A 44–60 GHz Monolithic pHEMT Grid Amplifier

Michael P. De Lisio[1], Scott W. Duncan[2], Der-Wei Tu[3], Sander Weinreb[4], Cheh-Ming Liu[5], and David B. Rutledge[5]

[1]Department of Electrical Engineering, University of Hawai'i at Mānoa, Honolulu, HI 96822
[2]Microwave Electronics Division, Sanders Corp., Nashua, NH 03061
[3]U.S. Army Research Laboratory, Adelphi, MD 20783
[4]Department of Physics and Astronomy, University of Massachusetts, Amherst, MA 01003
[5]Department of Electrical Engineering, California Institute of Technology, Pasadena, CA 91125

Abstract—**We present a 36-element monolithic millimeter-wave grid amplifier. The grid operates in the U-band, using pseudomorphic High Electron Mobility Transistors (pHEMT's) as the active devices. The grid has a peak gain of 6.5 dB at 44 GHz. The grid can be tuned to operate from 44 GHz to 60 GHz by changing the positions of external polarizers and tuning slabs. At 60 GHz, the grid has a peak gain of 2.5 dB. Gain and tuning curves are consistent with theoretical predictions.**

I. Introduction

Quasi-optics allows the output powers of many solid-state devices to be combined in free space without transmission line losses. Various quasi-optical grids have been demonstrated, including detectors, phase shifters, multipliers, mixers, oscillators, and more recently, amplifiers. A grid amplifier is an array of closely spaced differential pairs of transistors. Fig. 1 shows the approach. A horizontally polarized beam excites rf currents on the input leads of the grid, driving the transistor pair in the differential mode. Currents on the output leads produce a vertically polarized output beam. Metal-strip polarizers provide independent tuning of the input and output circuits. Grid amplifiers have been demonstrated using MESFET's [1], HBT's [2], and pHEMT's [3]. A monolithic slot-patch quasi-optical amplifier has been demonstrated with limited gain at 50 GHz [4]. Recently, a monolithic HBT grid amplifier has been developed at Caltech [5]. This HBT grid has produced 670 mW of power at 40 GHz [6]. Here, we present the first successful monolithic pHEMT amplifier, a 36-element grid fabricated by Lockheed Martin Laboratories, Baltimore. A photograph of the amplifier is shown in Fig. 2.

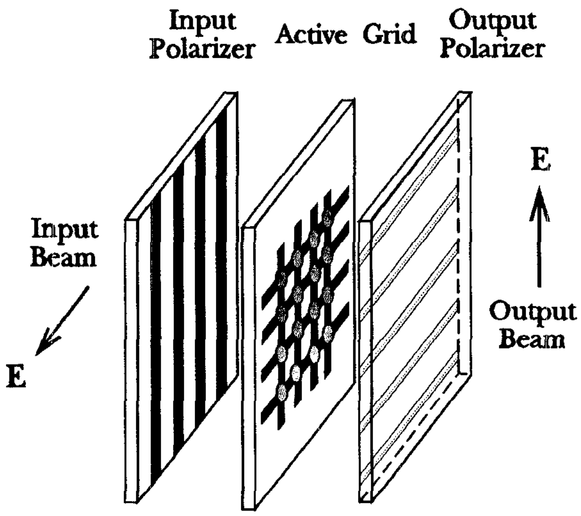


Fig. 1. A grid amplifier. The polarizers independently tune the input and output circuits.

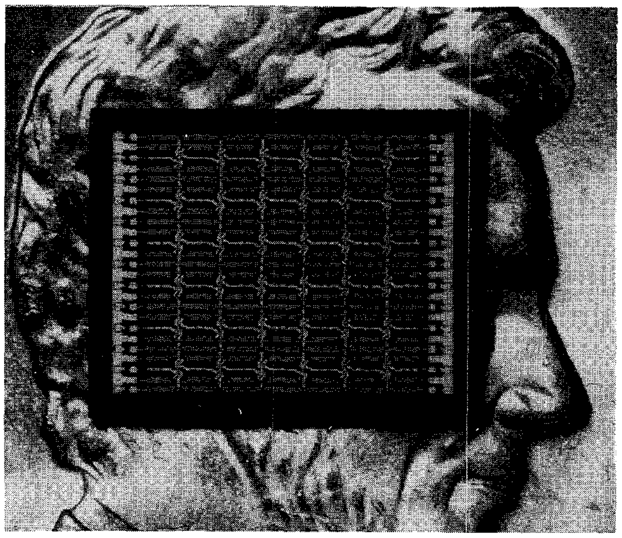


Fig. 2. Photograph of the 36-element monolithic pHEMT grid amplifier compared with a penny. The active area of the grid is 3.1 mm on a side.

This research was supported by the Army Research Office and the Lockheed Martin corporation. M.P. De Lisio held an AASERT fellowship.

0-7803-3246-6/96/$5.00 © IEEE
1996 IEEE MTT-S Digest

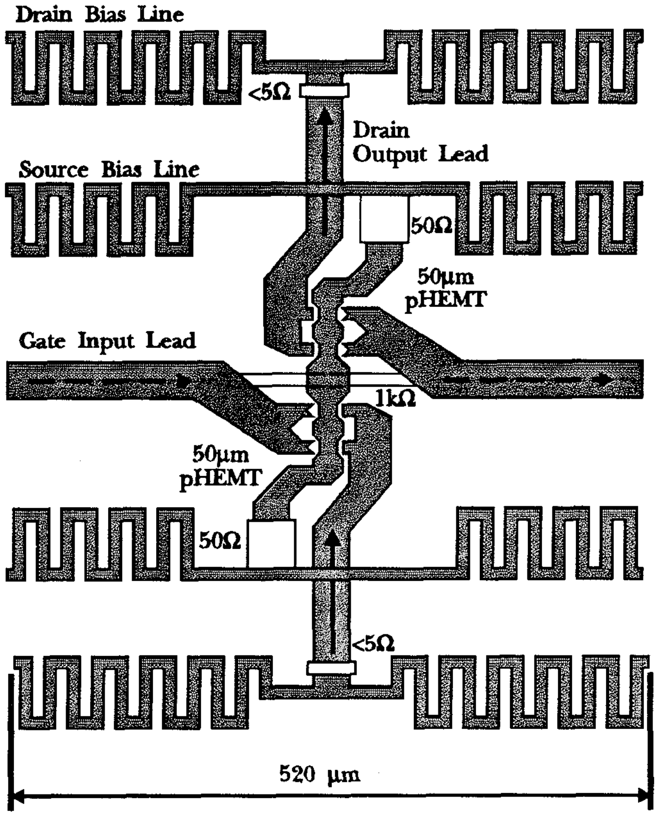


Fig. 3. The grid amplifier unit cell. Arrows indicate the direction of rf currents.

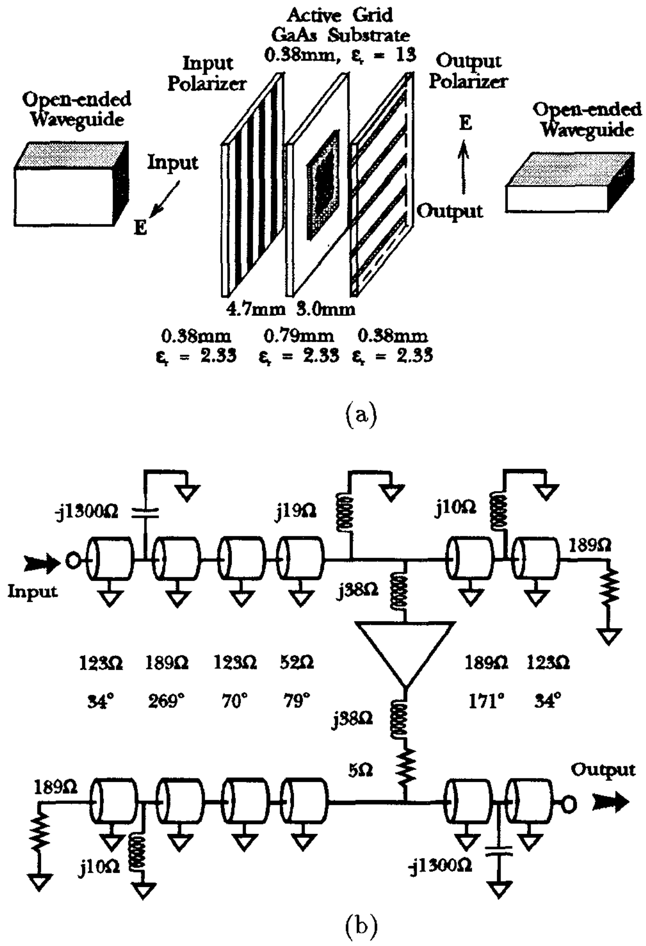


Fig. 4. The assembled grid amplifier (a). The polarizer positions are adjusted for optimum performance at 48 GHz. (b) Transmission-line equivalent circuit used for gain modelling.

II. Amplifier Construction

The pHEMT's are 0.1-μm AlGaAs/InGaAs/GaAs devices developed by Lockheed Martin [7]. The total gate width per transistor is 50 μm distributed among four fingers. These devices are designed to operate well into the millimeter-wave band, with a Maximum Stable Gain (MSG) of 11 dB at 50 GHz.

Fig. 3 shows the unit cell. The cell is 520 μm on a side. The sources of two pHEMT's are tied together to form a differential pair. The 1-kΩ resistor allows the external gate bias to flow from cell to cell. The two 50-Ω source resistors are intended to reduce the common-mode gain. The input beam is coupled to the gates of the transistors through the horizontal gate leads. These leads also supply the dc gate bias. The output beam is radiated from the vertical drain leads. The small resistors in the output leads are used for probing and diagnostics. Drain and source bias is provided by the thin meandering lines.

The assembled amplifier is shown in Fig. 4(a). The grid is monolithically fabricated on a 15-mil GaAs substrate. The grid is then mounted on a Rogers Duroid board with a relative dielectric constant of 2.33. The polarizers are also fabricated on low-dielectric Duroid. A simple transmission-line model for the grid is shown in Fig. 4(b), where the various air gaps and dielectric slabs appear as transmission lines. Reactive elements represent coupling to the grid and the effect of the polarizers. More details about the modelling can be found in [3].

III. Gain

The gain is measured by placing the grid in the far-field of two cross-polarized antennas [2]. We use open-ended WR-22 or WR-15 waveguide with the flanges sawed off as the antennas. The millimeter-wave source is a synthesizer-fed Hewlett-Packard 8355-series multiplier. An HP8563A spectrum analyzer with an HP11974-series preselected mixer receives the amplifier output. To avoid overheating, the grid is only biased

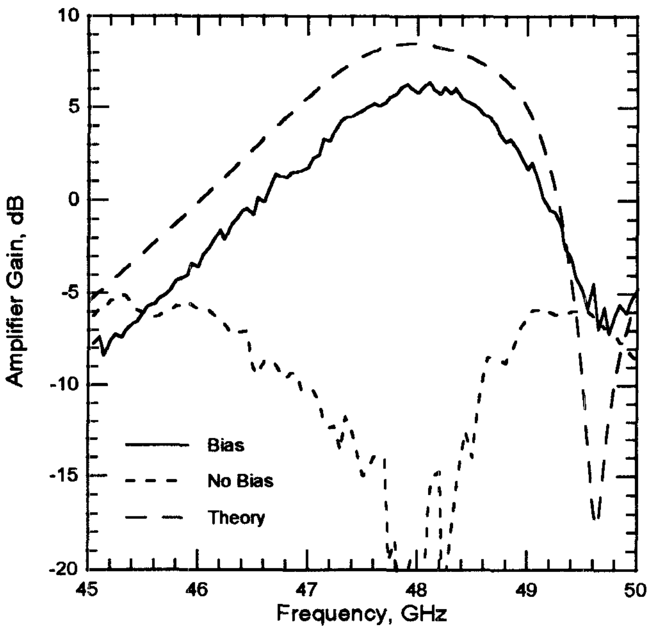


Fig. 5. Amplifier gain versus frequency. The polarizer positions are those shown in Fig. 4(a).

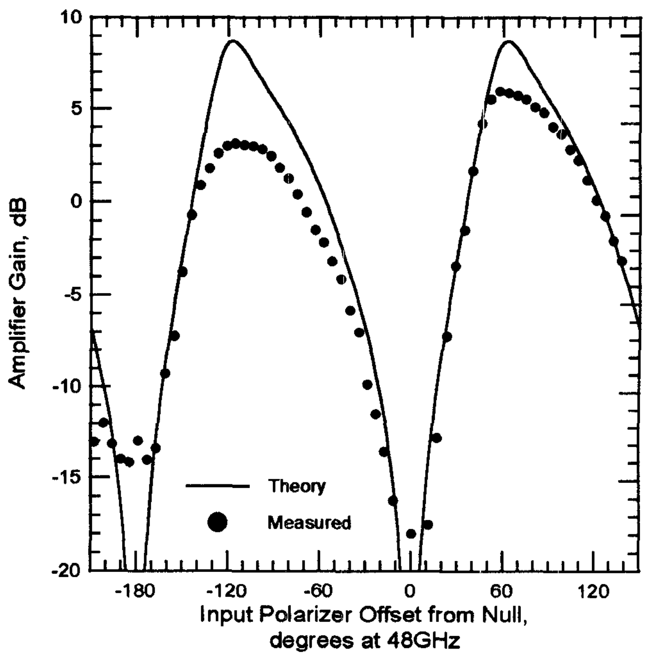
for one second at a time. The entire setup is computer-controlled to facilitate data collection. The amplifier was completely stable—no spurious oscillations were observed.

The measured gain is shown in Fig. 5. The amplifier is tuned to operate at 48 GHz. The peak gain is 6 dB. The 3-dB bandwidth is 1.7 GHz (3.5%). The modelled gain is also shown, and agrees with the measured results. Diffraction losses within the grid and device variation may account for differences between theory and experiment. The theoretical gain curve uses a measured value for the pHEMT transconductance g_m. Without bias, the gain is below −5 dB over the entire frequency range. The difference between the gain with and without bias is 30 dB at 48 GHz.

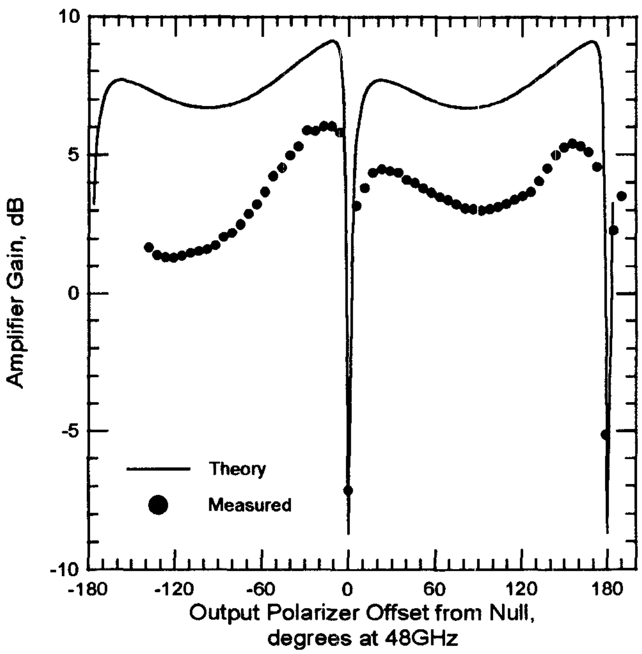
To further validate the model, the gain was measured at 48 GHz as a function of polarizer position. Fig. 6(a) shows the gain as function of input polarizer position. The input polarizer tunes the amplifier's output circuit. Fig. 6(b) shows the gain as a function of output polarizer position. Again, the modelling is in agreement with the measurements.

IV. Tuning

By changing the positions of the input and output polarizers, the amplifier can be tuned to operate at other frequencies. Fig. 7 shows the measured gain with the amplifier tuned for a higher frequency. The peak gain is 2.5 dB at 60 GHz. The modelled gain agrees



(a)



(b)

Fig. 6. Amplifier gain at 48 GHz as a function of input (a) and output (b) polarizer position.

with measurement. For this measurement, we use a high-dielectric Duroid slab at the grid output to act as a tuner. Fig. 8 illustrates the tuning range of the grid. Amplifier gain is plotted as a function of frequency with the amplifier tuned for 44, 48, 54, and 60 GHz. The gain is 6.5 dB with the grid tuned for 44 GHz, with a

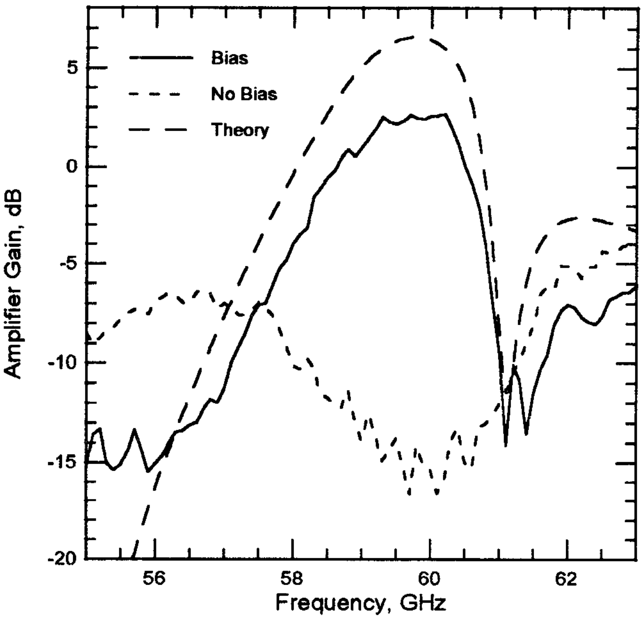


Fig. 7. Amplifier gain versus frequency. An output tuner has been added, and the polarizer positions are optimized for peak performance at 60 GHz. The noise floor of the spectrum analyzer prevents measuring gain below –15 dB.

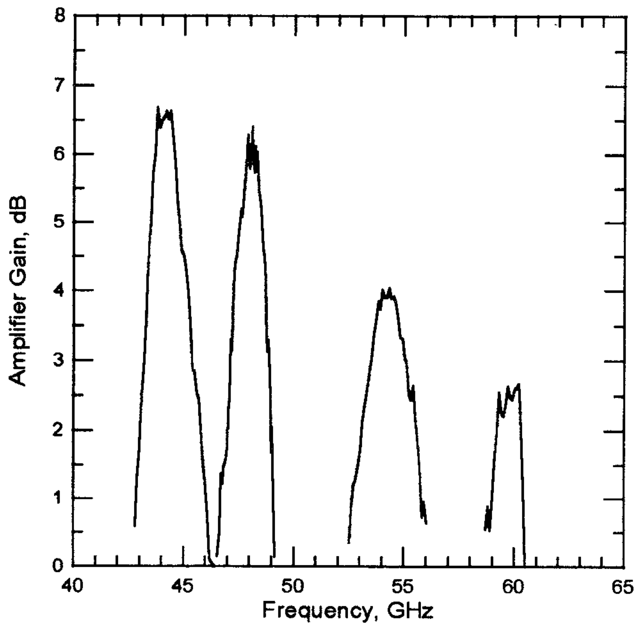


Fig. 8. Tuning range of the amplifier. The 60 GHz measurement includes an output tuner.

bandwidth of 2.0 GHz (4.5%). When tuned for 54 GHz, the gain is 4 dB with a 3.2 GHz (6%) bandwidth.

V. Conclusion

We have measured the first successful results from a 36-element monolithic pHEMT grid amplifier. The array was fabricated by Lockheed Martin. This grid has a peak gain of 6.5 dB when tuned for 44 GHz. By adjusting the external polarizers, the grid could operate up to 60 GHz with a gain of 2.5 dB. This is the highest reported frequency of operation for a grid amplifier. The maximum bandwidth is 6% with the grid tuned for 54 GHz. The gain and tuning curves agree with modelling.

VI. Acknowledgements

The authors gratefully acknowledge Norm Byer of Lockheed Martin and Erich Schlecht of the Army Research Laboratory for their support and helpful suggestions.

VII. References

[1] M. Kim, J.J. Rosenberg, R.P. Smith, R.M. Weikle, J.B. Hacker, M.P. De Lisio, D.B. Rutledge, "A Grid Amplifier," *IEEE Microwave and Guided Wave Lett., MGWL-1*, pp. 322–324, Nov. 1991.

[2] M. Kim, E.A. Sovero, J.B. Hacker, M.P. De Lisio, J.-C. Chiao, S.-J. Li, D.R. Gagnon, J.J. Rosenberg, D.B. Rutledge, "A 100-Element HBT Grid Amplifier," *IEEE Trans. Microwave Theory Tech., MTT-41*, pp. 1762–1771, Oct. 1993.

[3] M.P. De Lisio, S.W. Duncan, D.-W. Tu, C.-M. Liu, A. Moussessian, J.J. Rosenberg, D.B. Rutledge, "Modelling and Performance of a 100-Element pHEMT Grid Amplifier," submitted to *IEEE Trans. Microwave Theory Tech.*, April 1995.

[4] J.A. Higgins, E.A. Sovero, W.J. Ho, "44-GHz Monolithic Plane Wave Amplifiers," *IEEE Microwave and Guided Wave Lett., MGWL-5*, pp. 347–348, Oct. 1995.

[5] C.-M. Liu, E.A. Sovero, W.J. Ho, J.A. Higgins, D.B. Rutledge, "A Millimeter-Wave Monolithic Grid Amplifier," *Int. Journal Infrared Millimeter Waves*, vol. 16, pp. 1901–1910, Nov. 1995.

[6] C.-M. Liu, E.A. Sovero, W.J. Ho, J.A. Higgins, M.P. De Lisio, D.B. Rutledge, "Monolithic 40-GHz 670-mW HBT Grid Amplifier," to be presented at *1996 IEEE MTT-S Int. Microwave Symp.*, Oct. 1995.

[7] D.-W. Tu, S.W. Duncan, A. Eskandarian, B. Golja, B.C. Kane, S.P. Svenson, S. Weinreb, N.E. Byer, "High Gain Monolithic W-Band Low Noise Amplifiers Based on Pseudomorphic High Electron Mobility Transistors," *IEEE Trans. Microwave Theory Tech., MTT-42*, pp. 2590–2597, Dec. 1994.