Ka/Q BAND GaAs IMPATT AMPLIFIER TECHNOLOGY

G. Jerinic, M. Schindler, M. Cobb and J. Fines

Raytheon Research Division
131 Spring Street
Lexington, MA 02173

Abstract

GaAs IMPATT diodes are capable of generating 2 to 3 W simultaneously with 18-22% efficiency in the 33 GHz to 46 GHz frequency band. The design of the amplifier circuits which utilize these devices is discussed. The circuit design is based on a 3-step closed form algorithm. The first step is a passive circuit characterization with an automatic network analyzer. In the second step, a computer is used to generate diode device lines. The third step is load line synthesis for predictable operation. The resulting performance is described. 2 W over a 2-GHz bandwidth was achieved simultaneously with minimum gain of 9 dB.

Introduction

In Ka (33-36 GHz) and Q (36-46 GHz) bands, an IMPATT diode is the only solid-stage device capable of high power generation. Two device types most commonly used are GaAs double-drift and silicon double-drift IMPATT diodes. At Raytheon, the GaAs device technology has been developed exclusively and results achieved are described.

The design of high-power IMPATT diode circuits is not a trivial matter. These two-terminal devices present a negative resistance over a broad frequency range, and their impedance, which must be matched by the circuit, is very low. They are, therefore, difficult to control. One can empirically obtain an occasional impressive result; however, for predictable and repeatable operation, sound design procedures must be used. A procedure based on S-parameter circuit characterization with an automatic network analyzer.[1,2,3,4] is discussed, and examples of the state-of-the-art performance achieved with circuits so designed are given.

IMPATT Diode Performance

The performance achievablbe with IMPATT diodes in Ka and Q bands is:

Power (P_{rf})	2-3 W
Thermal resistance (Θ_T)	18-22° C/W
dc-to-rf conversion efficiency (η)	18-22% (GaAs) 10-12% (Si)

The diode junction temperature is the major factor which affects the reliability of operation. Typically, for reliable operation it should be less than 250°C. Since the junction temperature is inversely proportional to device efficiency and thermal resistance, these two parameters are the key to reliable operation. Because of the inherently higher efficiency of GaAs IMPATT diodes, this technology has been pursued at Raytheon during the last twelve years, resulting in the state-of-the-art results shown in Table 1.

Table 1

GaAs IMPATT Diode Performance

Frequency	34 GHz	42 GHz	45 GHz
RF Power	3 W CW	2.7 W CW	2 W CW
Efficiency	22%	18.6%	18%
Thermal Resistance	21.6°C/W	14.2°C/W	20°C/W
ΔT_j	230°C	170°C	182°C

In order to minimize the thermal resistance, the diodes are mounted on diamond heatsinks. With this technique, 14-15° C/W is the best achievable at this frequency; however, a more typical range is 18-22° C/W.

Circuit Design

To design an IMPATT amplifier or oscillator, one must know the device impedance or admittance for a specific dc bias as a function of frequency and power level. Such admittance for a typical Raytheon GaAs double-drift (optimized for 35 GHz) is shown in Fig. 1. This data can be generated by a computer model or measured in the laboratory. Computer modeling has the advantage of speed, but its validity must be confirmed by measurement for each circuit type, frequency, and rf power range. Figure 2 shows a schematic representation of the automatic (computer-controlled) network analyzer used for such a purpose in Raytheon's Research Division Laboratory.

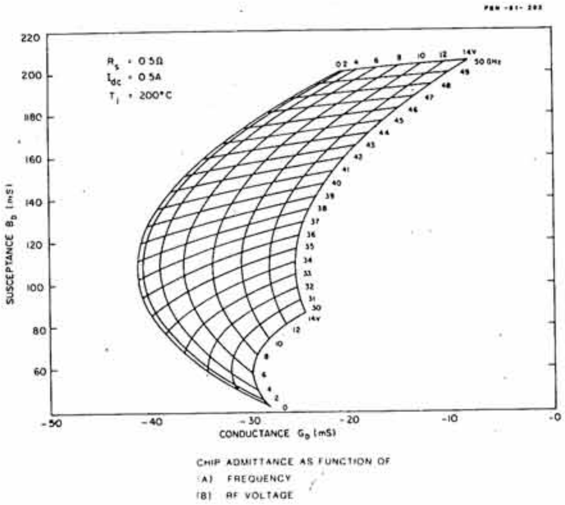

Figure 1. Chip admittance as a function of frequency and rf voltage.

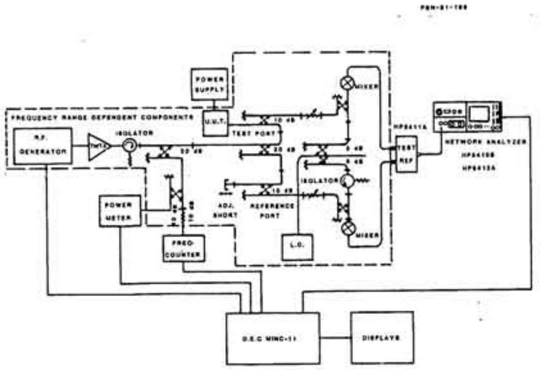

Figure 2. EHF computerized large signal network analyzer.

The IMPATT diode is a two-terminal, negative-resistance device, which can operate as either a free-running oscillator, an injectionlocked oscillator, or a negative-resistance amplifier. The interaction between the diode and the circuit, i.e., the relative position of the circuit impedance and diode chip impedance in the complex plane, will define in which of these three modes the amplifier will operate.

Hence, it is important to design the passive circuit with appropriate characteristics so that optimum gain, bandwidth, and power can be obtained for the mode of operation selected. Obviously, the circuit choice plays the key role in determining which characteristics are realizable. Four of the most suitable single and multidiode circuits are: "top-hat" circuit, reduced waveguide height circuit, cylindrical cavity power combiner and rectangular cavity power combiner. All these circuits have a single port and, hence, require a circulator to separate input from output.

Lumped elements equivalent for the above structures are frequently used to analyze their performance. The lumped element values may either be computed from basic principles or determined by measurements.

Although lumped-element analysis has given good agreement with passive impedance measurements on circuits with a small number of diodes and is useful in obtaining a qualitative understanding of circuit behavior (necessary for circuit optimization), the extension of this method to circuits with large numbers of diodes and to the millimeter-wave region has proven to have limited accuracy. A more accurate method has been developed and is presently employed for passive circuit characterization and optimization. This method utilizes a scattering matrix representation (Fig. 3).

An automatic network analyzer (see Fig. 2) is used to characterize the circuit alone (without diode(s)). The diode(s) are replaced with short circuit(s) and the reflection coefficient from the circuit output port is measured. By repeating this measurement for at least three short positions, the complete S matrix is obtained.[2,5] From the S matrix, the circuit efficiency and the impedance presented to the diode port(s) are determined.

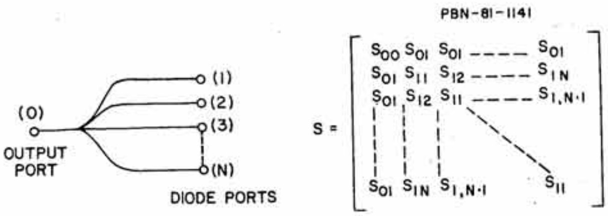

Figure 3. Scattering matrix for general combiner circuit.

Circuit Performance

Using the S-parameter circuit design process just described, a 3 stage amplifier was designed.

The resulting stateof-the-art performance is shown in Fig. 4: 2 W over the 2 GHz bandwidth, was achieved with minimum gain of 9 dB, and maximum gain of 10.7 dB. This combination of power, bandwidth, and gain flatness makes this amplifier suitable for communication applications.

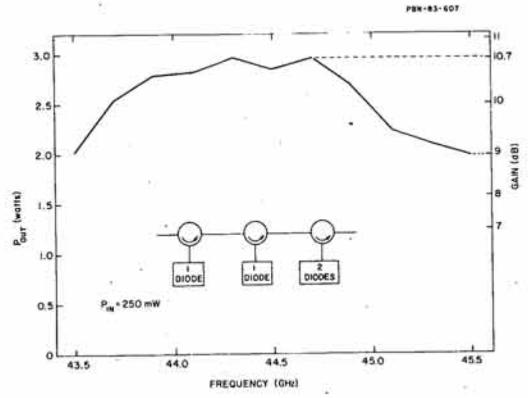

Figure 4. Three-stage amplifier performance.

References

[1] C.A. Drubin, A. L. Hieber, G. Jerinic, and A. S. Marinilla, "1 kW Peak 300-W Average IMPATT Diode Injection Locked Oscillator", 1982 IEEE MTT-S International Microwave Symposium Digest, pp. 126-128.

[2] Ku Band Amplifier Development, Technical Report AFAL-TR-791173, Final Report for Period May 1978-April 1979, Air Force Avionics Laboratory, Air Force Weight Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433.

[3] G. Jerinic, J. Fines, M. Schindler, "3 W, Q Band Solid State Amplifier", 1983 IEEE MTT-S International Microwave symposium Digest, pp. 481-483

[4] J. McClymonds, "A 16.5 W, 20 GHz IMPATT Diode Power Combiner", 1983 IEEE MTT-S International Microwave Sympsoium Digest, pp. 484-486.

[5] J. Lampen, G. Jerinic, C. A. Drubin, and L. Wagner, "ANA Measurement of IMPATT Diode Cavity Combiner Efficiencies and Impedances", to be published.