A HIGH POWER WAVEGUIDE IMPATT AMPLIFIER

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ABSTRACT

A CW waveguide amplifier using a silicon double-drift IMPATT diode provides 10 dB gain with 2 Watts output at 11.2 GHz. A design procedure for control of frequency, gain, and bandwidth is described.

INTRODUCTION

The increasing need for high power solid state sources led to the development of double-drift IMPATT diodes that have a higher power capability with respect to the commonly used single drift because of their physical structure.[1,2]

Most of the work done so far has concerned oscillators in coaxial and waveguide mounts; with either of them a CW power output of 2.8 watts can be achieved at 12 GHz with 10% efficiency.[1] A design procedure for a CW coaxial amplifier can be inferred from reference 1, but no explicit information has been published for the more complex waveguide mount. This paper proposes a design procedure for a flexible and controllable waveguide mount. Measured data are presented for an amplifier that has 10 dB gain and 2 W power output at 11.2 GHz.

WAVEGUIDE MOUNT

The waveguide mount used is shown in Fig. 1. It consists of a centered cylindrical post, a quarter wavelength from a short circuit plane, that feeds the waveguide through the gap region positioned in the middle of the waveguide height. One half of the post is formed by a coaxial line that connects the gap region to the diode; it is this part of the mount which strongly affects the performance of the amplifier and allows controllable flexibility in design.

The mount is similar to the widely used post mount for microwave diodes in waveguides, but has the major advantage of providing a good transition from the relatively high impedance of the waveguide to the very low diode impedance. An analytical solution for the electromagnetic field in the cavity has not been attempted because of the complexity of the boundary conditions (a solution for the standard waveguide mount is found in Refs. 3 and 4). A simplified model was used for a design approach to the problem and good correspondence was found with experimental data.

The post diameter is chosen by matching its impedance to the waveguide impedance. First the waveguide is assumed to be symmetrical and split in half by a centered H plane. The coaxial circuit at the gap, to be discussed in the next section, sees these two sections in series, so the coaxial circuit impedance must be double the impedance of the split waveguide with post, assumed to be 100 ohms. The post diameter, .175, is obtained from a graph[5] of impedance of a transmission line formed by a post in a trough.

DESIGN PROCEDURE

The amplifier gain specification is 10 dB at center frequency of 11.2 GHz with output power of 2 W. The IMPATT diode used is the HP 5082-0611 which is guaranteed for minimum power output of 2.5 watts at approximately 11.2 GHz when used as an oscillator.

Data sheets provide the average diode resistance vs. frequency in two conditions: small signal impedance when bias current is 200 mA and large signal impedance when junction temperature rise is T_j = 200°C. At 11.2 GHz the small signal impedance Z_D is -1.75 + j11 and the large signal impedance is -.7 + j11. Because the impedance is dependent on bias current and RF level, the required value for the design is in between the two provided. As a first attempt the value $Z_D = R_D + j X_D$ of -.7 + j11 is used. The required value for load impedance, $Z_L = R_L + j X_L$, is found from the gain relationship,

$$G = \left|\frac{Z_L - Z_D^*}{Z_L + Z_D}\right|^2$$

where Z_D^* is the complex conjugate of Z_D. If X_D is resonated, then

$$G = \left|\frac{R_L - R_D}{R_L + R_D}\right|^2$$

and R_L is found to be 1.35 ohms.

In order to match the 200 ohm waveguide impedance to the desired Z_L, a proper electrical length ℓ/λ of coaxial line of impedance Z_0 must be chosen. Z_0 is related to the diameter ratio b/a of the outer and inner conductors of the coaxial line.

$$Z_0 = 138 \log \frac{b}{a}$$

The curves in Fig. 2 are solutions of the formula

$$Z_L = Z_0 \frac{200 + j Z_0 \tan 2\pi \ell/\lambda}{Z_0 + j\, 200 \tan 2\pi \ell/\lambda}$$

For Z_L = 1.35 -j11, Fig. 2 shows that ℓ/λ = .132 and b/a = 1.225. The dimensions in Fig.1 may now be calculated. The waveguide used is standard X band waveguide WR90. The dimension b is chosen ".175. It must be mentioned that besides the transformer coaxial line, another powerful means to affect the amplifier performance is to change the dimension of the cavity around the diode. This can be done by a taper or a recess in the collet that holds the diode (see Fig.3). It has been verified experimentally that increasing the taper length A decreases the center frequency and increasing the recess increases the center frequency.

Experimental measurements of the amplifier show that oscillations at 11.9 GHz appear in the circuit when no RF power is injected into the mount. If high enough input RF power is injected in the proximity of 11.9 GHz, oscillations disappear and the device behaves as an amplifier. This can be understood if it is remembered that the diode impedance is lowered by increasing RF level: when the diode acts as an oscillator, its small signal impedance equals the congugate load impedance. When RF is injected, R_D is lowered and, because R_L is unchanged, oscillations are no longer supported and amplification takes place. However, this seems too dangerous a condition to work with and a higher value of R_L is chosen by slightly changing the diameter a. If the value a = ".139 is used and a taper A = ".020 is employed to lower the frequency of operation, oscillations do not take place and a maximum gain of 8.8 dB is measured at 11.8 GHz when input power is 23 dBm.

At 11.8 GHz the load impedance Z_L is found from Fig. 2; entering the graph with

$$\frac{b}{a} = \frac{.175}{.139} = 1.259 \text{ and } \ell/\lambda = \frac{.139}{1.000} = .139,$$

the value Z_L = 1.8 - J 12.2 is obtained. Using the measured value of G and the calculated Z_L it is possible to infer a closer value for the diode impedance.

$$- R_D = R_L \frac{\sqrt{G} - 1}{\sqrt{G} + 1} = .84 \text{ ohms}$$

$$X_D = - X_L = 12.2 \text{ ohms}$$

The diode impedance at the desired frequency of f = 11.2 GHz can be inferred by the graphs presented on data sheets assuming that the variation of impedance vs. frequency is the same as indicated but positioned at a different level: $Z_D = -1.1 + j9$ ohms. Now new values for Z_L and consequently new transformer dimensions can be used to meet the desired specifications: $Z_L = 2.1 - j9$, ℓ = .188, a = .128.

Experimental measurements show that the new transformer also causes oscillations in the circuit when no RF power is injected into the mount; 23 dBm power at 11.2 GHz is measured at the output when I_{DC} = 180 mA. Again a small correction in the circuit eliminates the oscillation. The coaxial line impedance was increased by reducing a to ".124. Now oscillation does not take place and satisfactory amplification performance is obtained at the desired frequency of 11.2 GHz.

Measured data are presented in Fig. 4 which is a graph of gain vs. frequency when bias current is 200 mA and input power is 23 dBm. In the same figure another graph refers to the case of a bias current of 180 mA. The lower bias current decreased the gain in the proximity of the center frequency but did not alter it at the ends of the useful bandwidth.

The maximum bias current to be used for a safe operating condition of the diode is limited by the maximum allowed junction temperature rise ΔT_j. This is related to the current by $\Delta T_j = \theta_T (P_{DC} - P_A)$ where θ_T is the diode thermal resistance. P_{DC} is the DC power delivered to the diode, $P_{DC} = V_{DC} I_{DC}$, and P_A is the RF power generated by the diode, $P_A = P_{out} - P_{in}$.

For Curve 1 of Fig. 4 at the center frequency, ΔT_j is 173°C, and at 11 GHz, ΔT_j is 184°C; for Curve 2 it is respectively ΔT_j = 190°C, ΔT_j = 203°C. The last figure exceeds the 200°C specified for the HP 5082-0611 diode, so operation of this amplifier at 11 GHz and 200 mA would not be recommended.

The effect of taper is clearly shown in Fig. 5. Besides the shift in frequency, a variation of gain is observed because of the variation of diode impedance with frequency. Figure 6 shows power output vs. power input.

CONCLUSION

A procedure has been presented for the design of a waveguide IMPATT amplifier with control of gain and center frequency. With small empirical adjustments, an amplifier was built with 10 dB gain and 2 watts of output power at 11.2 GHz.

REFERENCES

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3. R.L. Eisenhart and P.J. Khan, "Theoretical and Experimental Analysis of a Waveguide Mounting Structure," IEEE Trans. MTT, Vol. MTT-19, No. 8, August 1971, pp. 706-719.

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5. T.S. Saad, Ed., Microwave Engineer's Handbook, Vol. 1, Artech House, Dedham, MA., 1971, p. 95.

ACKNOWLEDGEMENTS

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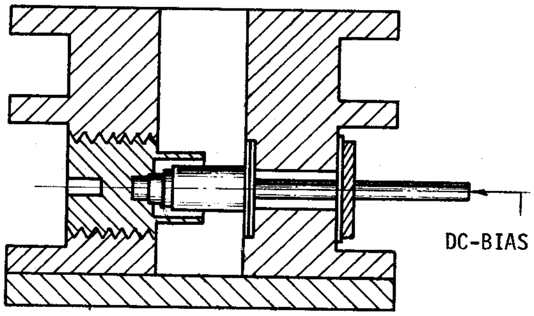

FIG. 1: WAVEGUIDE MOUNT

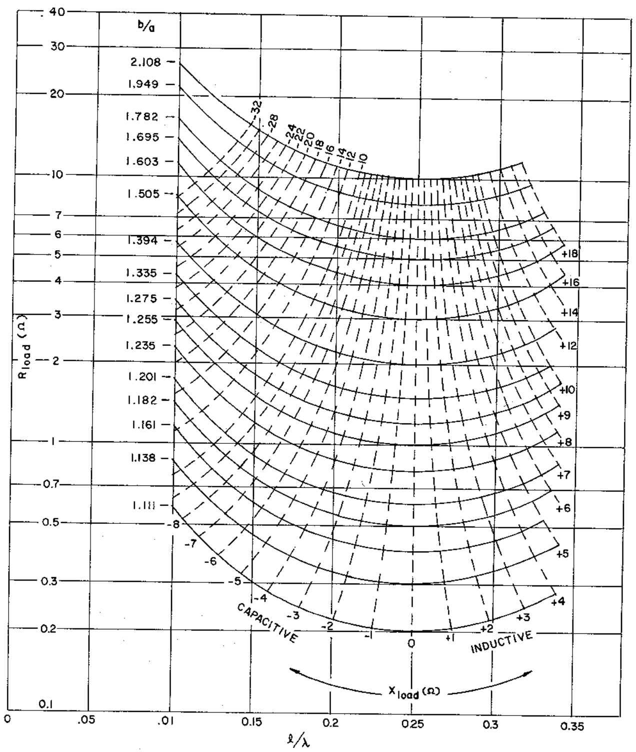

FIG. 2: DESIGN AID

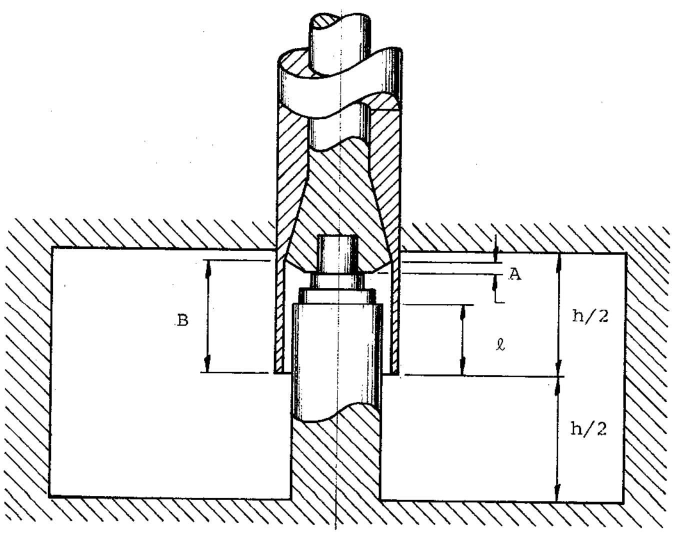

FIG. 3: DIODE MOUNT WITH TAPERED COLLET

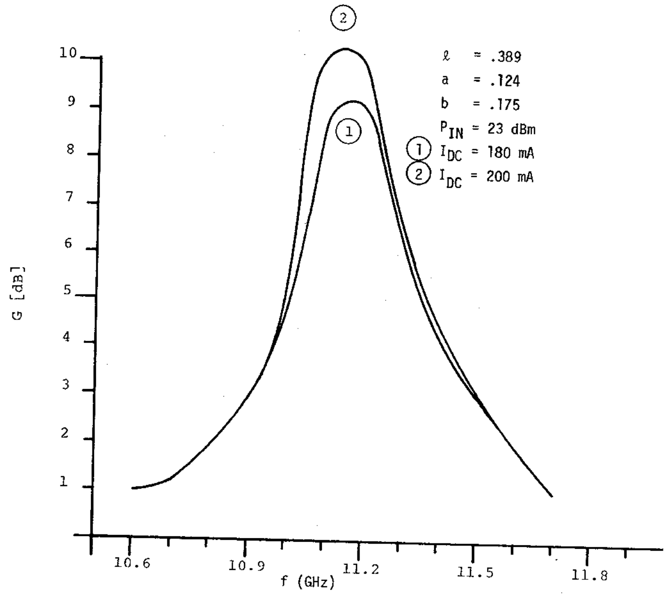

FIG. 4: EFFECT OF BIAS CURRENT ON GAIN CHARACTERISTICS

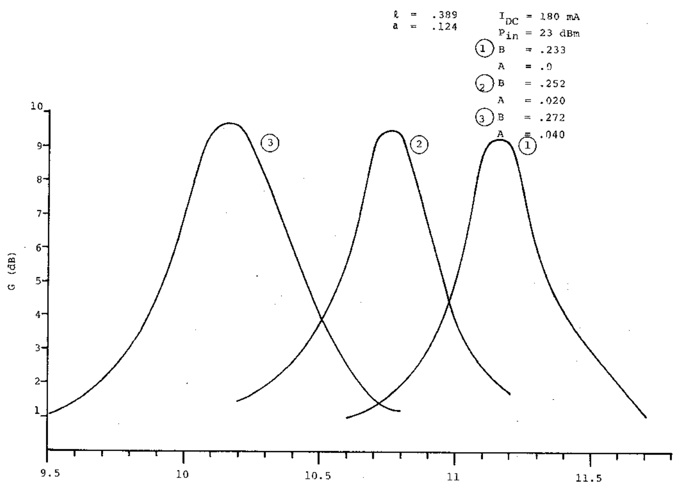

FIG. 5: EFFECT OF TAPER ON GAIN CHARACTERISTIC

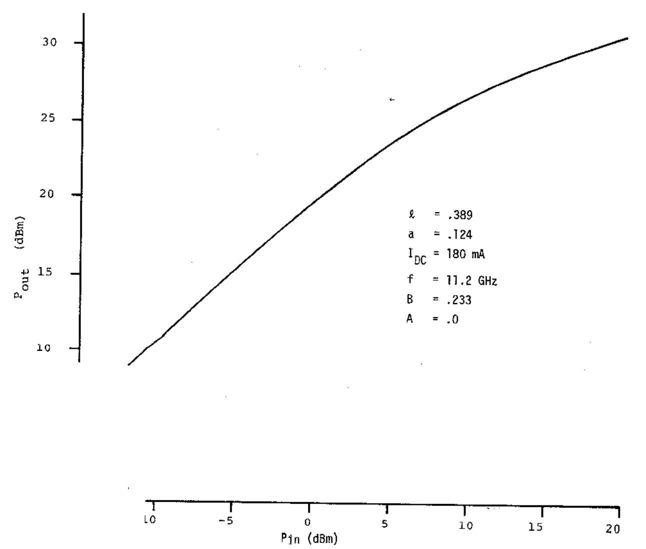

FIG. 6: TRANSFER CHARACTERISTIC