GaAs MOLECULAR BEAM EPITAXY MONOLITHIC POWER AMPLIFIERS AT U-BAND

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ABSTRACT

The design, fabrication, and measurements for 44-GHz band molecular beam epitaxy (MBE) monolithic power amplifiers are described. A five-stage balanced amplifier provided a linear gain of 15.1 dB and maximum output power of 500 mW at 42.5 GHz. These results may represent the highest power and gain achieved from a MIMIC in the 44-GHz band.

INTRODUCTION

Advances in GaAs field-effect transistor (FET) and power technology have led to recent progress in the development of microwave and millimeter-wave monolithic integrated circuits (MIMICs) for system applications such as satellite communications and phased-array radars. Recently, there has been a growing interest in developing MIMIC components for the 44-GHz band for MILSTAR applications. A monolithic, low-noise, high-electron mobility transistor (HEMT) amplifier has recently been reported at Q-band [1], and MIMIC power amplifiers have been presented at 41 GHz (135 mW) [2] and 58 GHz (136 mW) [3],[4].

This paper describes new results for U-band MIMIC power amplifiers based on an optimized device structure of large gate-width periphery (0.8 mm). The circuit design approach allows direct cascading of MIMIC chips to provide useful power gain for system implementation. The output power of 500 mW obtained from the MIMIC amplifier, with an associated gain of 7 dB, may represent the highest power/gain reported in the 44-GHz band.

DEVICE AND CIRCUIT DESIGN

The basic metal-semiconductor FET (MESFET) structure (Figure 1) is similar to that used in the K_a-band MIMIC amplifier [5]. For the U-band application, the device has a nominal gate length of 0.35 µm and consists of 12 fingers resulting in a device of 0.8-mm width. This relatively larger sized gate width is used to achieve high output power without using a multicombiner scheme, which can contribute to substantial circuit loss that degrades output power.

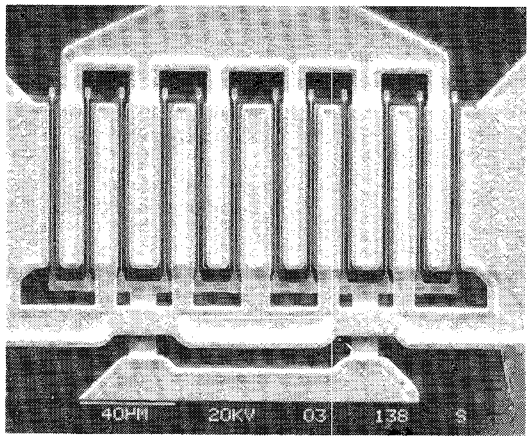

Figure 1. SEM Photograph of the Power MESFET From an MMIC

Prior to circuit fabrication, the COMSAT-developed CAD program for device circuit modeling (based on device physics) was used to optimize the MESFET structure geometry and channel carrier concentration as a function of circuit performance. The equivalent circuit model of the MESFET shown in Figure 2 was used in the load-pull subroutine to determine the optimal load required for the device to achieve maximum linear output power. A target gate length to channel height aspect ratio (L_g/H_c) of 3.5 was used with a channel carrier concentration of 5 x $10^{17}/cm^3$ to obtain high-power millimeter-wave operation.

The amplifier design incorporated distributed matching elements. The input circuit was designed to conjugate-match the MESFET input impedance with the device terminated with load impedance for optimum

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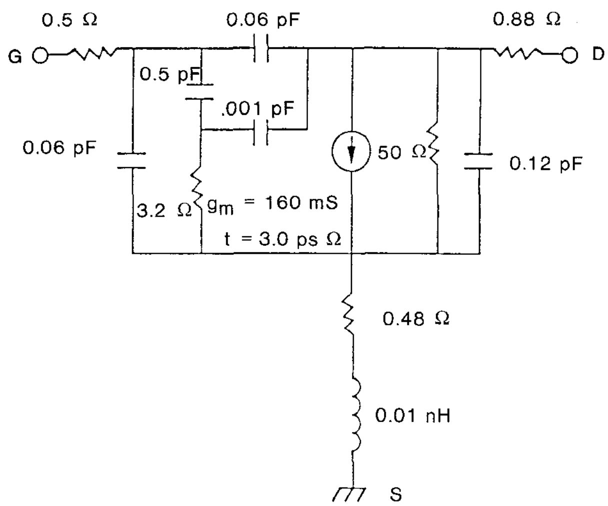


Figure 2. Equivalent Circuit Model of the MESFET

power. In the microstrip implementation, narrow transmission lines were avoided wherever possible to minimize millimeter-wave circuit loss. DC blocking, RF grounding, and RF bypass were implemented by using series and shunt metal insulator-metal (MIM) capacitors. Sufficiently large values of MIM capacitors were selected to minimize the RF performance uncertainties associated with smaller capacitors due to process-dependent sensitivity. Bias networks were also incorporated in the MIMIC design.

The mask was designed so that individual amplifier circuits could be cascaded or combined by interconnecting them with an e-beam at the gate metalization level to provide higher gain and power. The two-way divider/combiner network was designed as Wilkinson circuits and fabricated on 127-μm-thick sapphire substrates with a tantalum nitride resistor. This substrate material was selected to provide minimum circuit loss.

MBE GROWTH AND MIMIC FABRICATION

The circuits were fabricated from epitaxial GaAs n^+/n/buffer layers deposited in a Riber 2300P molecular beam epitaxy (MBE) machine onto undoped semi-insulating liquid-encapsulated (LEC) grown substrate, which was oriented 2° off the (100) plane toward the nearest (110) plane. Epitaxial deposition using elemental arsenic and gallium sources was performed at 580°C, with an arsenic-to-gallium flux ratio of 20.

Three layers were deposited sequentially on the substrate: an unintentionally doped p^- buffer layer, an n-active layer doped with silicon to $5 \times 10^{17}/cm^3$, and an n^+ layer. The MBE-grown active/buffer layers provided both highly uniform doping across the wafer and improved active channel definition with reduced leakage current.

COMSAT's mesa MIMIC process, using a combination of e-beam direct-write for the gate and optical photolithography techniques [4], was used to fabricate the monolithic circuits. An Au/Ge/Ni/Ag/Au alloy and a Ti/Pt/Au metalization were used for the ohmic contact and gates, respectively. Si_3N_4 was used for the MIM capacitor dielectric, and in glassivation of the device. The capacitor dielectric layer was 2,500 Å thick, giving a capacitance of 220 pF/mm^2. Low-inductance RF grounding was provided by via-holes. Figure 3 shows the MIMIC chip with dimensions of 0.97 x 0.9 x 0.09 mm.

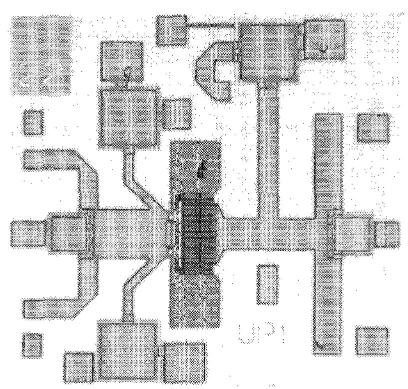
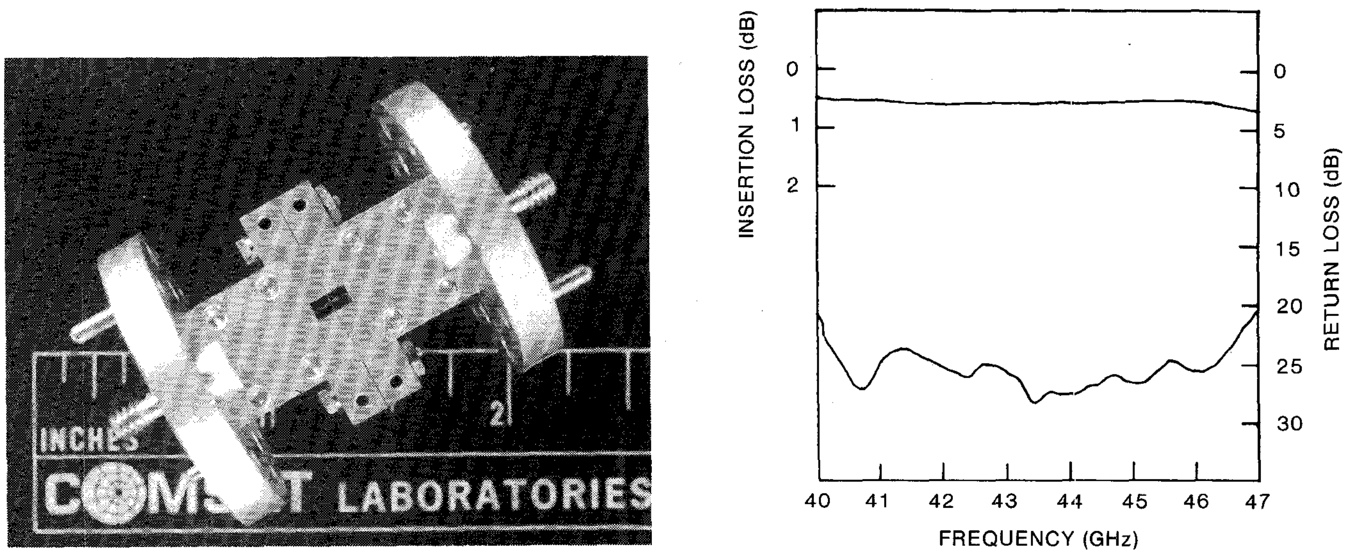


Figure 3. U-Band Power MMIC

MEASURED PERFORMANCE

The MIMICs were mounted in a U-band amplifier test fixture, which consisted of a copper center block and a pair of ridged waveguide-to-microstrip transitions. Bias feedthroughs and short (1.72-mm) 50-Ω



(a) Two Transitions Back-to-Back Plus Two Lengths of 50-Ω Lines (b) Performance of the Above Two Transitions Including 50-Ω Lines

Figure 4. Performance of Two 44-GHz Band Waveguide-to-Microstrip Transitions Plus Two Lengths of 50-Ω Lines

lines at the inputs and outputs of the MIMICs were included. The ridge waveguide transformer utilized four λ/4 sections to transform the waveguide field configuration into a field configuration of a microstrip line of height equal to the gap under the last section ridge and with air dielectric. The electromagnetic wave propagating in the waveguide is in TE mode, but as the wave propagates toward the microstrip line the ridge height increases, and the electric field becomes more concentrated under the ridge. This eventually turns the field configuration into a quasi-TEM mode similar to that of the microstrip line. The ridge heights in the transformer sections were designed to transform the 500-Ω impedance of the waveguide into the 50-Ω impedance of the microstrip line. A gold ribbon connected the microstrip line to the last section ridge through thermocompression bonding. The width of the ribbon was optimized to minimize its inductive effect and to avoid capacitive loading to ground. Figure 4a shows the waveguide housing and Figure 4b shows the performance of two waveguide-to-microstrip transitions measured back-to-back. From 40 to 47 GHz, the insertion loss and return loss of each transition were typically 0.3 and 25 dB, respectively.

The performance of a single-ended, two-stage power amplifier is shown in Figure 5. A linear gain of 5 to 6.2 dB was achieved from 42 to 44.5 GHz. An output power of 22.5 dBm (175 mW) and 4.6 dB of associated gain have been obtained at 42.5 GHz. The nominal drain voltage and current bias of each MESFET are 6 V and 130 mA, respectively.

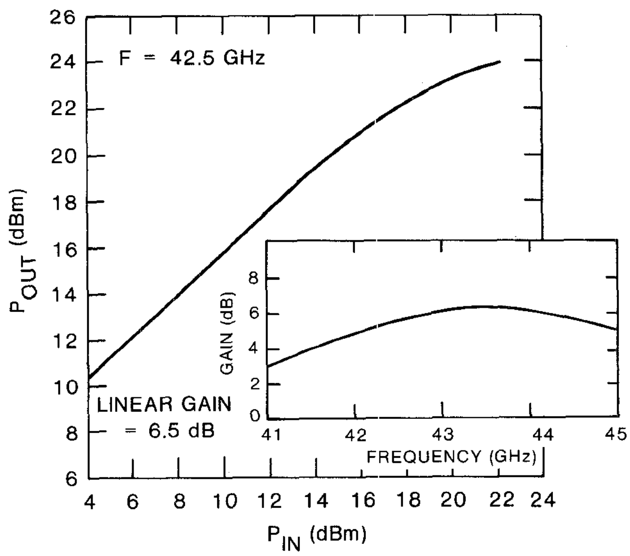
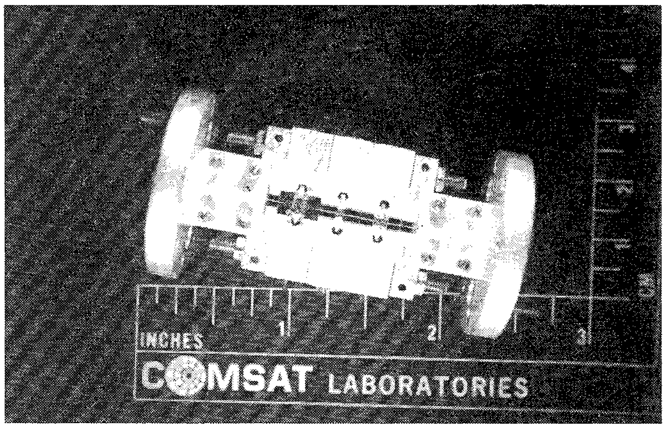
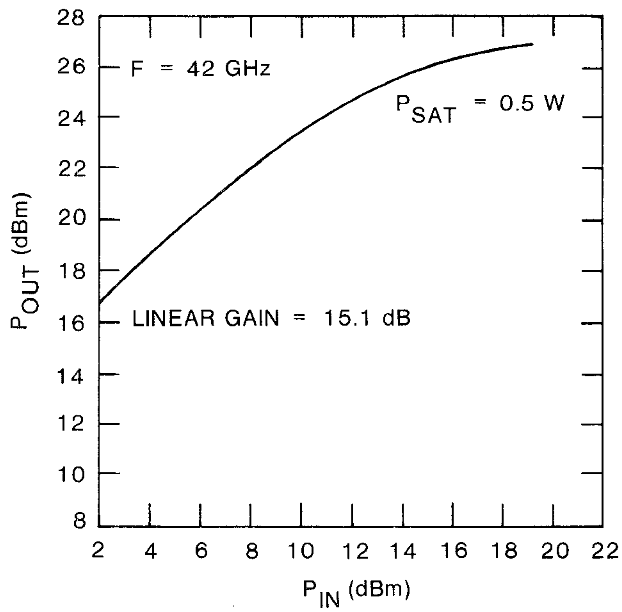


Figure 5. Power Transfer Characteristic and Frequency Response of a U-Band Two-Stage MIMIC Amplifier

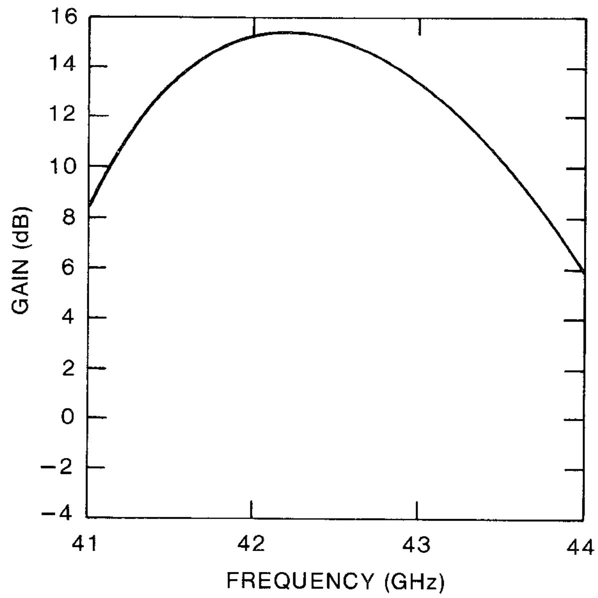
In order to achieve usable power gain and output power for system applications, a cascaded five-stage amplifier was fabricated. The last two stages were a balanced module with Wilkinson divider/combiner networks. Figure 6 shows the amplifier assembly and the performance of the amplifier. A linear power gain of 15.1 dB



(a) Amplifier Assembly



(b) P_{OUT} vs P_{IN}



(c) Frequency Response

Figure 6. Five-Stage U-Band MIMIC Amplifier

and a saturated output power of almost 27 dBm (500 mW) with associated gain of 7 dB were obtained at 42 GHz. The results take into account the loss of the divider/combiner networks, as well as the 50-Ω sections of microstrip line.

CONCLUSIONS

Power MIMICs have been developed for U-band applications. Based on a design that allowed the cascading and paralleling of individual modules, usable power gain and the highest output power yet achieved in the 44-GHz (0.5 W with 7-dB gain) band have been demonstrated using MESFET MIMIC chips. These amplifiers are suitable for 20/44-GHz satellite communications, as well as for phased-array radar applications.

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