A HIGH-POWER, C-BAND MULTIPLE IMPATT DIODE AMPLIFIER

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Abstract

The design and performance of a high-power, reflection type microwave amplifier is described. The amplifier utilizes four individually matched silicon IMPATT diodes and a hybrid-circuit power-combiner scheme to achieve a CW output of 8 watts at 5.23 GHz with 6-dB gain and a power added efficiency of over 5 percent. FM and AM noise performance of the IMPATT amplifier is compared to that of a medium power klystron. The design of the hybrid-circuit power combiner is outlined and test results obtained on the four-way combiner are presented.

Introduction

Several authors[1,2,3] have demonstrated techniques of combining IMPATT diode oscillators to achieve increased power output at microwave frequencies. Recently, similar approaches have been applied to IMPATT diode reflection type amplifiers[4,5] to enhance the output power capacities of these devices. This paper details the results obtained using a hybrid-circuit to combine the output from four silicon IMPATT diodes, each mounted in its own coaxial matching circuit and heat sink. Test results show the four-diode amplifier has 6-dB gain and 5-percent power-added efficiency at an output power level of 8 watts in the 5.20-GHz range. Output power of nearly 10 watts was obtainable with better power-added efficiency; however, the amplifier gain dropped to 4.9 dB for this power level.

Single Diode Amplifier Module

Four amplifier modules were constructed using high-power silicon IMPATT diodes (HP 5082-0467 silicon IMPATT diodes), similar to those described by Cowley and Patterson.[6] Each diode consisted of a parallel array of four mesas on a silicon chip. The mesas are connected electrically in parallel in a microwave varactor package, and behave as a single avalanche diode of quadruple the area of a single mesa. These p^+-n-n^+ diodes have a depletion width of ≈7 μm and yield a maximum output power of from 1.75 to 2.0 watts at 5.6 GHz when operated as an oscillator. The amplifier modules were constructed by mounting the IMPATT diode packages at the end of a singly tuned quarter wavelength coaxial matching circuit of 14.2 Ω characteristic impedance. The outer conductor around the diode is removed to form a small radial tuning cavity which is used to adjust the center frequency of the IMPATT amplifier. The dc input to the diode passes through a low-pass dc stabilization circuit to isolate the power supply from the active device and prevent any bias circuit interactions (the low-pass circuit consists of a two-section filter and ferrite-bead RF termination).

Typical test results obtained for the four single diode amplifier modules used in the final high-power amplifier (operation near 5.2 GHz) are summarized in Table 1.

Table 1

SINGLE DIODE (HP 5082-0467) AMPLIFIER RESULTS

Amplifier Number	Output Power (W)	Power Added (W)	Gain (dB)	Power Added Efficiency (percent)
1	2.28	1.73	6.17	5.15
2	2.21	1.66	6.04	5.18
3	2.44	1.90	6.57	6.07
4	2.27	1.72	6.16	6.04

The power added efficiency is defined as the power added (RF output power minus RF input power), divided by the total dc input power.

Power Combiner Circuit

Several methods of power combination using IMPATT diodes have been demonstrated.[1,2,3] We have chosen to use a hybrid-circuit power combiner scheme for implementation of the four-diode high-power amplifier. The power-combiner circuit design was based on the theory of three-port TEM-mode hybrids developed by Cohn.[7] A two-section hybrid was found to have adequate bandwidth for the desired amplifier application. The initial design values of the combiner circuit were taken from Ref. 7. However, in Ref. 7 the pairs of transmission lines are assumed to be uncoupled. (If the lines are coupled, the even- and odd-mode impedances (Z_{oe} and Z_{oo}) must be considered in the analysis of the device performance.) This assumption is not applicable for operation at 5 GHz when small chip isolation resistors are used. The initial circuit design was therefore subjected to a computer analysis and optimization. The analysis took into account (1) the finite coupling between the pairs of transmission lines, (2) the finite inductance of the chip resistors, and (3) the finite Q of the transmission lines. Figure 1 shows the basic two-way power combiner circuit (from which the four-way combiner is made) and the computed performance of the final design. Figure 2 shows the four-way hybrid combiner fabricated as a microstrip circuit on 1/16-inch Duroid printed circuit board (ϵ_r = 2.25). The thin copper patterns were produced by standard photoetch techniques, and thin-film chip isolation resistors were solder mounted to the lines for increased ruggedness.

Series dc blocking capacitors were also incorporated into each amplifier port of the power combiner (under the connector tabs) to isolate the RF output sum port from the dc bias applied to the avalanche diodes. To minimize the losses, it was found necessary to enclose the circuit with a metal cover. This tended to cause some deterioration in the isolation and power-division properties owing to waveguide modes propagating in the closed metal case. To circumvent this deterioration, two short circuit posts were used to suppress these disturbances or shift them far outside the frequency band of interest.

Figure 3 gives a summary of the measured performance of the complete four-way power-combiner circuit. Over the frequency range 5.0 to 5.3 GHz, the VSWR of the sum port, Port 1, with all the other ports terminated in 50 Ω was less than 1.2; the VSWR of any of the four output ports, Ports 2 to 5, with all other ports terminated was less than 1.13. Figure 3 also gives the measured isolation between two opposite amplifier ports (2 and 3) and two diagonal ports (3 and 5) across the frequency band of interest. The greater than 18-dB isolation between any two amplifier ports is substantially above the gain available from any amplifier and ensures stable amplifier operation when the four individual amplifiers are combined.

Thus the performance of the four-way power combiner is in good agreement with the computed results. This implementation is desirable because it is easy to fabricate, all dimensions and resistor values being easily achievable with standard manufacturing techniques.

High-Power Four-Diode Amplifier Performance

The four-diode amplifier was completed by attaching the four individually matched amplifier modules to each of the output ports of the hybrid circuit power combiner described above.

The measured performance of the four-diode amplifier at its optimum frequency of 5.23 GHz is summarized in Table 2.

Table 2

FOUR-DIODE AMPLIFIER TEST RESULTS

Output Power (W)	Power Added (W)	Gain (dB)	Power Added Efficiency (percent)
8.17	6.16	6.08	5.08
9.12	6.43	5.31	5.30
9.60	6.50	4.98	5.37

The results of measurements of swept-frequency output power versus input power for the four-diode amplifier are shown in Fig. 4. The three upper curves display the input power to the amplifier, while the lower curves give the corresponding output power levels. The total dc input power and 1-dB bandwidth of the amplifier, given in the insert, show bandwidth expantion from 350 MHz for a 2-watt input to 400 MHz at 3 watts. The amplifier test results show that the four-way power-combiner circuit performs as predicted from its network analyzer measurements. No spurious interactions occur between the single-diode amplifiers, with each performing as if it were being operated in an isolated 50-Ω system. These swept frequency measurements on the amplifier reveal the output signal to be free from any unwanted "jumps" or spurious triggered responses present in some avalanche diode amplifiers.[8]

The FM and AM noise characteristics of this IMPATT diode amplifier have been carefully measured, and are compared to that of a medium power klystron. In this test, the FM and AM noise close to the carrier was measured on the amplifier when it was being driven to ≈6 watt output level by a Varian Model VA-259-dB klystron source.

The same measurements were then repeated on the klystron driver alone, and the results of these two sets of measurements were plotted for easy comparison. This comparative noise measurement technique[9] is a standard test used to evaluate high-power microwave amplifiers in all frequency ranges from C band through K band. A comparison between FM and AM driver noise and driver-plus-amplifier noise is shown in Figure 5, covering the frequency range from 2 to 100 kHz from the carrier frequency of 5.4 GHz. The test results show the four-diode IMPATT amplifier to have little FM noise (essentially indistinguishable from the source alone) over the 2-to-100-kHz range. The results show that the amplifier contributes some excess AM noise over the klystron, with the largest component (≈88 dB below the carrier) occurring at the 2.0-kHz frequency point.

It is difficult to make direct comparisons of the noise produced by the four-diode IMPATT amplifier with previous measurements carried out on other solid-state or tube amplifiers. It can be stated that the measurements indicate the excess FM noise contributed by the amplifier to be small compared to that of the klystron source (operated as an oscillator).

Summary and Conclusions

To summarize, a high-power reflection type avalanche diode amplifier has been developed that is capable of 8-watt output power with 6-dB gain and 5-percent added efficiency in the vicinity of 5.2 GHz. The amplifier unit uses a microstrip hybrid power-combiner circuit to combine the outputs of four individually matched IMPATT diodes. The measured results show the hybrid circuit technique to be a highly desirable method of combining individual amplifier devices (as illustrated in Fig. 3 by the ≈0.25-dB-per-power-division excess loss of the combiner). It is believed that this simple design approach should allow even larger numbers of devices to be combined to achieve all solid-state high-power microwave amplifiers. The most apparent conclusions drawn from the amplifier noise measurements are: (1) The bias circuit has been designed so as to minimize any up-converted noise contributions, and (2) the IMPATT diodes are terminated with RF loads that permit both low FM noise to be achieved along with large RF power added.

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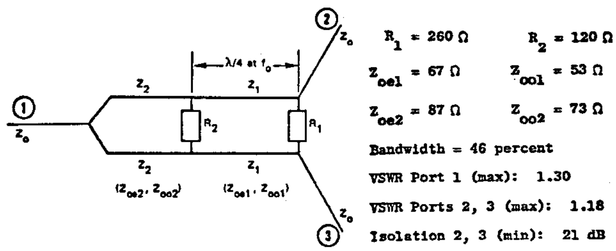

Fig. 1 Modified Design Values and Specifications of Three-Port Hybrid From Computer Analysis

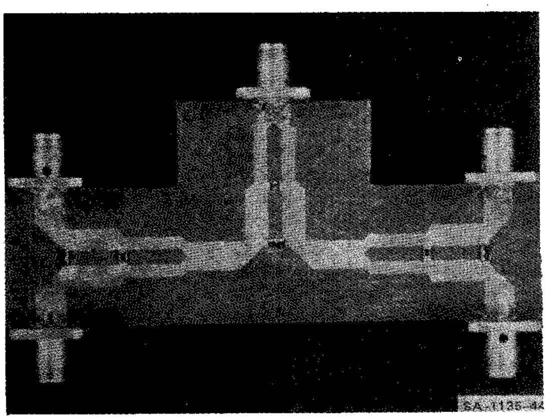

Fig. 2 Photograph of Four-Way Microstrip Hybrid Power Combiner Circuit

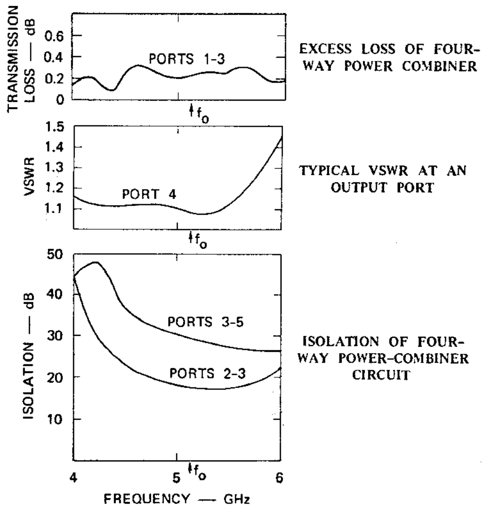

Fig. 3 Typical Performance of Hybrid Power Combiner

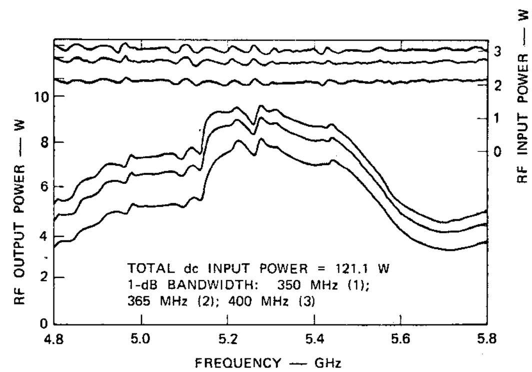

Fig. 4 Swept-Frequency Response Measurement of Four-Diode IMPATT Amplifier at Three Drive Levels

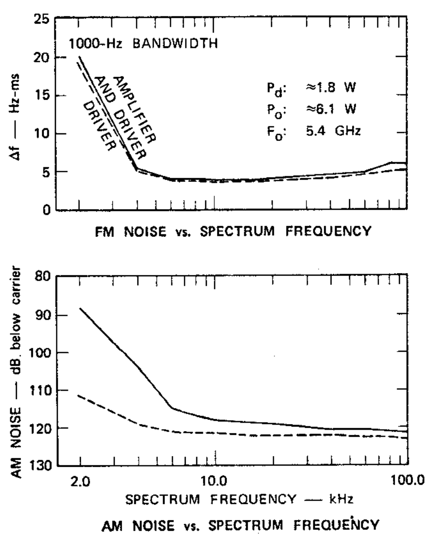

Fig. 5 Comparison of FM and AM Noise Measured on A Low-Noise Klystron Driver and on Four-Diode IMPATT Amplifier-Driver Combination