A HIGHLY-EFFICIENT 7-WATT 16 GHz MONOLITHIC PSEUDOMORPHIC HEMT AMPLIFIER

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ABSTRACT

A record cw output power of 7-W with 4.5-dB gain and 30.8% power-added efficiency was achieved with a monolithic, single-stage, 0.25 μm x 12-mm AlGaAs/InGaAs pseudomorphic HEMT amplifier at 16.3 GHz. At 5-W output, the power-added efficiency was 35% with 6-dB power gain. The chip size is 3-mm x 3.5-mm.

INTRODUCTION

Tremendous progress has been made in the development of AlGaAs/InGaAs pseudomorphic HEMTs for high-efficiency power amplifier applications at microwave and millimeter-wave frequencies. This class of device is characterized by high transconductance and current, which result in high power density, gain, and efficiency. So far, most of the reported work has been on either discrete devices or hybrid amplifier circuits [1-3]. This paper reports the development of an efficient, totally monolithic Ku-band amplifier with multiwatt output for power transmitter applications in high-performance microwave systems.

AMPLIFIER DESIGN

Double heterojunction pseudomorphic HEMTs with parallel gate fingers (0.25 μm gate length) and air bridge source interconnects were used in the MMIC amplifier design. The amplifier consists of eight unit cells with each cell having 1500-μm gatewidth for a total gatewidths of 12-mm. Electron-beam defined 0.25-μm gates were used for enhanced gains at Ku-band. The MBE grown structure consists of an undoped InGaAs channel layer sandwiched between two AlGaAs layers (Figure 1). Silicon planar doping was used on both the upper and lower AlGaAs layers to provide carriers to the InGaAs channel. The indium concentration is nominally in the 15 to 20% range to ensure good transport property. The single quantum well thus formed will provide efficient carrier modulation at microwave frequencies. An AlAs/GaAs superlattice buffer was used to improve the interface between the substrate and the active channel.

The amplifier design was based on a small-signal device model with modified load-line for optimum large-signal performance. The 1500-μm unit cell was included in the mask for on-wafer S-parameter measurements and subsequent modeling work. Figure 2 shows the measured and modeled S-parameters of the unit cell over the 0.1 to 40 GHz frequency range. The agreement between the modeled and measured S-parameters is excellent. The device was biased at a drain voltage of 6 V with a drain current of 285 mA. Figure 3 shows the measured and calculated power gain (MSG/MAG) and current gain (h_{21}) of the same device as a function of frequency. Again, the fit is excellent. The extrapolated current gain cutoff frequency, f_t, is about 35 GHz.

Figure 4 shows a photograph of the MMIC amplifier. The chip measures 3-mm by 3.5-mm. The GaAs substrate thickness is 4 mils (0.1 mm). A simplified schematic circuit diagram of the one-stage amplifier is shown in Figure 5. A binary cell combining scheme was adopted for preserving the amplifier bandwidth and maximizing the cell combining efficiency. Multiple low-pass sections with high-impedance transmission lines and shunt MIM capacitors were used to allow optimum impedance matchings. Because of the lower device input impedance, more matching sections were required for the input circuit. Integrated gate and drain bias networks as well as input/output coplanar rf probe pads were also provided. Special precautions were used in the circuit design and layout to prevent possible detrimental "odd-mode" oscillations [4].

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AMPLIFIER PERFORMANCE

The MMIC amplifier chip was mounted in a gold-plated carrier for rf testing in a 50-ohm system. A small-signal gain of 8-dB at a drain voltage of 3 V was obtainable at mid-Ku-band frequencies. Figure 6 shows the power performance of the amplifier at a drain voltage of 7-V. At 16.3 GHz, an output power of 5-W with 6-dB gain and 35% power-added efficiency (PAE) was achieved. The 1-dB bandwidth was about 1 GHz. The amplifier performance at higher drain voltages is summarized in Table 1. At a drain voltage of 9-V, a record cw output power of 7.13-W with 4.53-dB gain and 30.8% PAE was achieved. The power density per unit chip area is a respectable 0.68 W/mm^2.

CONCLUSION

High power MMIC amplifiers using pseudomorphic AlGaAs/InGaAs HEMTs were demonstrated at Ku-band. A record cw output power of 7-W with 4.5-dB gain and 30.8% power-added efficiency was achieved with a single-stage, 0.25 μm x 12-mm amplifier at 16.3 GHz. At 5-W output, the power-added efficiency was 35% with 6-dB power gain. The demonstrated performance makes pseudomorphic HEMTs highly suitable for multi-watt MMIC amplifier implementations at X- and Ku-band frequencies for advanced microwave system applications.

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Table 1. Amplifier Performance at 16.3 GHz

Power (W)	Gain (dB)	P.A.E. (%)	Vd (V)	Id (A)
5.00	6	35	7	1.53
6.31	5	33.1	8.3	1.57
7.13	4.53	30.8	9	1.67

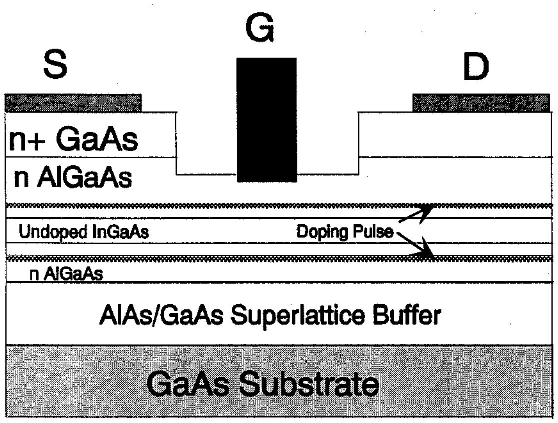

Fig. 1. Pseudomorphic HEMT structure.

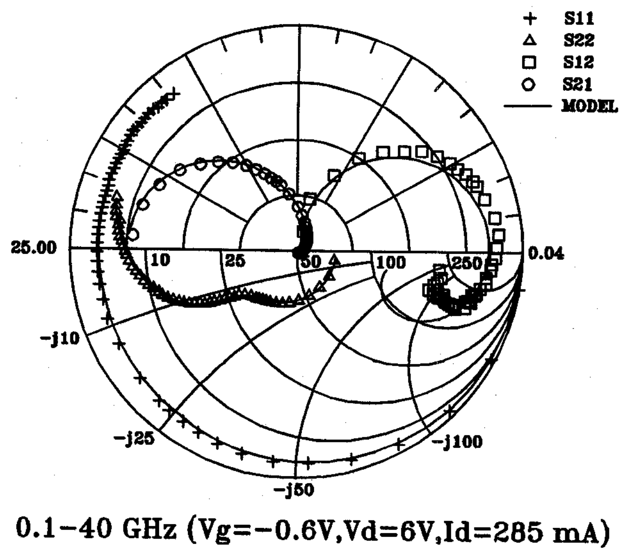

Fig. 2. Modeled and measured S-parameters of a 1500-μm gatewidth pseudomorphic HEMT.

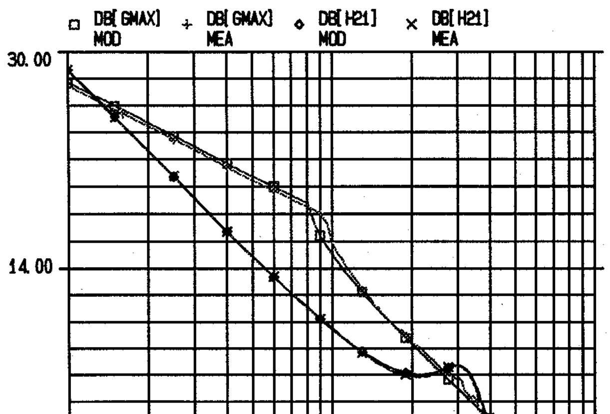

Fig. 3. Calculated and measured small-signal gains of a 1500-μm gatewidth pseudomorphic HEMT.

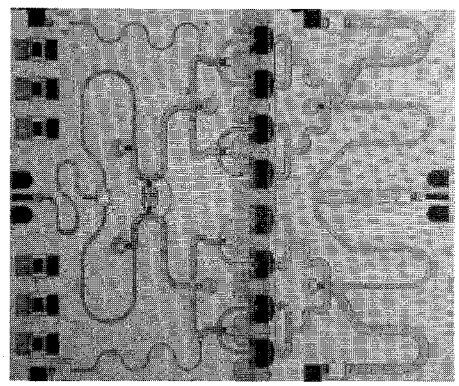

Fig. 4. Single-stage MMIC amplifier.

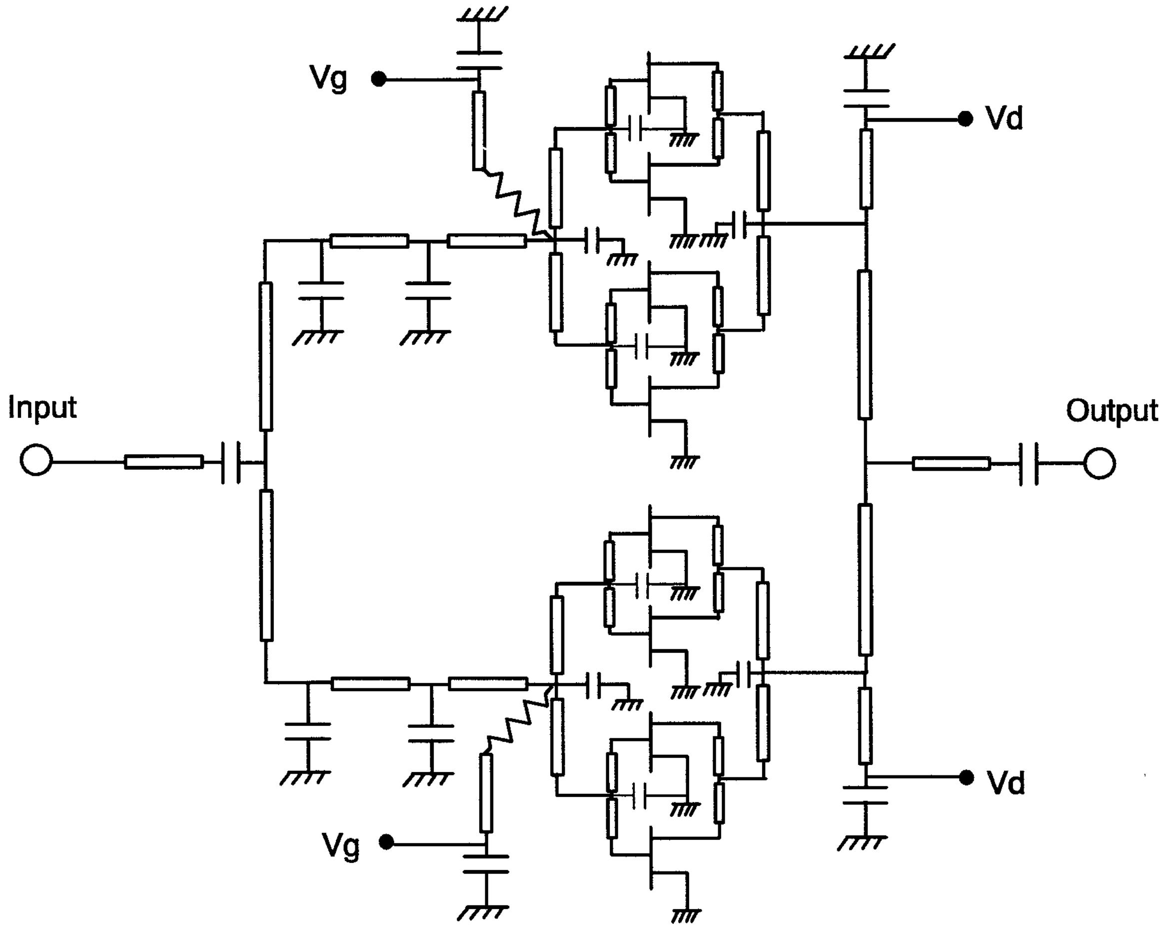

Fig. 5. Simplified schematic circuit diagram.

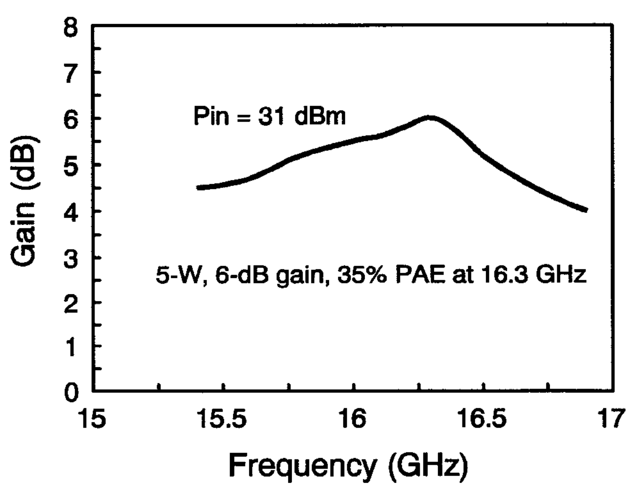

Fig. 6. Amplifier performance.