A 30-GHz GaAs FET AMPLIFIER

C.F. Krumm
Hughes Research Laboratories
Malibu, California
H.T. Suyematsu and B.L. Walsh
Hughes Space & Communications Group
El Segundo, California

ABSTRACT

A Ka-band GaAs FET amplifier with 11 dB maximum single-stage gain at 33 GHz has been developed. At reduced drain currents and drain source voltages, noise figures as low as 5.5 dB were measured, and minimum noise measures of 7.0 dB were obtained from the experimental data. The Hughes 0.5 μm GaAs FETs used in this development were fabricated using electron-beam lithography. The device fabrication technology of these Hughes FETs and the design and performance of the 30 GHz FET amplifier are discussed in some detail.

Introduction

During the last five years, the GaAs MESFET has demonstrated its usefulness in microwave systems. This device not only provides gain and low noise figures in the microwave frequency domain, but stable two-port operation over large percentage bandwidths as well.[1] Currently unanswered is the question of how high in frequency these devices will prove useful.[2] The results presented here demonstrate acceptable, usable performance in the Ka-band of the microwave spectrum for GaAs MESFETs.

Device Technology

Electron-beam lithography was used to fabricate the GaAs FETs used in this amplifier. The active channel layer was grown by liquid-phase epitaxy directly on the semi-insulating substrate. The channel doping was 7×10^{16} cm^{-3}, and initial channel thickness was 2200 A. The gate and source-drain patterns were defined by direct-writing electron-beam lithography in PMMA resist. The metallization patterns were formed by liftoff. The ohmic contacts were AuGeNi alloy, and the gate was Al. Gate length was typically 0.5 μm and was very uniform along the width of the channel. The channel was thinned under the gate to control the current and to reduce parasitic resistance. Overlay metal for bonding purposes was defined by photolithography. S-parameter measurements indicated a maximum frequency of oscillation for these devices of >100 GHz.

Circuit Design and Description

The 30 GHz GaAs FET amplifier was constructed with WR 28 waveguide input and output connections, as shown in Figure 1. This design provides a metallic structure that completely surrounds the FET chip and prevents radiation loss and higher order modes. The amplifier consists of a short input and output section of waveguide and two 90° mitered bends to provide for parallel alignment of input and output. Following the bends is a wafer somewhat similar in concept to the Sharpless package for diodes, but containing the FET chip, matching circuits, bias circuits, and two waveguide-to-microstrip probe elements. Another double section of waveguide and a metal plate for a short circuit complete the amplifier.

Rather than attempt to measure the scattering parameters of the mounted GaAs FET chip, an approximate circuit design was selected based on typical FET impedance curves at lower frequencies and the measured tuning behavior of a recently completed 20-GHz GaAs FET amplifier. These data indicated that a very low

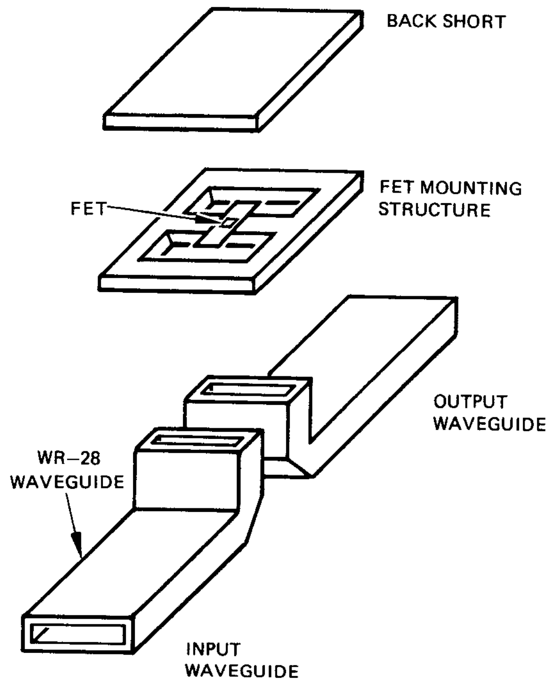

Figure 1. Waveguide FET amplifier

inductance (≈0.14 nH) would be required to series resonate the gate circuit. The real part of the input impedance would be small, less than 10 Ω. This required that the waveguide to hybrid circuit probe be made wide to achieve low impedance while retaining enough lateral space for circuit modification. The input probe coupler was constructed on a 10-mil-thick alumina substrate with a 30-mil-wide metallic strip to provide a characteristic impedance of 26 Ω.

The real part of the drain circuit impedance when series resonated at 30 GHz was expected to be close to 50 Ω. Thus the output hybrid circuit to waveguide probe was designed for a characteristic impedance of 50 Ω.

Both probe transitions were matched over the 27 to 33 GHz band by modifying their end geometries to obtain better than 20 dB return loss. The length of each probe transition including its constant characteristic impedance section was approximately 0.1 in. To achieve the low-loss, low-inductance connections required, special ribbon lead bonds were fabricated by photolithography. Most interesting was the double-pronged ribbon for connection to the gate. Figure 2

This work sponsored in part by the Air Force Avionics Laboratory under Contract F33615-76-C-1114.

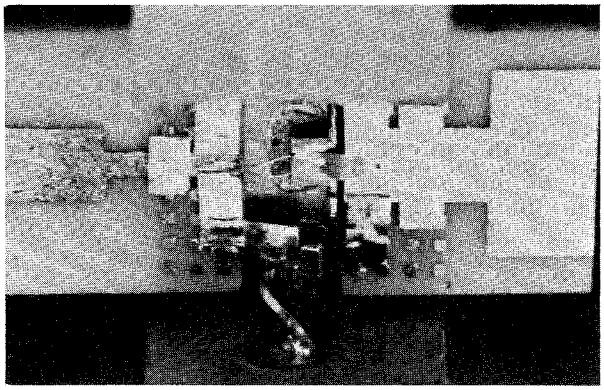

Figure 2. GaAs FET bonded in 30 GHz amplifier circuit

shows the connection of this ribbon to the gate and the wire bonds to the drain of the FET from the top. The source ground was accomplished by using a 50-mil-wide by 0.5-mil gold ribbon thermocompression bonded to the source connection on the FET. Figure 3 shows the cross sectional details of the amplifier construction.

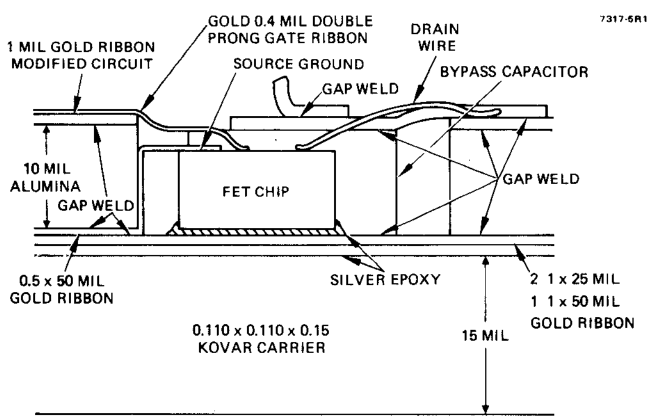

Figure 3. Assembly cross section for 30 GHz GaAs FET amplifier

Experimental Results

Measurements were made on the 30-GHz GaAs FET amplifier under two tuning and bias conditions. For the first condition, the amplifier was biased at 3.4 V drain to source and at I_{DSS} (I_{DSS} = 13.5 mA). The amplifier was then tuned for maximum gain at 30 GHz. Figure 4 shows the measured gain of the amplifier under these tuning and bias conditions.

Next, the amplifier was reversed in the measurement setup and a reverse loss measurement was taken. The results are shown in Figure 5. Typical reverse loss was between 10 and 12 dB indicating that the amplifier was not highly unilateral.

Finally, input return loss and output return loss were measured on the amplifier under the identical tuning and bias conditions. The results of these measurements are shown in Figure 6. The input return loss varied between 0 and -7.5 dB over the 27 to 35 GHz band. The output return loss varied from +1 dB to -3.0 dB over the same band.

In the frequency range from 31 to 33.5 GHz, the output return loss becomes slightly positive (approximately +1 dB) indicating that the amplifier has a real

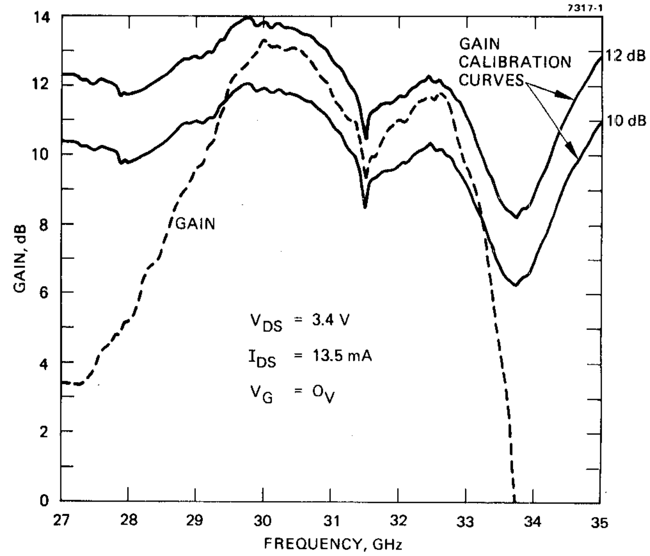

Figure 4. Gain versus frequency for Ka-band FET amplifier

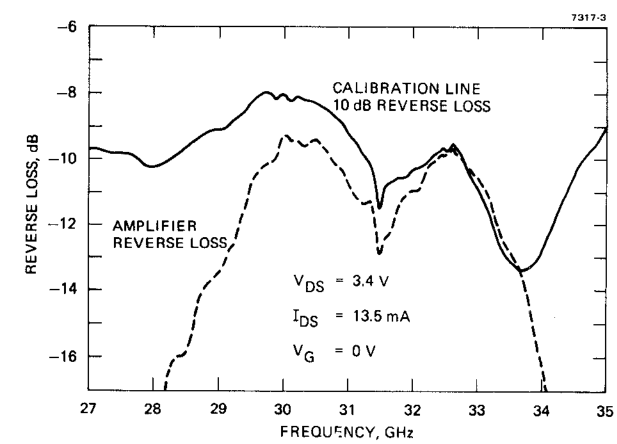

Figure 5. Reverse isolation versus frequency of Ka-band FET amplifier

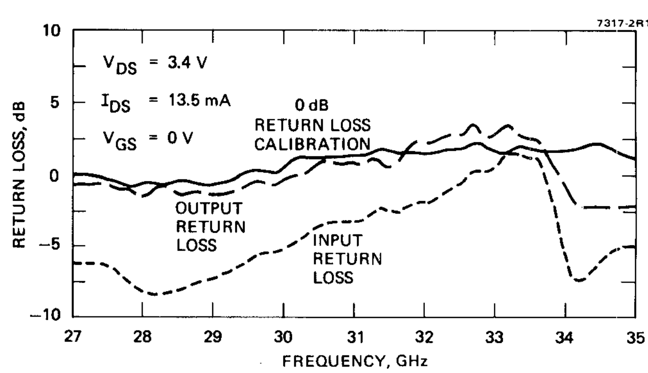

Figure 6. Input and output return loss versus frequency for K-band FET amplifier

impedance that is negative. This plus the fact that the reverse isolation is relatively low indicates that there are fairly large feedback effects. This is probably due to coupling via the source lead inductance and the FET drain-gate capacitance. The broad instantaneous bandwidth and general stability of the amplifier indicate that the circuit is not on the verge of oscillation even with these feedback effects.

Following these measurements at a drain-source voltage of 3.4 V and drain current equal to I_{DSS}, the amplifier was re-biased and retuned for best noise figure at 30 GHz. Noise figure and gain were measured versus drain current, and noise measure was calculated from these measured values. Figure 7 shows the data obtained at a drain voltage of 1.75 V. Minimum noise figure of 5.5 dB was obtained with the 1.75 V drain source voltage as well as minimum noise measure of 7.0 dB.

Conclusion

An amplifier was designed, constructed, and tested over the frequency range 27 to 35 GHz employing a Hughes GaAs FET with a 0.5 μm gate length. The FET was designed and fabricated at Hughes Research Laboratories using electron-beam lithography. The measured results demonstrated GaAs FET amplifier operation with excellent noise figures in the Ka-band microwave frequency spectrum.

Acknowledgment

The authors wish to acknowledge the efforts of F. Ozdemir and L.H. Hackett in device fabrication and S. Kamath in GaAs epitaxy and to thank Mark Calcaterra and Robert Lyons of the Air Force Avionics Laboratory for their support and encouragement.

References

1. Gary E. Glase, "FET Amplifier Spans 4-12 GHz," Microwave System News 8, No. 2, pp. 49-59, February 1978.
2. Harry F. Cooke, "Microwave FETs, a Status Report," ISSCC, February 16, 1978, San Francisco.

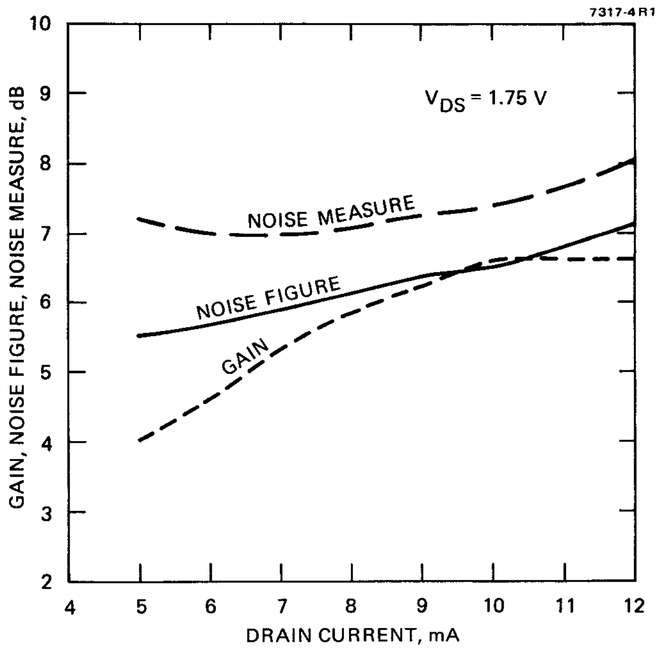

Figure 7. Gain, noise figure and noise measure of 30 GHz amplifier