LARGE SIGNAL DEVICE CHARACTERIZATION FOR BROADBAND KA-BAND IMPATT AMPLIFIER DESIGN

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Abstract

A three-stage 0.5 watt avalanche diode amplifier has been developed with 23 dB of gain and 0.5 dB bandwidth of 2 GHz from 34 to 36 GHz. The voltage gain bandwidth product of the first stage exceeds 12 GHz - a state-of-the-art value for Ka-band IMPATT amplifiers. The amplifier uses GaAs modified Read profile devices which produce 0.5 watt at 8-9 percent efficiency. The flat broadband response of this waveguide amplifier is the result of applying lower frequency circuit design techniques such as network analysis and circuit synthesis to millimeter wave frequencies. Diode matching is controlled and predictable, no tuning screws are utilized.

This paper describes the design approach, the circuit, and the results; including amplifier system performance tests such as input-output, noise figure and intermodulation products.

Introduction

The broadband amplifier described in this paper is one of a series of high performance transmitter and receiver components developed for wideband applications including spread spectrum communications, frequency hopping and high data rate analog and digital systems.

The flat broadband high gain response of this waveguide amplifier using packaged diodes is realized by the application of advanced design techniques to millimeter wave frequencies. These include careful characterization at both small and large signal levels; the capability of controlling and predicting, through computer-aided design, the impedance seen by the diode in the basic waveguide circuit, the impedance of this external broadband matching network, and the detailed overall characterization of the amplifier. While this approach is typically employed in the design of high performance amplifiers at X-band or below, and particularly with coaxial type circuits, in aggregate it has not previously been employed at Ka-band.

Packaged Diode Equivalent Circuit and Measurement Circuit

The packaged diode equivalent circuit used in this paper is shown in Figure 1. This equivalent circuit is consistent with previous models when reduced to their simplest forms.[1,2]

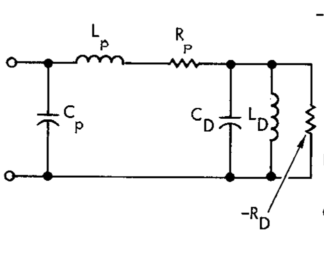

Figure 1. Typical Equivalent Circuit for the Packaged Impatt Diode

The determination of the various equivalent circuit elements is facilitated by the use of a Ka-band reflection test unit and a network analyzer. A special fixture is provided via a waveguide to coaxial transition, to mount the diode at the end of a coaxial line thus allowing direct impedance measurement data to be obtained as a function of frequency, bias level and drive power. Figure 2 shows the network analyzer reflection test unit used for the indicated measurements. The system is initially calibrated with a short circuit termination in the shape of a diode package to reference the parasitic elements which are not included in the equivalent circuit. With the system calibrated over the swept frequency range, the device is substituted into position for the impedance locus evaluation from which the parasitic elements and the active elements can be determined. This impedance locus of the Ka-band device is measured at the package terminals since it is the point at which the device is accessible as far as any functional circuit is concerned, and thus the device is defined by this locus. A typical result is shown in Figure 3; the device terminal impedance is X-Y plotted directly onto a compressed Smith Chart.

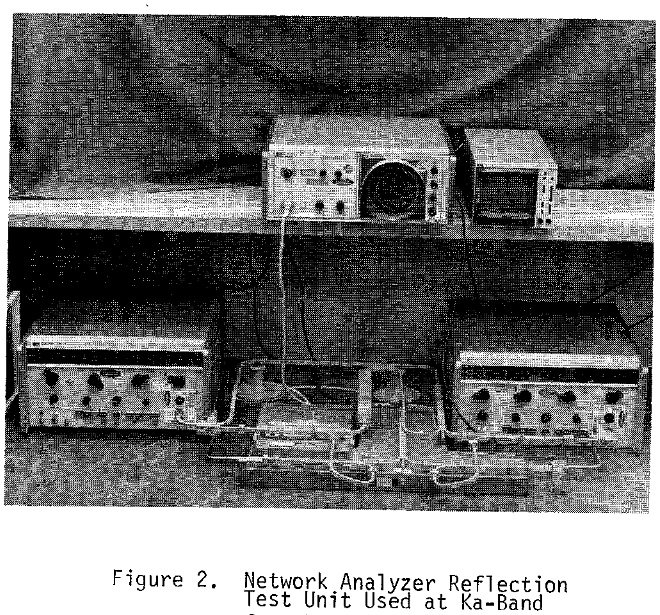

Figure 2. Network Analyzer Reflection Test Unit Used at Ka-Band for Characterization

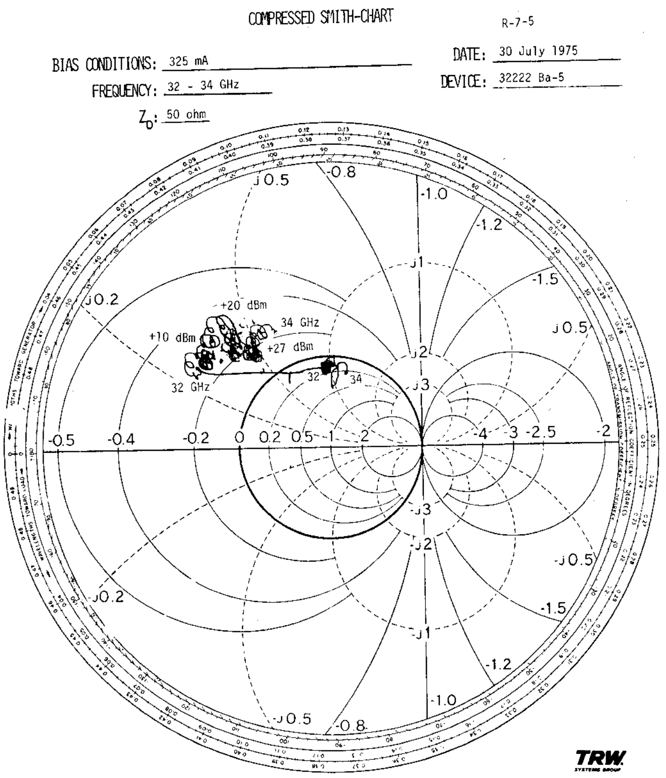

Figure 3. Diode Characterization with Impedance Data for Three Input Power Levels Plotted on a Compressed Smith Chart

Waveguide Circuit Design

The basic waveguide amplifier circuit allows a large amount of design freedom; major variables over which judicious control can be exercised include the bias line, the waveguide height,[3] the diode position,[4] the backshort, the transformer and waveguide circulator, as well as controlled external broadband matching as described by Getsinger[5] and Peterson.[3] For example, bias is supplied by a special filter structure which serves a variety of functions, which include provisions to:

1) Provide DC isolation for the bias line
2) Provide proper harmonic termination impedances
3) Establish an additional tuning element required to stabilize the diode at its operating frequency

The design of the bias line is accomplished by terminating the coaxial line in an absorbing material or in effect the characteristic impedance of the line. Working backwards through transformer sections of varying dimensions, it is possible to determine the impedance loci that are seen looking into the bias pin at the location of the diode. Measurements on the bias pins using the network analyzer indicate the calculated results to be quite accurate. As further evidence that this concept is useful in amplifier design, it can be demonstrated that the single pole amplifier response of the basic circuit can be controlled and changed as a function of the bias pin input impedance.

In addition, it is possible to directly measure the impedance the diode sees looking into the waveguide. This is accomplished with a special adapter circuit, shown in the upper right portion of Figure 4. Also shown is the 50 ohm device characterization circuit with a built-in broadband waveguide-to-coaxial transition (lower right), the basic reduced height waveguide amplifier circuit (left) and a cross-section view of a similar circuit (upper center). Displayed on the Smith Chart are typical device and circuit impedance loci, all measured over the same frequency range. The circuit impedance loci are shown for both an amplifier and oscillator case, with the waveguide short the controlling element in moving from one condition to the other. It is seen from Figure 4 that the circuit impedance loci are small, evidencing a large bandwidth situation. In general, the waveguide short plays a role in the design procedure outlined, with the control of the bias pins reactance contribution rather heavily. This is also demonstrated in Figure 4 with the location of the calculated bias pin impedance.

Results

Using the design procedure described above, the three-stage amplifier shown in Figure 5 was developed. The broadband amplifier performance is demonstrated in Figure 5. It is seen that approximately 2 GHz of 1 dB bandwidth is obtained from 34.2 to 36.2 GHz.(over most of the band the output power is flat to within 0.2 dB). For example, with 12.5 dB of gain the voltage gain-bandwidth product of the first stage is 12 GHz, a state-of-the-art value. Normalized to frequency, this represents a figure of merit of 0.34. The first stage is the critical one in terms of establishing the bandwidth. The input-output performance is shown in Figure 6. Linear performance at 38 dB gain is obtained up to -25 dBm input. The third order intermodulation products were measured using the standard two-tone test. For small signals, the IM products are more than 20 dB below the carrier. The intercept point of the third order IM product is 10 dB above the 1 dB compression point. At this level, the third order IM product is 25 dB below the carrier. (Figure 6) The amplifier noise figure is 28 dB.

Conclusion

This paper described a design approach achieving outstanding performance with multi-stage millimeter wave avalanche diode amplifiers. Extensive use is made of network analysis and circuit synthesis to achieve controlled broadband matching.

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References

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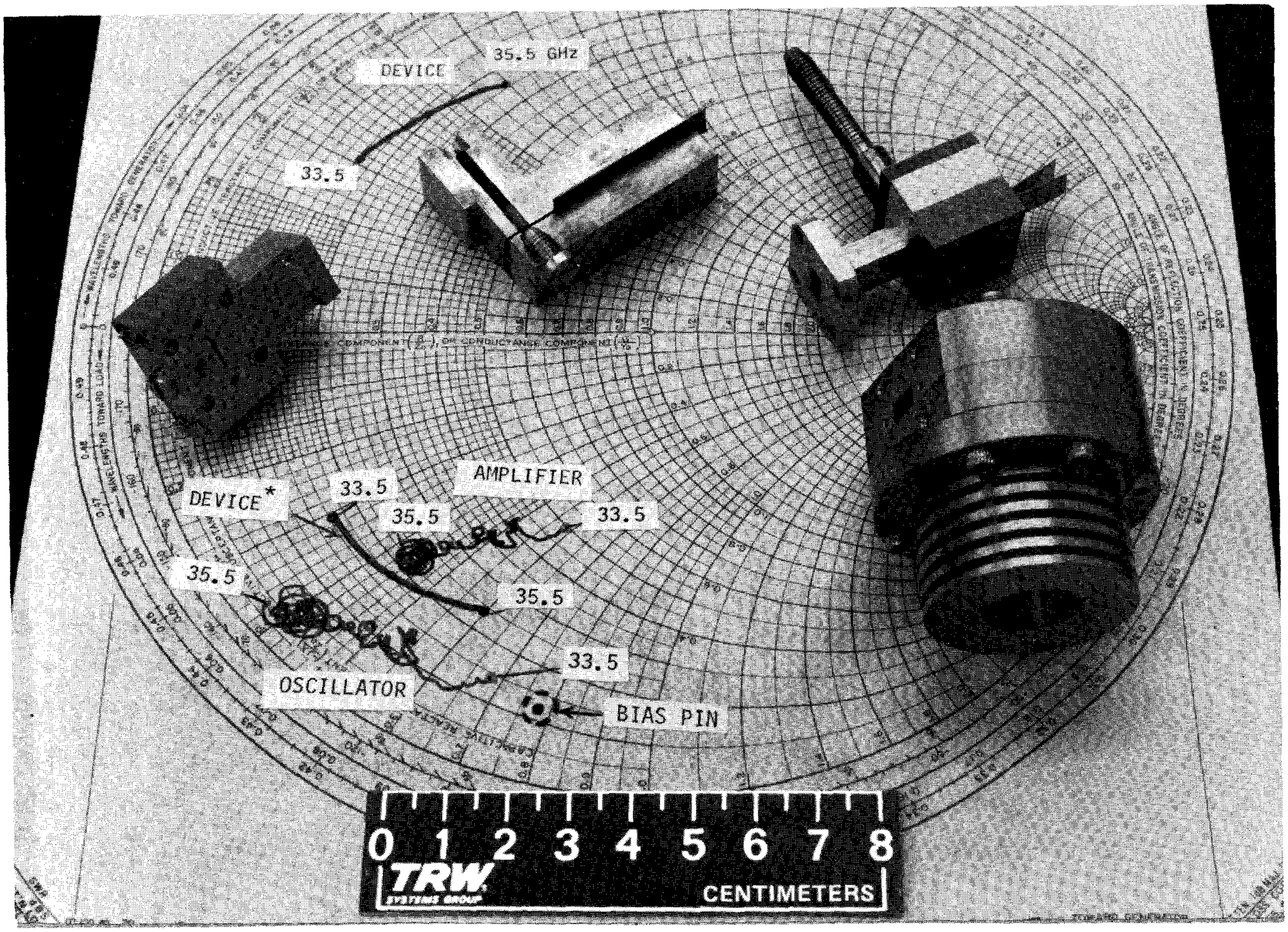

Figure 4. Composite relationship between circuit and device interface. Shown are assembled compact reflection amplifier circuit (left), a sectioned view of the amplifier circuit (top center), circuit impedance measurement adapter (top right), coaxial diode characterization mount including waveguide-to-coaxial transition (right).

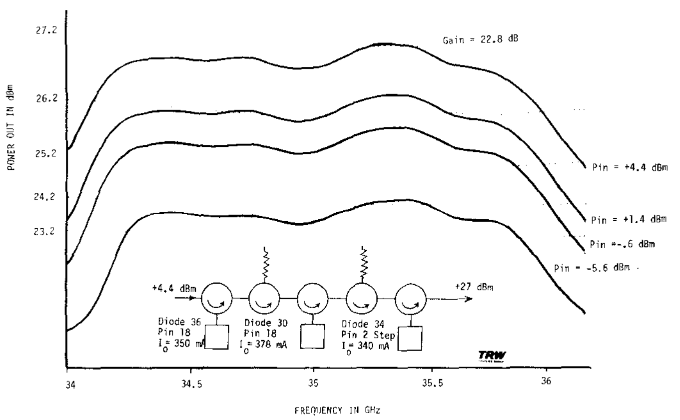

Figure 5. Three-Stage Read IMPATT Diode Amplifier Response

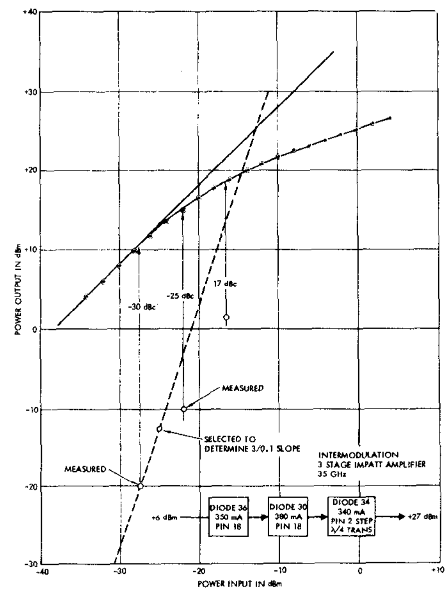

Figure 6. Three-Stage Intermodulation - Gain Compression Curve