X-BAND MIC GaAs FET POWER AMPLIFIER*

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Abstract

The microstrip circuit development of an X-band, one watt, 22 dB gain GaAs FET amplifier will be discussed. Microwave performance characteristics such as intermodulation, AM to PM conversion and noise figure will be presented.

Introduction

High-power, high-efficiency amplification of microwave power using GaAs FETs has been demonstrated recently for operating frequencies in C-, X- and Ku-band.[1,2] Single-stage and multistage amplifiers with 1 watt output power have already been reported in the C-band frequencies with a bandwidth of 500 to 600 MHz.[3,4] The feasibility of using the state-of-the art FET in the design of power amplifiers suitable for application as driver amplifiers in the 9 to 10 GHz frequency band will be described. The GaAs FETs used in these amplifiers are similar to those reported elsewhere.[2] The single-cell GaAs FET has a nominal gate length of 1.5 to 2.0 μm with a gate width of 600 μm. Up to four cells can be connected in parallel in a single FET chip to provide a larger gate width for increased output power requirements. Low noise, wide dynamic range, low distortion, and high efficiency are some of the desirable characteristics of this class of solid-state microwave amplifiers. The circuit design effort involved measurements of small- and large-signal S-parameters, broadband microstrip circuit design and dc bias circuitry.

Circuit Development and Microwave Performance

Figure 1 shows a simple, broadband microstrip circuit. The circuit consists of two short sections of impedance transformers ($\sim 0.15\ \lambda$) and a short length of edge-coupled filter ($\sim 0.18\ \lambda$). This matching circuit is less than 0.300 inch long and has been used for the matching of the input and output impedances of the power FET. The edge-coupled filter section also serves as a dc block for the input and output of the amplifier. Microwave tuning has been accomplished by a selective bonding of gold straps to the "tuning pads" that can be seen in the photograph adjacent to the impedance transformers. A fairly wide range of circuit impedances with desirable reactance slope parameters can easily be obtained. The dc blocking scheme described above has also been used successfully in the designs of X- and Ku-band IMPATT/Read Amplifiers.[5,6] The FET device was mounted upright on a Au-plated Cu block sandwiched between the input and output circuits. This device mounting scheme ensures a good rf ground plane and allows for easy device and circuit replacement. Minimum thermal resistance was also obtained by mounting the FET directly on the copper block.

Figure 2 demonstrates the bandwidth capability of the circuit described above. A bandwidth of 3 GHz (7 to 10 GHz) and a gain of 6 ± 1 dB was achieved for a device with a gate width of 600 μm. With a 2400 μm gate-width device, an output power of 1 watt with 4 dB gain and 24.3% power-added efficiency was obtained at a frequency of 9.8 GHz.

Figure 3 shows a photograph of a completely integrated three-stage FET amplifier module. Cascading was achieved by removing the input/output OSM connectors used for testing the individual stage. Three stages were then cascaded by bonding a gold strap between the input and output transmission lines. Each of the amplifier stages was then screwed down to the amplifier housing from the bottom side. One-, two- and three-cell FETs were used in the first, second and third stage, respectively.

The bias networks were provided on each side of the amplifier with a removable circuit board. Two bias pins are provided for the gate and drain dc supplies. Figure 4 shows the output-power frequency response of this amplifier with an rf input power of + 5 dBm. An output power (cw) of 360 mW was achieved with a gain of 20.5 dB at 9.3 GHz. A gain of 20 ± 0.5 dB was obtained over the frequency range from 9.1 to 9.8 GHz. The design 1 dB bandwidth was 600 MHz (9.2 to 9.8 GHz). The 3 dB bandwidth is 1 GHz (8.9 to 9.9 GHz).

To achieve an output power of one watt a fourth stage with a four-cell FET (2400 μm gate width) was added to the three-stage amplifier. Figure 5 shows a photograph of the four-stage amplifier. Figure 6 shows the microwave performance of this amplifier. One watt of output power was obtained with 22 dB gain at 9.5 GHz. The 1 dB design bandwidth was also 600 MHz (9.2 to 9.8 GHz). The small-signal linear gain was 24 dB at 9.5 GHz. A 3 dB bandwidth of 1.1 GHz (9.1 to 10.2 GHz) can be obtained.

Third-order intermodulation distortion was measured for the three- and four-stage amplifiers by injecting two equal amplitude signals separated in frequency by 10 to 50 MHz and located at the band edges and at band center. The input levels of the two signals were increased from -20 dBm to +8 dBm while recording the amplitude of the third-order intermodulation product. From these measurements it can be shown that (1) the third-order distortion is not sensitive to the frequency separation of the two input signals; and (2) the third-order distortion of the FET amplifier is essentially independent of frequency within the amplifier pass band. The output power was typically 20 to 25 dBm at a third-order intermodulation level of -20 dB.

AM to PM conversion measurements were also performed on the one watt, four-stage amplifier. The conversion factor remains below 4 degrees/dB for output powers up to one watt.

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The small signal noise-figure of the three-stage FET amplifier was measured to be in the range of 13 to 15 dB. Considering that the amplifier was not tuned for minimum noise figure (especially the first stage), the noise figure performance was still superior to that of any other solid-state microwave amplifier with comparable output power and gain.

To demonstrate the feasibility of using the FET amplifier as a driver amplifier, a single-stage, X-band IMPATT amplifier was used as the output stage in a four-stage hybrid FET/IMPATT amplifier shown in Figure 7. Figure 8 shows the output-power-frequency response of this amplifier. An output power of 1.2 watts with 26 dB gain was obtained at 9.5 GHz. The 3 dB design bandwidth is 700 MHz (9.1 to 9.8 GHz).

Third-order intermodulation measured with this hybrid amplifier indicates a slight degradation in the nonlinear distortion. This is to be expected, since the highly nonlinear avalanche process of the IMPATT diode will undoubtedly add to the third-order distortion even under medium signal conditions.

The degradation of the noise performance due to the IMPATT stage was also measured. In general, a 3 to 4 dB increase in the small-signal noise figure was observed. This is in close agreement with a prediction based on a theoretical calculation using the gains of the FET and the IMPATT amplifiers and the estimated noise figure of the IMPATT stage ($\sim$35 dB).

With the use of a high-power Read diode amplifier as the output stage, it is possible to design a hybrid amplifier having an output power of 5 to 10 watts, while still having the desirable characteristics of low-noise and low distortion.

Conclusions

The feasibility of using the state-of-the art GaAs FET devices in the design of power amplifiers suitable for application as driver amplifiers in the 9 to 10 GHz frequency band has been demonstrated. It is shown that one watt of cw output power can be obtained with 22 dB gain with a single-ended amplifier design. Microwave performance characteristics such as intermodulation, AM to PM conversion and noise figure have also been presented.

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Figures

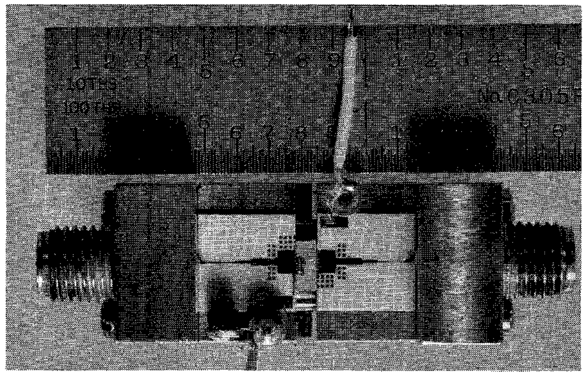

Figure 1. A Simple Microstrip FET Amplifier

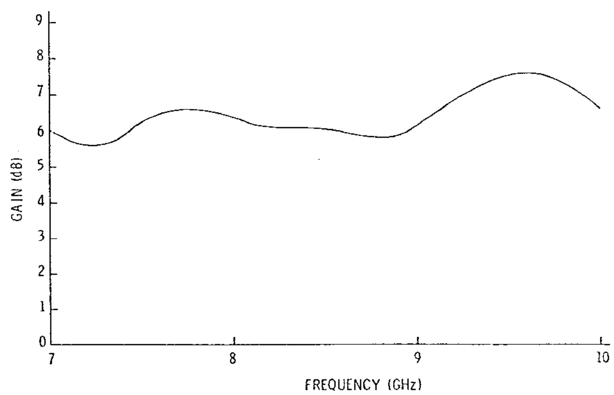

Figure 2. Gain-Frequency Response of a Single-Stage GaAs FET Amplifier

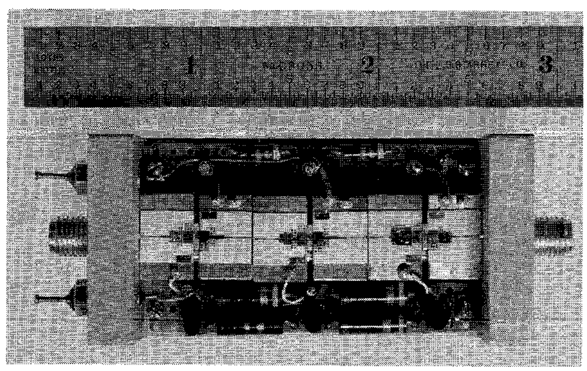

Figure 3. Photograph of Three-Stage Power FET Amplifier

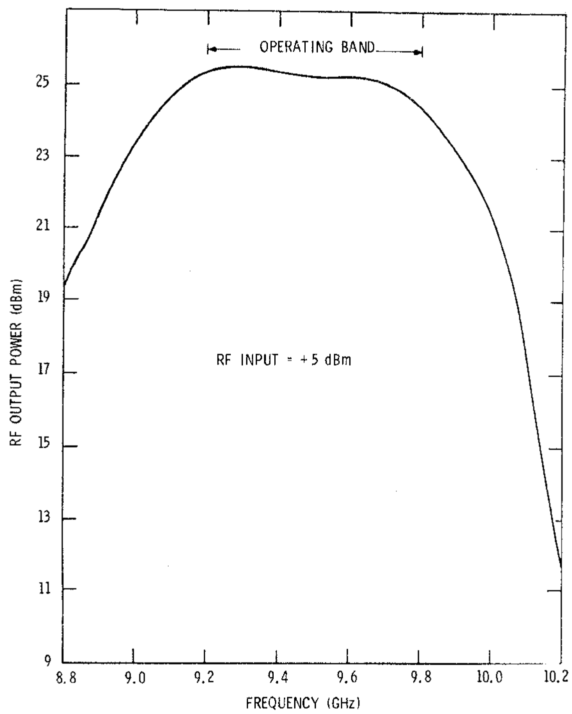

Figure 4. Output Power versus Frequency Response of the FET Amplifier Shown in Figure 3.

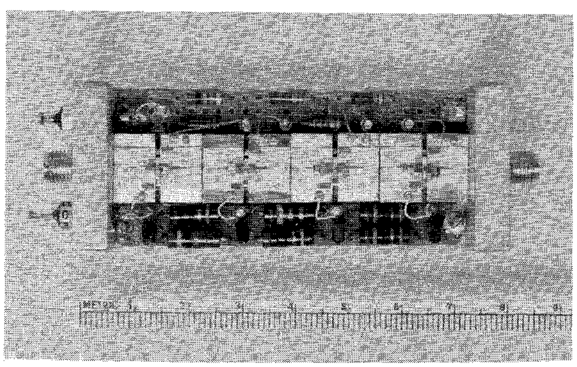

Figure 5. Photograph of a Four-Stage Power FET Amplifier

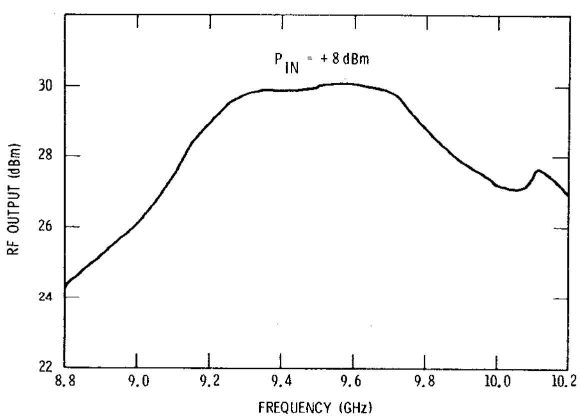

Figure 6. Output-Power-Frequency Response of a Four-Stage FET Amplifier

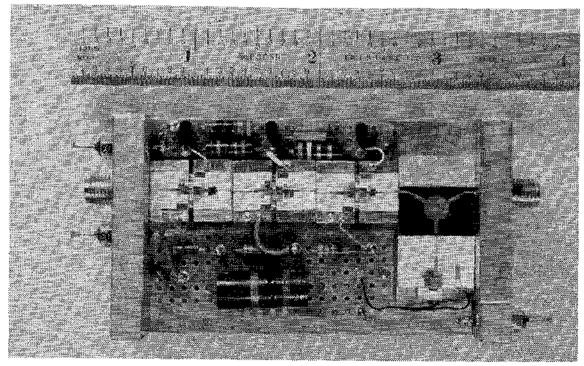

Figure 7. A Photograph of a FET/IMPATT Hybrid Amplifier

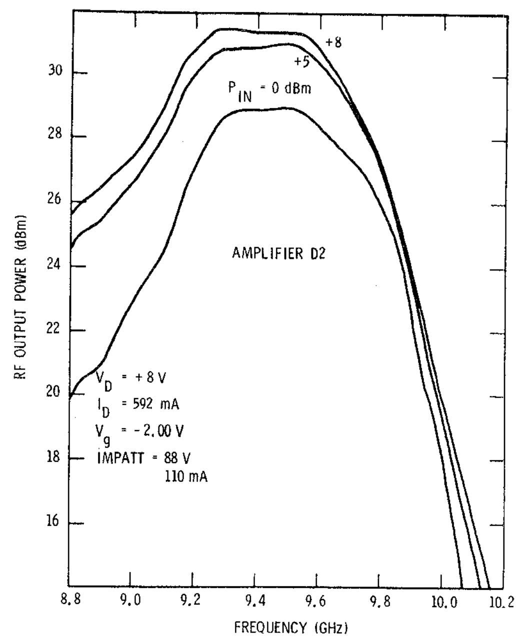

Figure 8. Output Power versus Frequency Response of the FET/IMPATT Amplifier Shown in Figure 7