A FOUR STAGE V-BAND MOCVD HEMT AMPLIFIER

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ABSTRACT

V-band multi-stage Low Noise Amplifiers (LNA) were developed utilizing MOCVD High Electron Mobility Transistors (HEMTs). The amplifiers have demonstrated 16.57 dB gain with an associated noise figure of 5.65 dB and over 19 dB gain with 7.91 dB noise figure at 60.4 GHz. Another amplifier achieved over 5 GHz bandwidth with greater than 14 dB gain. The amplifier is integrated in a single housing that is 1.75 inch long.

INTRODUCTION

Future intersatellite link receivers and space-based radar will require millimeter-wave frequency amplifiers. With the advance of GaAs device technology, amplifiers operating at millimeter-wave using MESFET or HEMT devices have been reported (1,2). However, due to the low device gain and high circuit loss encountered at these frequencies, amplifiers with useful gains often exhibit poor noise performance. This paper reports the development of the first V-band four stage MOCVD HEMT amplifier achieving high gain as well as useful noise figure performance.

HEMT DEVICE

HEMT devices were fabricated on high quality MOCVD materials. The MOCVD-grown material has significant advantages over MBE-grown material including: the absence of oval and other morphological defects which impair high yield device fabrication, the potential for high throughput production scaleup, the capability for better run to run reproducibility, and a better device reliability.

The material structure consists of a 300 Å N+GaAs cap layer, a 500Å $Al_{.3}Ga_{.7}As$ layer doped to 1.5 x 10^{18} cm^{-3}, a 10 to 30Å undoped AlGaAs spacer layer, and a 5000Å undoped GaAs channel layer, grown on a semi-insulating GaAs substrate wafer.

The HEMT geometry consists of two 0.25 x 30 m gate fingers with low resistance mushroom-shaped cross-sections, defined by E-beam lithography. The physical dimension of the device is approximately 9.5 x 11.5 mils, as shown in Figure 1.

The measured dc transconductance of the HEMT is in the 300 to 375 ms/mm range. Preliminary reliability

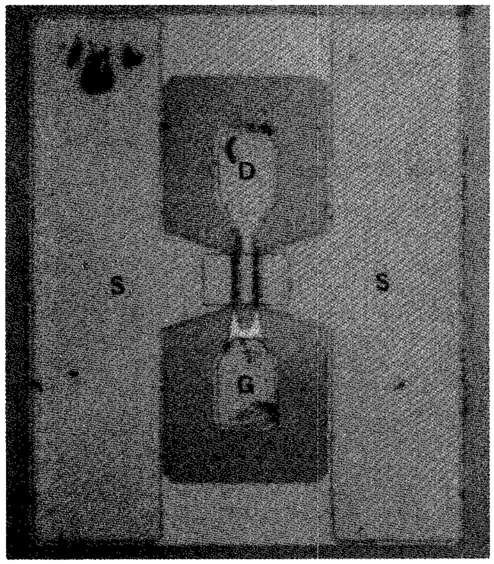

Figure 1 A 0.25 x 60μm MOCVD HEMT device.

tests show no device degradation after being stressed for 1000 hours at 200° C channel temperature; a distinct advantage over MBE HEMTs.

DEVICE MODEL AND CHARACTERISTICS

The device model was obtained using small signal S-parameter data measured at lower frequencies (2 to 18 GHz). The 14 element equivalent circuit model shown in Figure 2 was optimized to the measured data utilizing computer aided design tools. Based on the model, Fmax of approximately 80 GHz was expected.

A simplified noise model (3) was developed for these devices. Noise figure measurements were performed at 18 and 35 GHz to evaluate the model. A 1.0 dB device N.F. with an associated gain of 11.5 dB and a 1.8 dB N.F. with a 7.2 dB associated gain were obtained, respectively.

To evaluate these devices at 60 GHz, a single stage amplifier was fabricated. It demonstrated a 4 dB gain and

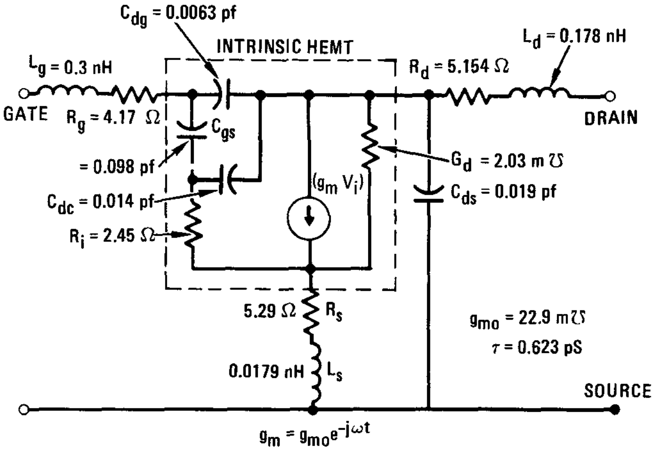

Figure 2 A 0.25 x 60μm HEMT equivalent circuit model.

5 dB noise figure at 58 GHz. (The measurements were performed without optimized circuits).

AMPLIFIER DEVELOPMENT

The multi-stage amplifier design was based on the HEMT equivalent circuit model. The amplifier consists of four single-ended, cascaded stages. Each stage includes input and output matching circuits. Between stages are dc blocking circuits. The input/output networks include integrated waveguide to microstrip transition circuits. The RF circuitry was fabricated on 4 mil thick quartz substrates using TiWAu metallization.

The input matching circuit includes an open circuit stub and a quarter-wave transmission line. The output circuit consists of a high impedance transmission line and quarter-wave matching circuit. Both input and output circuits were designed to match in to a 50 ohm system.

A simple, planar waveguide to microstrip transition (probe) was utilized in this development. The probe is inserted into the middle of the waveguide parallel to the E-field. Its geometry, size, and repeatability allow it to be printed and fabricated as part of the input/output matching circuit on a substrate. This integration significantly reduced hardware difficulties and eliminated discontinuities from a mechanical interface. A set of V-band probes, fabricated back to back on a 4 mil thick quartz substrate, had a measured insertion loss of 1.1 dB across the entire V-band (50 to 75 GHz). The return loss was better than 11 dB across the majority of the frequency band, as shown in Figure 3. The whole circuit was approximately 0.7 inches long.

DC isolation is required between amplifier stages. At lower frequencies, thin film or chip capacitors are commonly employed. However, at millimeter-wave frequencies, these elements become distributed and sometimes introduce unwanted parasitics. To alleviate these problems, a two finger, edge coupled symmetric microstrip dc blocking circuit (4,5) utilizing approximately quarter-wave length long inter-digitated fingers was developed. Fabricated together with a set of

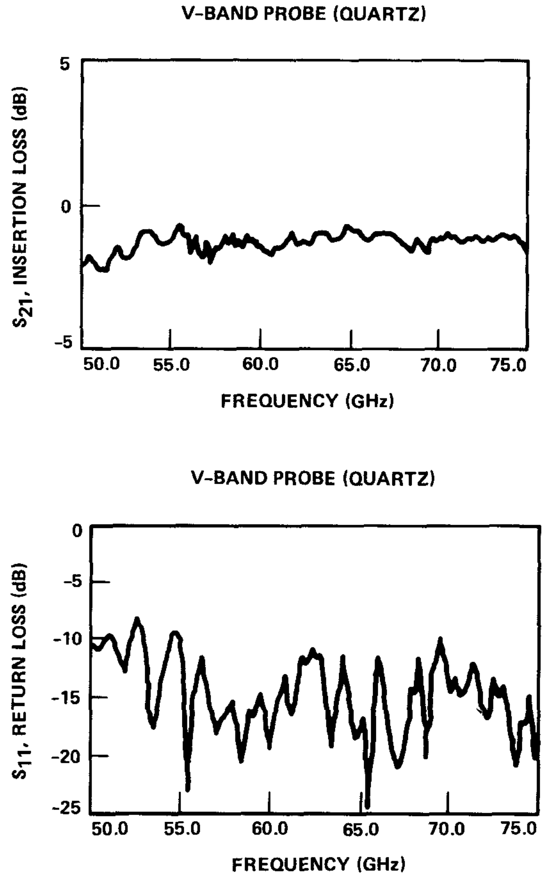

Figure 3 Performance of V-Band waveguide-to-microstrip transistion.

microstrip to waveguide transitions, a total insertion loss of approximately 1.3 dB measured across the 56 to 65 GHz frequency range was obtained. Compared to the measurement of the V-band probe by itself, the dc blocking circuit exhibits approximately 0.2 dB loss.

DC bias for each device drain and gate were supplied through a low pass filter (LPF) consisting of a multi-section high and low impedance transmission line network. The filter, with over 30 dB rejection was employed to reject any RF signal presented to the bias line. In addition, a 100 pf chip capacitor was attached between the LPF and the bias pin to terminate any low frequency RF signal.

The four stage amplifier circuit was assembled inside a split block housing, made out of aluminum. The entire circuit was approximately 1.0 inch long and was located in a 60 mil wide channel below waveguide cutoff. The height of the channel was chosen so that it does not impact the characteristic impedance of the amplifier circuitry; it also eliminated possible moding problems. WR-15 waveguide served as input/output ports. Adjustable back shorts were provided to use as tuning elements. The complete amplifier circuit is shown in Figure 4.

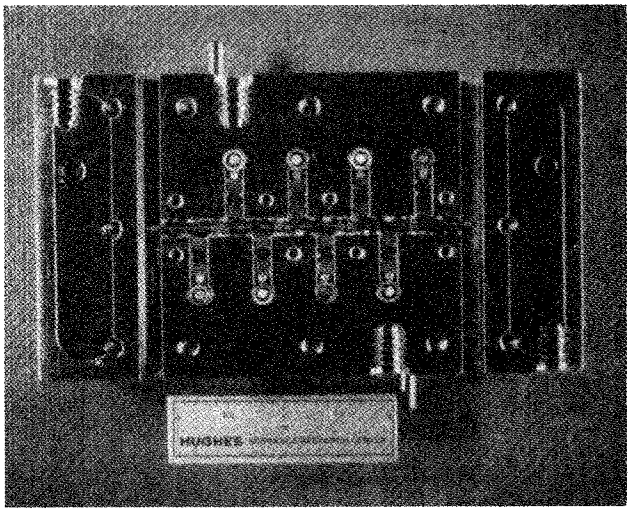

Figure 4 A four-stage V-Band HEMT amplifier.

AMPLIFIER PERFORMANCE

The amplifier performance was measured using a V-band scalar network analyzer and was verified with an automatic noise/gain measurement system. A gain of 16.57 dB and a 14 dB input return loss were obtained at 60.4 GHz, with an associated noise figure of 5.66 dB. The 1 dB bandwidth was approximately 1.5 GHz, the gain and noise figure vs. frequency are shown in Figure 5a. When optimized for gain, the amplifier achieved over 19 dB gain at 60.4 GHz, with an associated noise figure of 7.91 dB, as shown in Figure 5b.

The amplifier bandwidth was optimized and over 5 GHz bandwidth, from 56 to 61 GHz, was obtained. The gain, however, degradated approximately 2.5 dB. Greater than 14 dB gain and less then 7 dB noise figure were achieved across the majority of the bandwidth. A less than 10 dB return loss was obtained across the same frequency band. The gain and noise figure measurement vs. frequency is shown in Figure 6.

Gain compression measurements were performed at 60.4 GHz. Typically, these amplifiers achieved an output power of -2.6 dBm at the 1 dB compression point, as shown in Figure 7.

CONCLUSION

We have demonstrated the first V-band four stage MOCVD HEMT amplifier with high gain and useful noise performance. The good return loss achieved by these amplifiers allow easy cascading and system integrations without the use of isolation networks between stages. The elimination of isolation network is imporant particularly in monolithic receiver system where size and noise performance is a major emphasis.

These amplifiers employ microstrip integrated circuits to reduce parasitic elements and achieve repeatable mechanical interfaces in a topography suitable for monolithic implementation. It is the pioneer of future

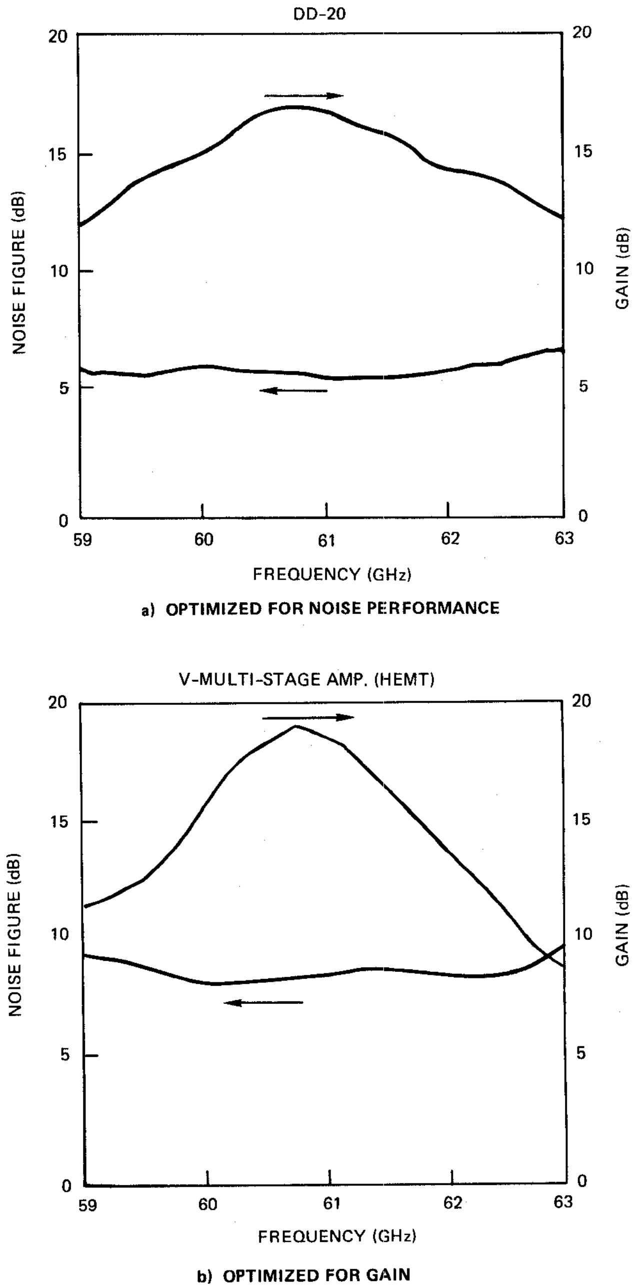

Figure 5 Gain/noise performance of V-Band multi-stage HEMT amplifier.

monolithic V-band circuits for satellite communication and space-based radar.

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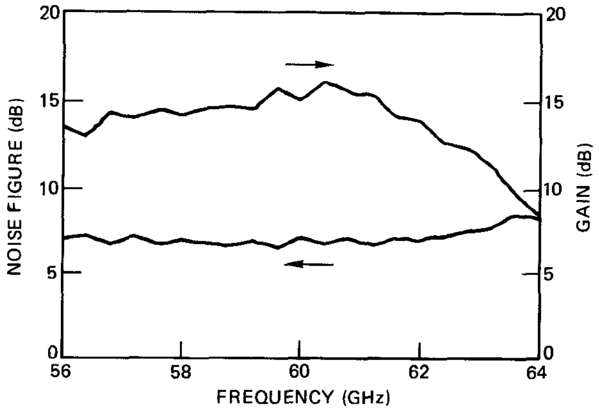

Figure 6 Gain/noise performance of V-Band multi-stage HEMT amplifier. (Optimized for bandwidth).

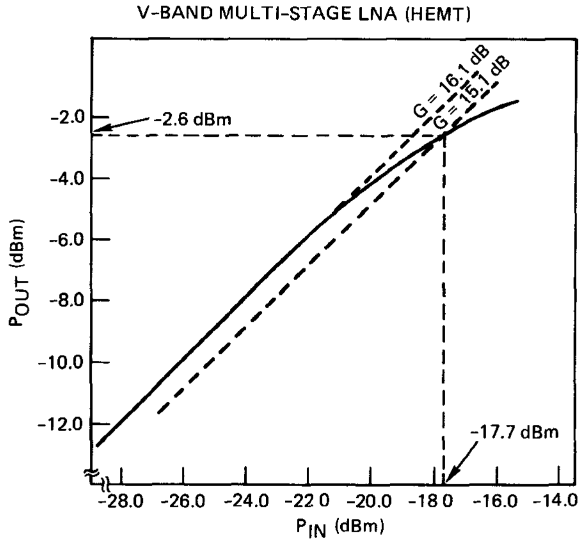

Figure 7 Typical gain compression characteristic of V-Band multi-stage HEMT amplifier.

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REFERENCE

(1) E. T. Watkins, J. M. Schellenberg, L. H. Hackett, H. Yamasaki, and M. Feng, "A 60 GHz GaAs FET Amplifier," 1983 IEEE MTT-S Digest, pp. 145-147, June 1983.

(2) M. Sholley, A. Nichols, "60 and 70 GHz (HEMT) Amplifiers," 1986 IEEE MTT-S Digest, pp. 463-465, June 1986.

(3) A. F. Podell, W. H. Ku, L. C. T. Liu, "Simplified Noise Model and Design of Broadband Low-Noise MESFET Amplifiers," Proceddings Seventh Biennial Cornell Electrical Engineering Conference 1979, Vol. 7, pp. 429-443, 1979.

(4) B. Easter, B. S. Schivashankaran, "Some results on the edge-coupled microstrip section as an impedance transformer," IEE J. Microwaves, Optics and Acoustics, Vol, 3, pp. 63-66, March 1979.

(5) D. LaCombe, J. Cohen, "Octave-Band Microstrip DC Blocks," IEEE Trans. Microwave Theory Tech., Vol. MTT-20, pp. 555-556, Aug. 1972.