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A 0.6-Watt U-Band Monolithic MESFET Power Amplifier

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Abstract

A high performance four-stage MMIC power amplifier chip has been developed using 0.3-µm gate-length and molecular beam epitaxial (MBE) MESFET technologies. These power MMIC chips have been combined to constitute a 47 GHz power amplifier with output power of 0.46 watts with associated gain of 16.6 dB. A saturated output power of over 0.58 watts was also achieved at 47 GHz. These results represent the highest reported power and gain at U-band from an MMIC amplifier utilizing a 0.3-µm gate-length MESFET. This amplifier has potential application as a driver for a monolithic doubler to obtain more than 80 mW transmitted power at 94 GHz for W-band system applications.

INTRODUCTION

The next generation millimeter-wave systems require high performance, reliable and low cost monolithic solid-state components to be affordable. Monolithic millimeter-wave integrated circuits (MMICs) offer the greater potential to reduce cost, enhance performance, and improve the reliability of such systems. Considerable effort is therefore being directed toward the development of monolithic millimeter-wave integrated circuit components for radar, missile seeker, communications, smart weapon, electronic warfare and radiometry system applications. The power amplifier presented in this paper is a key component for such millimeter-wave systems. Recently, several monolithic power amplifiers were developed which demonstrated very good RF performance for U-Band applications [1]-[3]. However, further gain and power enhancement is desired for system implementation. Toward this goal, we have developed a high performance 47-GHz power MESFET MMIC amplifier.

In this paper, we describe the design, fabrication, and performance of this 47-GHz power MESFET MMIC amplifiers. A four-way combined MMIC power amplifier demonstrated 460 mW output power with an associated gain of 16.6 dB at 47 GHz. The saturated output power of this amplifier exceeded 580 mW. We believe this power amplifier exhibits the highest reported power and gain at this frequency. This amplifier has application as a driver for a monolithic doubler circuit to reliably produce greater than 80 mW of output power at 94 GHz as a transmitter source for missile seeker applications.

AMPLIFIER DESIGN

A high performance four-stage 47 GHz monolithic power amplifier was developed using a 400-µm gate width MESFET device. The amplifier design consists of a two-stage driver amplifier followed by a two-stage power amplifier. Figure 1 shows the micrograph of the four-stage power amplifier chip. The baseline monolithic driver amplifier design consists of a dual-stage, 400-µm MESFET amplifier. The power stage consists of two dual-stage driver amplifiers combined using integrated in-phase Wilkinson type divider/combiner circuits. A high frequency small-signal equivalent circuit was obtained for the MESFET device by matching an equivalent circuit model to the measured S-parameters up to 40 GHz. The optimal load impedance, required by the MESFET device to deliver its maximum power at 47 GHz, was calculated with a load-pull simulation program [4][5]. Both the equivalent circuit model and optimal load impedances were used for the MMIC power amplifier design. In the MMIC circuit design, the output matching circuit was designed for optimal load impedance to the MESFET in its bandwidth of operation, resulting in maximum delivered power in that bandwidth. The input matching circuit was designed for a conjugate match to the MESFET input impedance with the device terminated with the optimal load impedance to achieve maximum power gain. The input match was then optimized for input return loss and gain flatness across the design bandwidth by using Touchstone microwave circuit analysis program. The stabilizing RC circuits were integrated with the gate bias networks to ensure unconditional stability of the chip operation

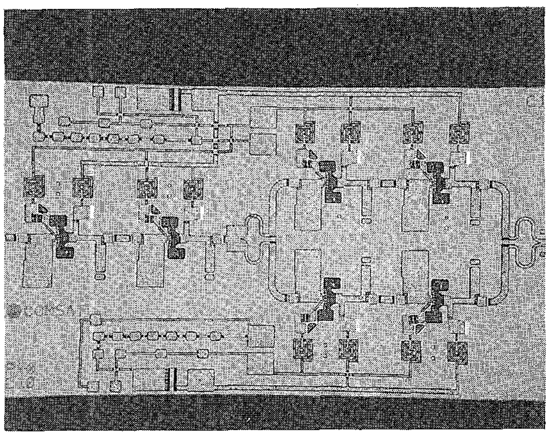

Figure 1. Microphotograph of 47-GHz GaAs MESFET power MMIC chip. (chip size : 5.0 x 2.8 x 0.09 mm)

down to few megahertze region. A resistor divider circuit was also included to bias FET gates of each amplifier stage at a norminal value of -0.7 volts with a power supply of -5 volts. At the drain side, the +5 volts power supply voltage of the system was applied to each amplifier stage directly, without scaling to bias the drain.

To achieve usable power and gain for system applications, a four-way combined power amplifier using the above four-stage power MMIC chips was also developed. The hybrid combiners and dividers were regular and offset Wilkinson type circuits to form a four-way combining circuit. This four-way combiner/divider was fabricated on 5-mil-thick fused silica substrate. Four power MMIC chips, together with a four-way combiner/divider, were mounted on a flat center block as shown in Figure 2. The amplifier block was then sandwiched between two ridged waveguide-to-microstrip transitions.

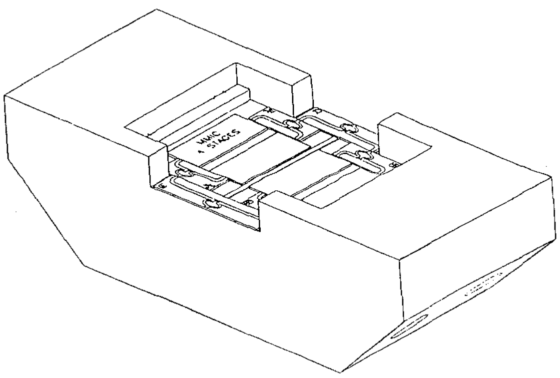

Figure 2. 47 GHz Four-Way Combined Power Amplifier.

MMIC FABRICATION

The amplifiers were fabricated on epitaxial layers grown by the molecular beam epitaxy (MBE) technique. The chips were isolated by the mesa etching process and a combination of direct-write e-beam and optical lithography was used for defining 0.3 μm gates and fabrication of the circuits. Au-Ge-Ni-Ag-Au alloy and Ti-Pt-Au metallizations were used for the ohmic contacts and gates, respectively. Si_3N_4 was used for the MIM capacitor dielectric, and for the chip passivation. The dielectric layer was 2500 Å thick, providing a capacitance of 220 pF/mm^2. The chips have via-holes for source grounding. Mesa-resistors in the range of 100 ohms were used as resistive power termination for the on-chip Wilkinson power combiner/divider. Figure 1 shows the MMIC chip with dimensions of 5.0 x 2.8 x 0.09 mm.

AMPLIFIER PERFORMANCE

A high-performance waveguide-to-microstrip transition is essential for accurately evaluating MMICs at U-band. A ridged-waveguide transition was selected and developed to provided low RF loss and a rigid structure. Over the frequency range of 40 to 48 GHz, the insertion loss was typically 0.25 dB and the return loss was better than 20 dB for each transition. The MMIC power amplifier chips were tested by mounting in a U-band amplifier test fixture, which consisted of a copper center block and a pair of low-loss ridged waveguide-to-microstrip transitions. A four-stage MMIC power amplifier chip was assembled and tested using the U-band waveguide test set-up. The associated overall gain versus frequency is shown in Figure 3 for four input drive levels, namely -5, 4, 6, and 8 dBm. The

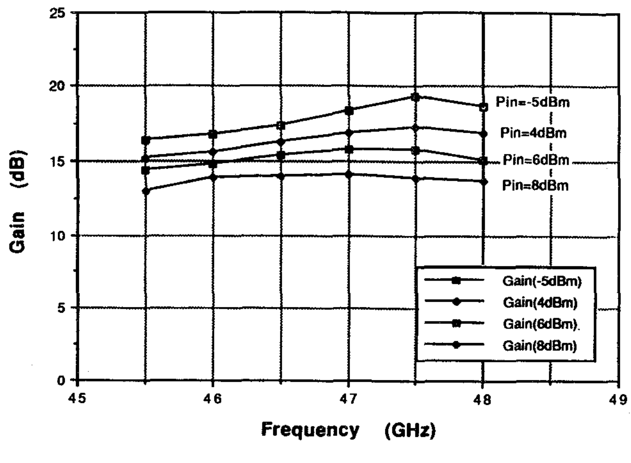

Figure 3. Measure power gain vs. frequency of four-stage GaAs MESFET power amplifier for four input drive levels.

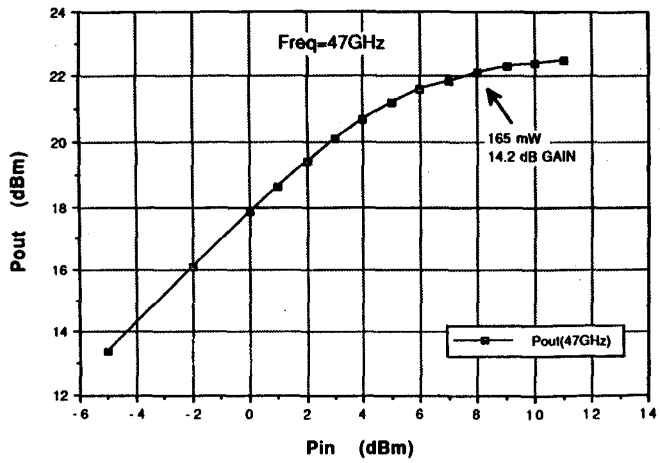

Figure 4. Measured output power vs. input power of four-stage GaAs MESFET power amplifier at 47 GHz.

amplifier associated gain is about 14.2 dB across the frequency band from 46.5 to 47.5 GHz with an output power level of 165 mW. The input and output return losses were better than 15 dB and 9 dB, respectively in the same frequency band. Figure 4 shows the power transfer characteristics of this amplifier at 47 GHz. A saturated power of over 180 mW with 11.2 % power added efficiency was also achieved. Stable power amplification was achieved without connecting any off-chip stabilizing R-C elements. This result represents the highest power gain and complexity known from a single MMIC chip at U-band.

A four-way combined MMIC power amplifier was also assembled and tested using the above power MMIC chips as shown in Figure 1. The complete four-way combined power amplifier module assembly with the input and output ridged waveguide-to-microstrip transitions is shown in Figure 5. The associated power gain versus frequency is shown in Figure 6, namely -10, 5 8, and 10 dBm. For this data, the amplifier was biased with Vds=4.5 volts and Vgs=-0.75 volts. The amplifier associated gain is about 16.6 dB across the frequency band of 46.5 to 47.5 GHz with an output power of 460 mW. The output power versus input power of the amplifier is shown in Figure 7 for 47 GHz. The saturated 47-GHz output power of the amplifier exceeds 0.58 W.

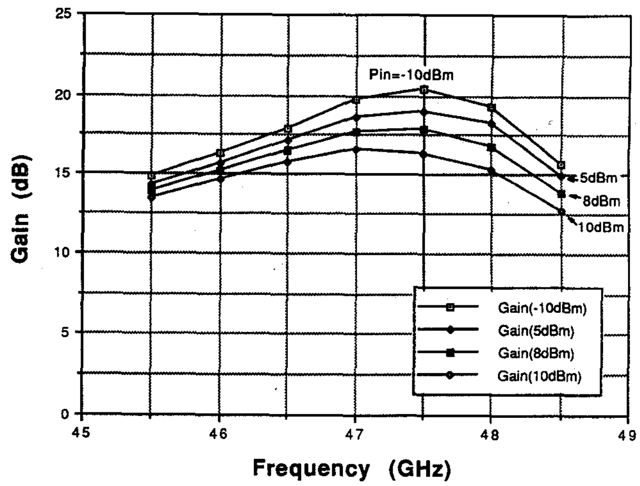

Figure 6. Measured power gain vs. frequency of four-way combined power amplifier.

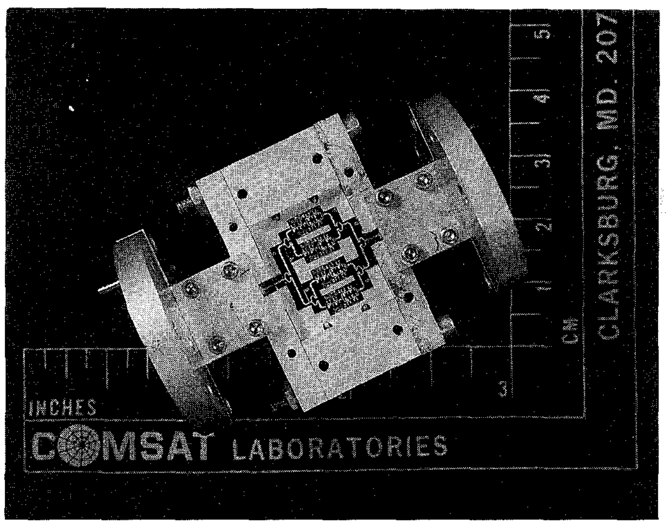

Figure 5. Complete four-way combined power amplifier module assembly.

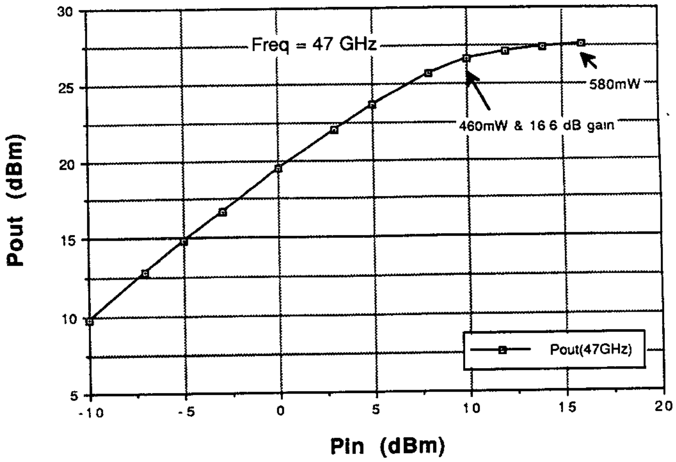

Figure 7. Measured output power vs. input power of four-way combined power amplifier.

CONCLUSIONS

A 0.6-watt, millimeter-wave power amplifier has been developed which delivered 460 mW of output power with an associated power gain of 16.6 dB at 47 GHz. This power amplifier exhibits the highest reported power and gain in this frequency range using GaAs MESFET technology. The amplifier is to be used also as a driver for a 47 to 94 GHz monolithic doubler to obtain more than 80 mW transmitter power at 94 GHz for W-band system applications.

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