PERFORMANCE COMPARISON OF 1 WATT Ka-BAND MMIC AMPLIFIERS USING PSEUDOMORPHIC HEMTs AND ION-IMPLANTED MESFETs

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ABSTRACT

We have demonstrated a high-gain, high-efficiency Ka-band three-stage MMIC power amplifier providing >1 watt CW output power, >20 dB power gain, with an average 35% power-added efficiency (37% peak) over a 26.5 to 28 GHz band using 0.25 μm AlGaAs/InGaAs pseudomorphic HEMT (pHEMT) process technology. The pHEMT amplifiers exhibit third-order intermodulation products >29 dBc with the output power backed off by 5 dB. As an alternate low-cost solution, we processed three wafers of the Ka-band monolithic amplifier designed with pHEMT technology using direct ion-implanted 0.2 μm GaAs MESFETs achieving >1 watt CW output power, >18 dB power gain, with an average 24% power-added efficiency (27% peak) over the band. The MESFET amplifiers demonstrate third-order intermodulation products >21 dBc with the output power backed off by 5 dB. All amplifier results reported here contain no de-embedding of fixture and connector losses. This paper presents 0.25 μm pHEMT and 0.2 μm MESFET device results, as well as amplifier design and performance over a 26.5 to 28 GHz band.

I. INTRODUCTION

Highly efficient, compact solid-state power amplifier modules are required for emerging wireless communication applications at Ka-band frequencies. Because of its excellent transport properties, pseudomorphic HEMT is ideally suited for MMIC amplifier implementation for high-efficiency, high-gain applications at these frequencies. For commercial applications, production cost is also a major design consideration. Ion-implanted MESFETs have been proven to have a cost advantage from material and processing standpoints. In this paper, we compare the performance of a three-stage amplifier using both pHEMTs and ion-implanted MESFETs as the active devices. Output power, gain, efficiency, and intermodulation distortion are compared.

II. DEVICE CHARACTERISTICS

Double heterojunction pseudomorphic HEMTs with electron-beam defined 0.25 μm gate lengths were used in the amplifier design. The MBE-grown structure consists of an undoped InGaAs channel between two low-doped AlGaAs layers. The indium concentration is 18% to ensure good transport property. Carriers are provided to the channel by silicon planar-doped layers on both the upper and lower AlGaAs layers. An AlAs/GaAs superlattice buffer provides an improved interface between the channel and GaAs substrate. Above the upper AlGaAs layer is a low-doped GaAs layer followed by an n+ GaAs cap layer completing the structure. We etched a "wide recess" into the GaAs and AlGaAs layers, which provides the best compromise between f_t and breakdown voltage. I_{dss} is 230 to 250 mA/mm with a 0.8 V pinch-off voltage. Maximum transconductance is 450 mS/mm with an I_{max} of 550 to 600 mA/mm. The channel breakdown voltage at 1 mA/mm is 13 to 15 V.

The MESFET is made by silicon beryllium co-implantation. The gate length is 0.2 μm. I_{dss} is 230 to 250 mA/mm with a 1.3 V pinch-off voltage. Maximum transconductance is 250 mS/mm with an I_{max} of 490 mA/mm. The source-drain breakdown voltage is 5 V at 1 mA/mm and 10 V at 10 mA/mm.

Figure 1 shows the s-parameter measurements of g_{max} and h_{21} for 0.25 × 600 μm pHEMT and 0.2 × 600 μm MESFET devices. From the plot, f_t can be extrapolated at 33 GHz with a 78 GHz f_{max} for the 600 μm pHEMT, and 31 GHz f_t with a 76 GHz f_{max} for the 600 μm MESFET.

The devices were tuned for maximum power-added efficiency (PAE) using an automated loadpull testset. Figure 2 shows measured output power and PAE performance at 27 GHz for 600 μm pHEMT and MESFET cells from the maskset. The pHEMT has 45% maximum PAE with 25.2 dBm (552 mW/mm) output power at V_d = 6 V. The MESFET has 37% maximum PAE with 24.9 dBm (515 mW/mm) output power at V_d = 6.5 V.

III. AMPLIFIER DESIGN

The 1 watt, Ka-band monolithic amplifier was designed using 0.25 μm pHEMT technology for high gain and efficient operation. As an alternate low-cost solution, we processed the MMIC amplifier designed for pHEMT using 0.2 μm ion-implanted MESFET technology without any circuit modifications. Figure 3 shows a photograph of the MMIC amplifier. The chip measures 3.0 mm by 4.1 mm on a 0.1 mm GaAs substrate.

The amplifier design is based on characterization of a 600 μm pHEMT cell from a prior maskset with 8 gate fingers (0.25 μm gate length, 75 μm gate width each) and airbridged source interconnects. A measured 600 μm maximum PAE load impedance of 32 Ω and 0.2 pF was used in designing the 2.4 mm output and 1.2 mm interstage networks. For enhanced performance at Ka-band, we modified the 600 μm cell topology to 10 gate fingers (0.25 μm gate length, 60 μm gate width each), with a reduced gate-to-gate spacing to minimize source inductance and enhance device gain, while maintaining adequate thermal dissipation. The amplifier achieved 1 watt output power by combining four 600 μm cells using low-loss series transmission lines, and shunt connecting RF-grounded transmission lines that provide shunt inductance at the drain of each 600 μm cell. The binary cell ap-

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proach preserves amplifier bandwidth and maximizes cell combiner efficiency. Based on measured device and amplifier power performance, combiner efficiency is 87%.

The 2.4 mm to 1.2 mm interstage network uses multiple lowpass sections (with MIM shunt capacitors) for bandwidth, a dc blocking capacitor, and shunt transmission lines to provide a high-efficiency load line to the two 600 μm cells.

A 400 μm cell at the input consisting of eight 50 μm wide gate fingers provides additional amplifier gain. The 400 μm to 1.2 mm interstage network was designed to maximize amplifier gain and provide gain flatness. The amplifier input is reactively matched to 50 Ω with a seven-element network that includes shunt and series transmission lines, an input-blocking capacitor, and a shunt MIM capacitor close to the gate of the 400 μm device and crucial to the input match.

Bias is applied through integrated gate and drain networks along the GaAs chip edge, with an option to bias along one side of the chip only. All pHEMT cells contain stability networks to suppress parametric and high-frequency oscillations. In addition, the 1.2 mm interstage and 2.4 mm output stage incorporate high impedance "straps" to prevent "odd-mode" oscillations [1].

IV. AMPLIFIER RESULTS

The MMIC amplifier chips were mounted on gold-plated carriers, with the input and output bonded to short sections of 50 Ω microstrip line on 10 mil thick alumina substrate. RF connections are made to the test fixture with 2.4 mm K-connectors in a WR-28 waveguide testset environment.

Figure 4 shows output power, power gain, and PAE performance for 0.25 μm pHEMT and 0.2 μm ion-implanted MESFET amplifiers. (Note: No waveguide-to-coaxial transitions, or fixture or connector losses are de-embedded.) The pHEMT and MESFET amplifiers were biased at drain voltages of 6 V and 6.5 V, respectively, and measured at input power levels of 10 dBm and 12 dBm, respectively. Both amplifiers maintain output power >1 watt from 26.5 to 28 GHz. The pHEMT amplifiers achieved >20 dB power gain and 35% average PAE (37% peak), with the MESFET amplifiers demonstrating >18 dB power gain and 24% average PAE (27% peak) over the band.

Figure 5 shows measured pHEMT and MESFET amplifier compression characteristics at 27 GHz. The pHEMT amplifier has 23.5 dB small-signal gain and is 2.9 dB compressed at the 37% maximum PAE point; the MESFET amplifier has 22 dB small-signal gain with 3.8 dB compression at the 24% maximum PAE point.

Signals at 27 and 27.0008 GHz (800 kHz offset) were injected into the amplifier and the third-order intermodulation products measured on an HP 8565E spectrum analyzer. Figure 6 shows the resulting pHEMT and MESFET amplifier distortion performance. The pHEMT and MESFET amplifiers exhibit third-order intermodulation products >29 and >21 dBc, respectively, with the output power backed off by 5 dB. At moderate signal levels around 0 dBm, both amplifiers exhibit third-order intermodulation products >32 dBc. Measured third-order intercept point (TOI) at 27 GHz for the pHEMT amplifier is 38.5 dBm. Calculated TOI for the MESFET amplifier based on measured output power at 1 dB compression, +10 dB [2] is 36 dBm.

V. CONCLUSIONS

We have demonstrated 1 watt CW output power, high-gain, three-stage MMIC amplifiers using 0.25 μm pseudomorphic AlGaAs/InGaAs HEMTs and 0.2 μm ion-implanted MESFET technologies at Ka-band. The 0.25 μm pHEMT process achieved the highest gain and power-added efficiency performance, demonstrating greater than >20 dB power gain and an average 35% PAE (37% peak) over a 26.5 to 28 GHz band. An alternate, low-cost solution was demonstrated with direct ion-implanted 0.2 μm GaAs MESFETs at a penalty of 2 dB lower power gain, and 9 to 13 percentage points lower PAE performance. High carrier to third-order intermodulation ratios at moderate to low signal levels indicate these amplifiers are suitable for wireless communication applications at millimeter-wave frequencies.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

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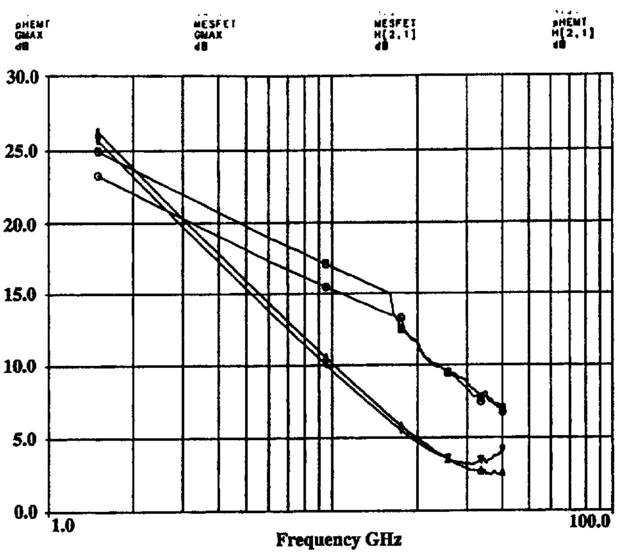

Figure 1. 600 μm pHEMT and MESFET MSG and f_t.

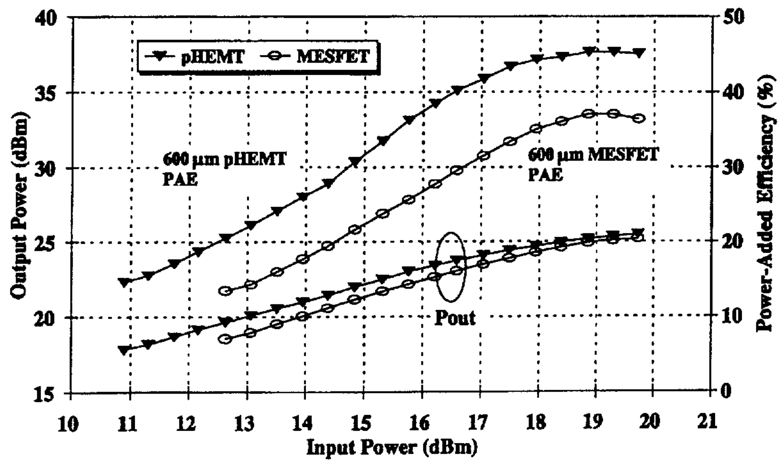

Figure 2. 600 μm pHEMT and MESFET measured power and PAE performance at 27 GHz.

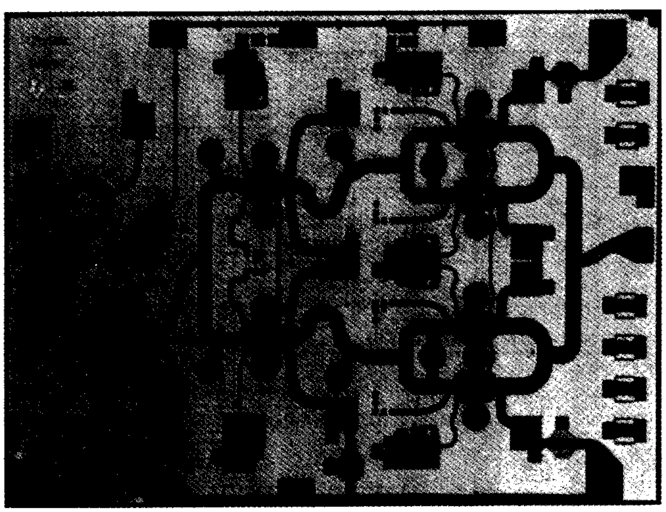

Figure 3. Ka-band, 1 watt MMIC amplifier.

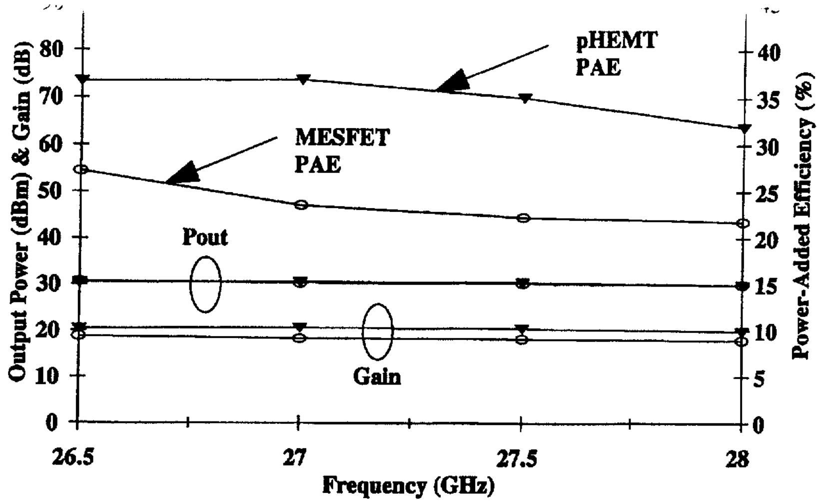

Figure 4. 0.25 μm pHEMT and 0.2 μm MESFET amplifier performance.

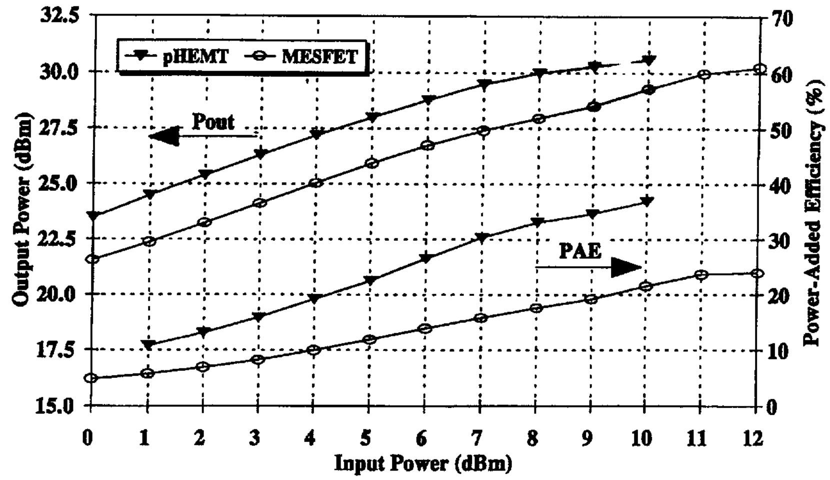

Figure 5. 0.25 μm pHEMT and 0.2 μm MESFET amplifier compression curves at 27 GHz.

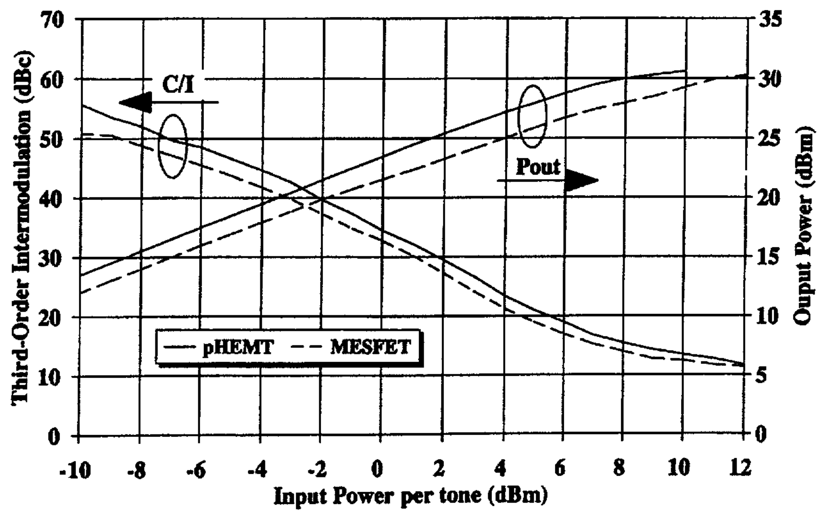

Figure 6. 0.25 μm pHEMT and 0.2 μm MESFET amplifier third-order intermodulation (C/I) at 27 GHz.