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A 6-GHz Four-Stage GaAs MESFET Power Amplifier

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***Abstract*—A 6-GHz GaAs MESFET power amplifier with 1-W output power, 26-dB gain, and 8-dB noise figure is described. It is a fully integrated four-stage amplifier with an efficiency of 22 percent. The third-order intermodulation product is 31.5 dB below the carrier at an output power of 1 W.**

I. Introduction

Gunn and IMPATT diodes have been widely used as high-power devices in microwave oscillators and amplifiers for radio-communication systems in the frequency range beyond 6-GHz [1]–[3]. Considering the recent progress in the fabrication and performance of the high-power GaAs MESFET [4], this three-terminal device is expected to replace conventional two-terminal devices in system applications.

Many authors have reported low-noise and small-signal FET amplifiers [5], [6] and also high-power GaAs MESFET devices [7], [8]. This short paper describes the performance of a 6-GHz four-stage GaAs MESFET high-power amplifier which was fabricated on a Teflon-glass-fiber printed-boards with microstrip circuits. The bandwidth, the power variation with temperature, the third-order intermodulation, and the AM-to-PM conversion of the completed amplifier are discussed.

Manuscript received September 30, 1975; revised December 15, 1975.
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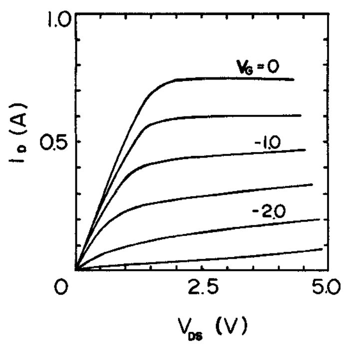

Fig. 1. Static current-voltage characteristics of a power FET with the gate-source voltage as a parameter. The vertical scale shows source-drain current I_{DS} (100 mA/div) and the horizontal scale shows source-drain voltage V_{DS} (500 mV/div).

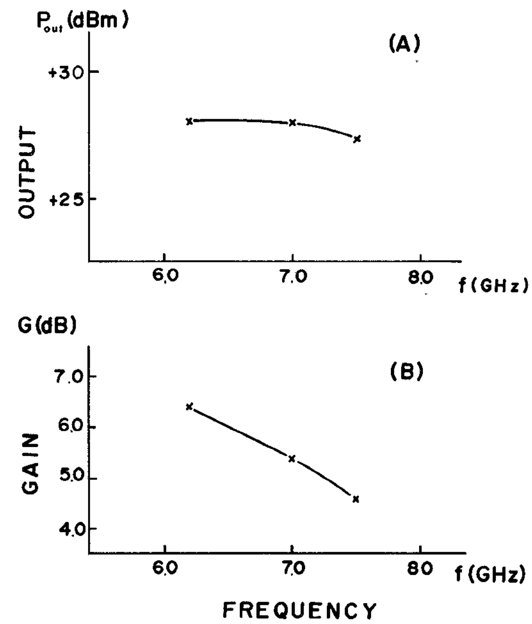

Fig. 2. Frequency response of an FET power amplifier. (a) Output power at 1-dB gain compression point. (b) Small-signal gain.

The four-stage amplifier has the following characteristics: the output power is +30.2 dBm with a gain of 26.2 dB and a noise figure of 8 dB. The 3-dB bandwidth is almost 200 MHz and the third-order intermodulation product is 31.5 dB below the carrier at an output power level of 1 W. The amplifier power efficiency exceeds 22 percent.

II. A Microwave Power GaAs MESFET

A microwave high-power GaAs MESFET is composed of many small-signal FET's which are connected in parallel yielding a high drain current. Some characteristics of the GaAs MESFET's incorporated in this amplifier will be introduced. The static current-voltage characteristic of the FET was measured using a curve tracer to determine the dc bias point for class A common-source operation. Typical V_{DS}–I_{DS} characteristics are shown in Fig. 1. The frequency response of a high-power GaAs MESFET was measured, and is shown in Fig. 2. The output power at the 1-dB gain compression point remains almost constant over the

TABLE I
INPUT AND OUTPUT IMPEDANCES OF THE FET AT TWO DIFFERENT SIGNAL POWER LEVELS

Signal Level	Input Impedance	Output Impedance	Method
Small	7.3 + j14.0 (Ω)	16.5 - j5.5 (Ω)	S-parameter Measurement
Small	5.0 + j16.5	12.8 + j13.3	Conventional substitution method
Large	4.5 + j13.5	14.8 + j13.0	

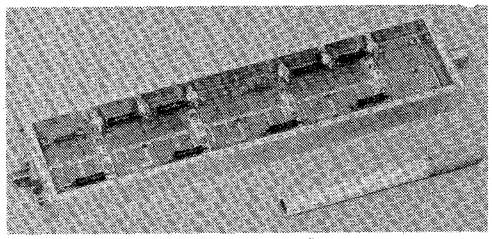

Fig. 3. A photograph of the four-stage amplifier chain with 1-W output power. The size is 19.0 cm × 4.0 cm × 2.6 cm.

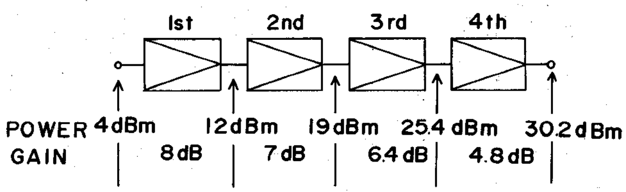

Fig. 4. A block diagram of the four-stage amplifier. Power levels and power gain of each stage are shown.

frequency range of 6.1–7.5 GHz [Fig. 2(a)], but the small-signal gain varies by 1.8 dB [Fig. 2(b)].

III. A FOUR-STAGE GaAs MESFET AMPLIFIER

First, a single-stage amplifier which is a component of the four-stage amplifier chain will be described. We measured small-signal S-parameters with 50-Ω source and load impedances for the first step and designed the matching circuits. However, those circuits needed some modifications when the amplifier was optimized for output power. This was due to the fact that the input and output impedances calculated from the S-parameters differed from those of a FET operating at a high-power level. The dynamic impedance (input and output impedances of the FET, which actually operates as an amplifier) at two different power levels were measured with the conventional substitution method. The results are shown in Table I. The input dynamic impedances at two power levels are almost the same as the impedance derived from the small-signal S-parameter S_{11}. However, the output impedances differ from S_{22}.

Next, the experimental data of an amplifier chain will be described. A photograph and a block diagram of the amplifier chain are shown in Figs. 3 and 4. Each amplifier stage was designed using the procedure previously described. The circuits were fabricated on 0.8-mm-thick Teflon-glass-fiber printed-boards mounted on aluminum carriers. Each stage was made as a unit of an amplifier chain. Since the input and output impedances of all stages are matched at the input and output to 50 Ω, four amplifiers were connected in cascade without any isolators and mounted in an aluminum housing. This amplifier chain can deliver an output power of 1 W with a gain of 26 dB and a bandwidth of 200 MHz. The output versus input power and the temperature dependence of the output power versus frequency are shown in Figs. 5 and 6. The power saturation was mainly determined by the last stage. The other stages were operating in a linear region. At the center frequency ($f = 6.2$ GHz), the output power P_0 varies by 0.8 dB[1] over the temperature range from 0 to 50°C. A noise figure of 8 dB, an efficiency of 22 percent, a third-order intermodulation product 31.5 dB below the carrier at an output power level of 1 W (2-dB gain compression point), and an AM-to-PM conversion of 1.2 deg/dB were obtained with this amplifier at 6.2 GHz. The previously mentioned data are summarized in Table II. These results indicate that the FET amplifier is superior to any solid-state high-power amplifier reported to date in this frequency range.

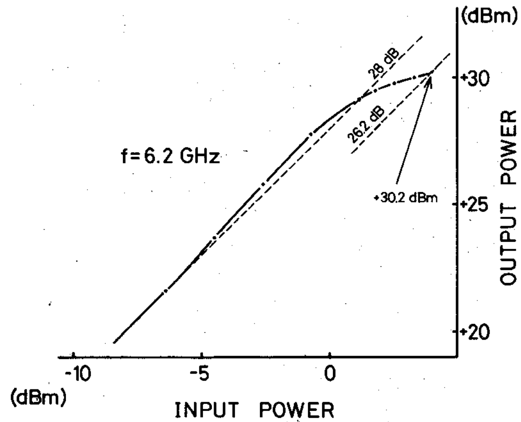

Fig. 5. Output versus input power of the four-stage amplifier at 6.2 GHz.

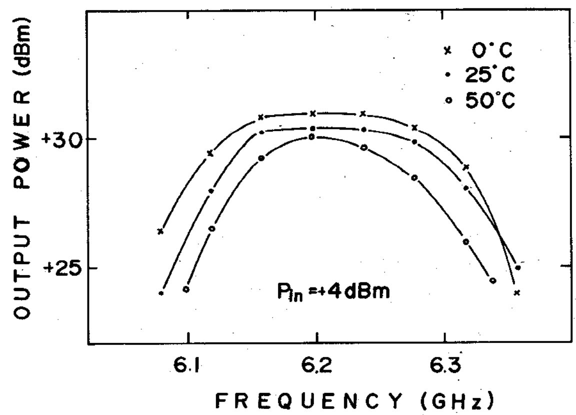

Fig. 6. Temperature dependence of the output power versus frequency.

[1] P_0 increases about 0.5 dB from 25 to 0°C, and decreases 0.3 dB from 25 to 50°C.

TABLE II
CHARACTERISTICS OF THE HIGH-POWER FET AMPLIFIER

Frequency	6.2 GHz
Output Power	30.2 dBm
Gain	26.2 dB
3 dB Bandwidth	200 MHz
DC Input Power	4.74 watt
Efficiency	22 %
AM-PM at P=+30 dBm	1.2 deg/dB
Noise Figure	8 dB
3rd order IM Distortion at P=+30 dBm	31.5 dB

IV. CONCLUSION

A four-stage GaAs MESFET power amplifier capable of delivering 1-W output power with 26-dB gain has been discussed. This amplifier was developed for a microwave FM radio relay. The third-order intermodulation product of this amplifier chain was 31.5 dB below the fundamental and the power efficiency was 22 percent.

ACKNOWLEDGMENT

The authors wish to thank Dr. K. Kurokawa for supporting this work, and T. Sekizawa for his kind guidance in the development of the microwave high-power FET amplifier. They also appreciate stimulating advice and cooperation recieved from H. Ishikawa, M. Fukuta, H. Suzuki, and K. Suyama.

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Letters

Feedback Effects in the GaAs MESFET Model

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Abstract—**GaAs MESFET models correctly predict a positive feedback conductance. The effect of common-lead inductance on y_{12} using computer modeling techniques is examined. Experimental data are also included which indicate that the common-lead inductance of about 0.06 nH cannot be omitted from the model in order to accurately predict the feedback conductance.**

Several authors [1]–[3] have reported the existence of a positive feedback conductance term in both MOSFET and MESFET devices. This result is usually observed by calculating $g_{12} = \mathrm{Re}\,(y_{12})$, which is positive for a negative resistance between gate and drain. Both Johnson [1] and Dawson [3] have shown that a positive g_{12} may be explained by an internal capacitance between drain and channel interacting with input capacitance and common-lead resistance, which produces a positive g_{12} proportional to f^2.

Manuscript received October 2, 1975; revised December 11, 1975. This work was sponsored by the Fairchild Semiconductor, Transistor Division, Microwave Group, Mountain View, CA 94042.
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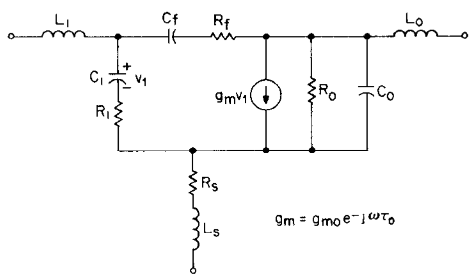

Fig. 1. GaAs MESFET Model (1-μm gate length). Fairchild element values: $R_i = 11\ \Omega$, $R_0 = 400\ \Omega$, $R_f = 237\ \Omega$, $R_s = 7.28\ \Omega$, $C_i = 0.25$ pF, $C_0 = 0.04$ pF, $C_f = 0.007$ pF, $L_s = 0.059$ nH, $L_i = L_0 = 0.3$ nH, $g_{m0} = 20$ mS, $\tau_0 = 5$ ps.

In this letter a slightly different chip model [4], which includes inductances at all three terminals, will be used to calculate feedback effects. The importance of including common-lead inductance will become apparent since g_{12} increases significantly due to this element. Experimental data for GaAs MESFET chips are also included in order to verify the validity of the model.

The circuit model [4] used for the GaAs MESFET is given in Fig. 1. This model is slightly different from Dawson's because the drain capacitance C_0 is returned to the common-source