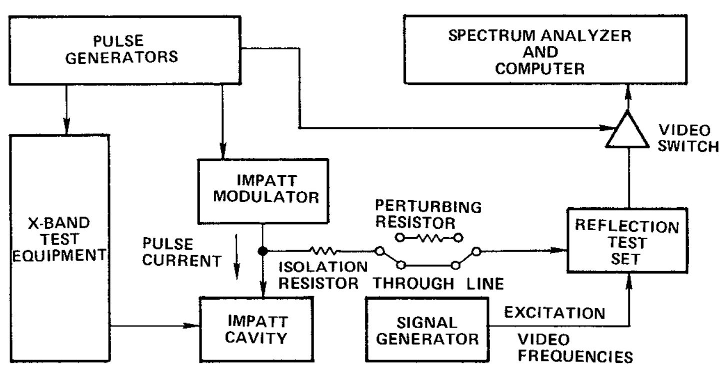

Figure 1. Block Diagram of the Pulsed Impedance Measurement System

$$* \quad |\Gamma| = \sqrt{\frac{\text{Power Reflected}}{\text{Power Incident}}}$$

The reflected energy out of the reflection test set is gated with a video switch. The switch allows rf energy to flow to the spectrum analyzer during the portion of the pulsed operation under consideration. The spectrum analyzer filters out all but the excitation frequency. Thus, PRF and harmonics do not corrupt the measurement information.

The system is operated in the following manner. The microwave equipment and IMPATT amplifiers are tuned and adjusted for desired operating conditions. A "through line" is inserted in place of the perturbing impedance. The video excitation frequency is set and located on the spectrum analyzer. Then, the gating pulse generator is set so the measurement system is observing the proper portion of the pulsed waveform. A reference level is determined by shorting out the reflection test set (while the IMPATT diode power is off) at the input to the "through line." The IMPATT power is then turned on and the reflected power is noted on the spectrum analyzer.

The "through line" is replaced by the perturbing

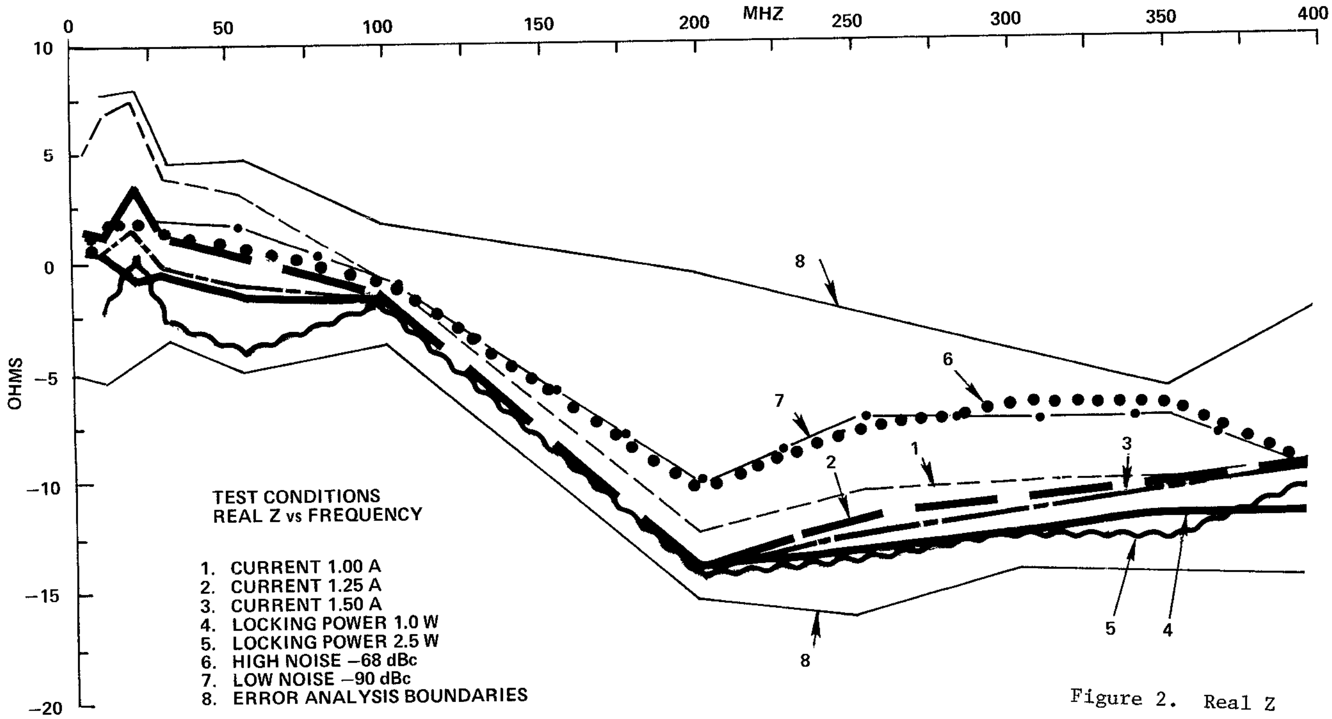

Figure 2. Real Z

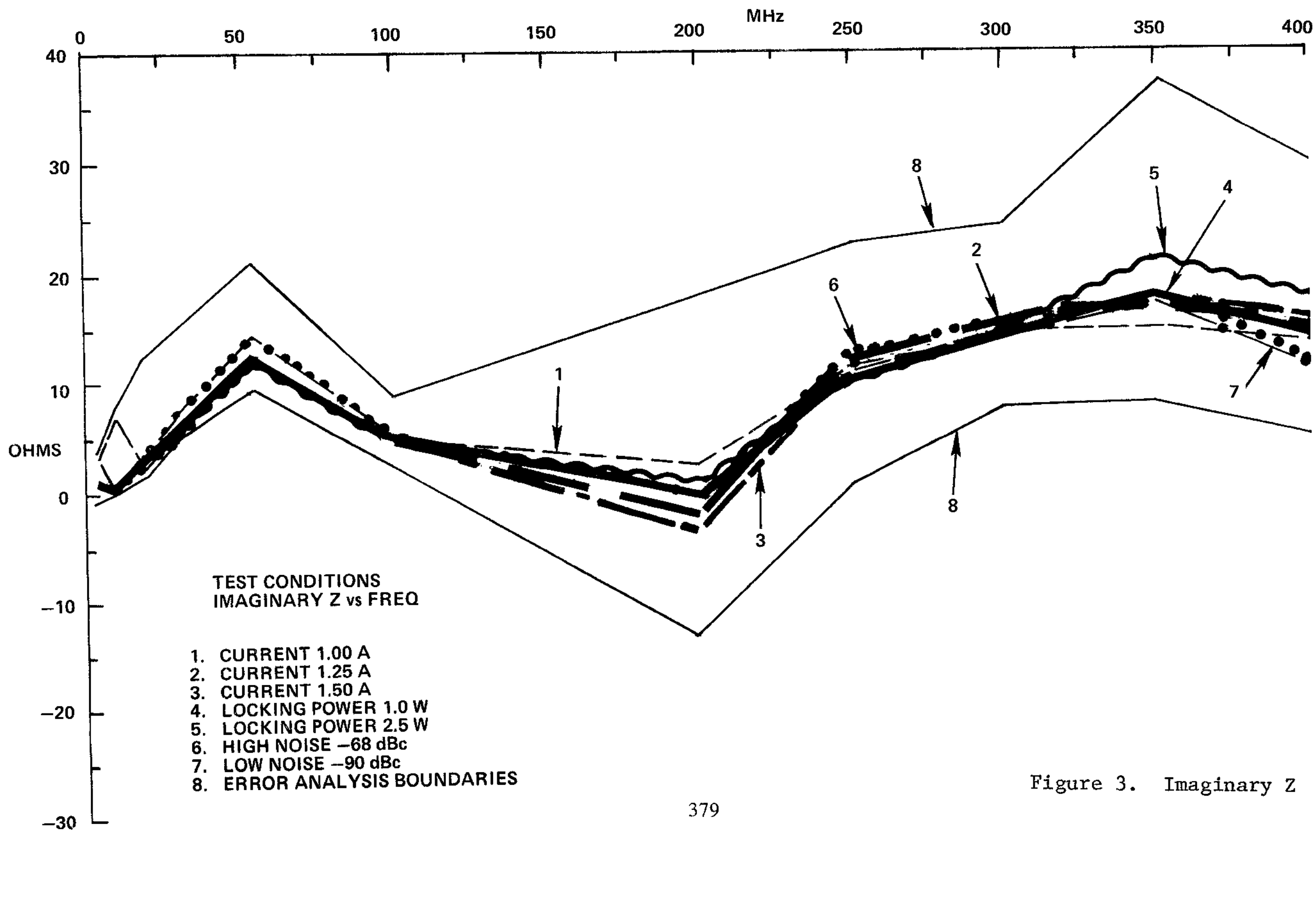

Figure 3. Imaginary Z

impedance and the reflected power is measured. The squared reflection coefficient for the perturbed and non-perturbed conditions are obtained by dividing the perturbed and non-perturbed power levels by the reference power level. These two values are used to calculate the sum of the impedance of the isolation resistor plus the parallel combination of the IMPATT modulator and IMPATT diode bias circuit. The IMPATT diode's bias circuit impedance is then obtained by de-embedding the components of the other impedances that have been independently measured by means of a network analyzer.

Measurement Results

Figures 2 and 3 show the results of the measurement from 5 to 500 MHz of a pulsed (600 nsec pw-1μsec PRI) single injection locked GaAs Double Drift Raytheon IMPATT diode. The family of curves in each figure represents the impedance (in ohms) of the IMPATT diode under various operating conditions (see legend). The two solid lines bounding this family of curves represent the maximum value of uncertainty in this measurement technique due to power level measurement error.

All measurements were taken using a TM_{010} circular cylindrical cavity as the rf circuit. At the present time no investigation has been undertaken to see how the IMPATT diode impedance may change as a function of the rf circuit (Q)1 for this configuration.

The above measurements show that radical variations of diode impedance occur only as a function of bias current, and that the diode real part can be negative in certain regions.

Time Domain Analysis

The pulsed video impedance measurement of the IMPATT diode provides required information with which Current Pulsers may be designed. Essentially, the problem is that posed by the simple circuit model of Figure 4. From this model and the information obtained from the measurements of Z_M and Z_D, the current I_D is predictable.

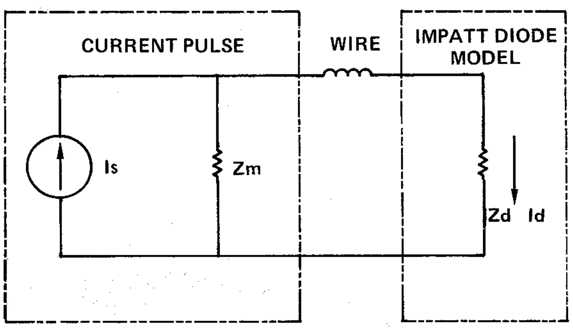

Figure 4. Circuit Model

A program was written to compute the Fourier coefficients of a trapezoidal current pulse with specified rise and fall times. Using these and the impedances of the modulator and IMPATT diode (as a function of frequency), the current I_D through the IMPATT diode is computed at each frequency. (The impedance from 0 to 5 MHz is assumed to have the same value as that of 5 MHz, and the values between known impedances are assumed to be a linear interpolation). After this frequency dependent diode current has been computed, an inverse Fourier transformation predicts the time dependent current through the diode, which is plotted every 2 nsec over the region of the original pulse. The resulting waveform is thus a mathematical solution for the current through the IMPATT diode. Provisions have been made to allow for addition of wire "inductance" between IMPATT and modulator, and to vary the rise time, fall time, and amplitude of the input current waveform. Figure 5 is a picture of an actual current pulse of the operating IMPATT with the wire length gradually increased. Comparison of this with the model shows good general agreement. Thus, the model provides a method for predicting how the waveform of the current will change as a function of diode and (more important) modulator impedance.

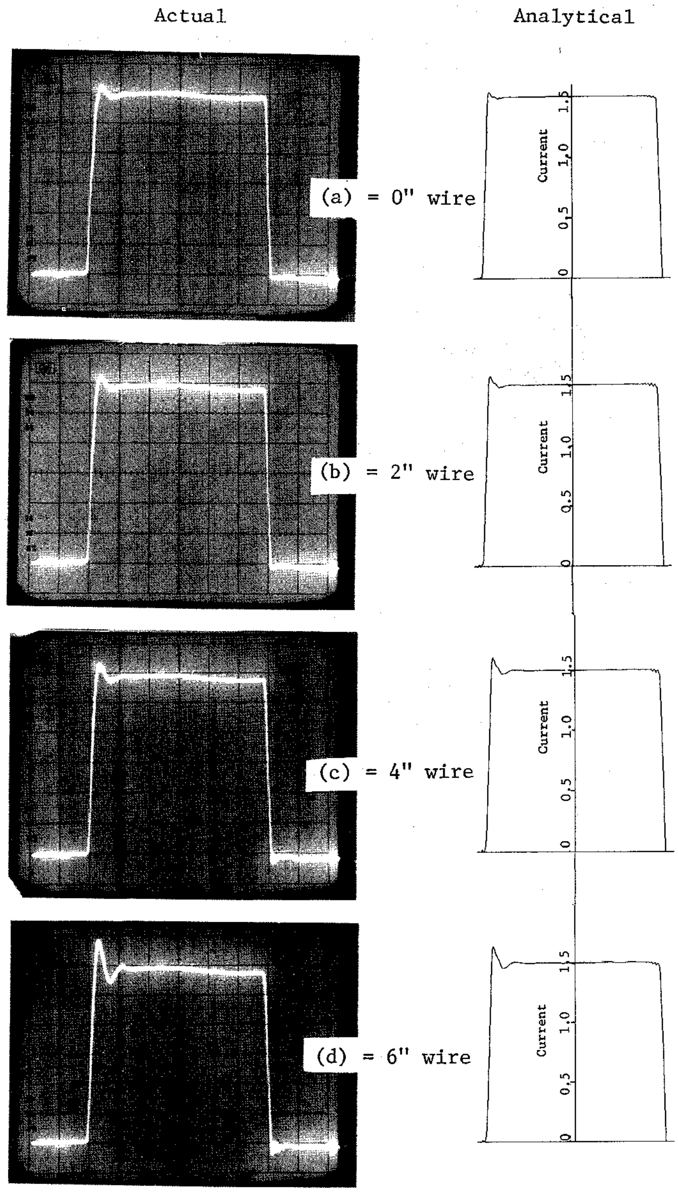

Figure 5. Actual Current Pulse of Operating IMPATT, with Wire Length Gradually Increased

Conclusions

A technique has been developed that allows video frequency impedance measurements to be made of a pulsed GaAs IMPATT diode operating under large signal conditions. Use of this information and the analysis techniques described earlier permits drive circuitry (modulators) used with IMPATT diodes to be more analytically designed.

References

1. C.A. Brackett: "The Elimination of Tuning Induced Burnout and Bias-Circuit Oscillation in IMPATT Oscillators, The Bell System Technical Journal, Vol. 52, No. 3, March 1973, pp. 271-306.