A 20 mW, 150 GHz InP HEMT MMIC Power Amplifier Module

Lorene Samoska*, Alejandro Peralta*, Ming Hu**, Miro Micovic**, and Adele Schmitz**
*Caltech – Jet Propulsion Laboratory, M/S 168-314, 4800 Oak Grove Drive, Pasadena, CA 91109, Phone 818-354-0849, Fax: 818-393-4683, Email: Lorene@merlin.jpl.nasa.gov
**HRL Laboratories, LLC, Malibu, CA

This paper describes a power amplifier (PA) module containing an InP High Electron Mobility Transistor (HEMT) Monolithic Millimeter-wave Integrated Circuit (MMIC) amplifier chip, designed and packaged at the Jet Propulsion Laboratory, and fabricated at HRL Laboratories. The module features 20 mW of output power at 150 GHz, with more than 10 mW available in the 148-160 GHz frequency range.

Until recently, MMIC PAs were limited in frequency and power, but in the last few years PA development has surged, with the advent of 0.1μm gate-length or smaller InP HEMTs and associated HEMT MMICs. While excellent results exist at W-Band (75-110 GHz) using either 0.15 μm InP HEMT [1] or 0.1 μm GaAs PHEMT [2] MMICs and multichip power-combined modules[3], few power amplifier results have been reported above 110 GHz. HRL Laboratories has achieved a 4 finger, 150 μm gate width device capable of producing high gain per stage and several milliWatts of power up to at least 170 GHz. Our results to date using this device include a 65-145 GHz medium power amplifier capable of 10 mW or more over 80 GHz of bandwidth [4], packaged waveguide modules capable of 10 mW up to 140 GHz [5], and an active MMIC HEMT doubler to 164 GHz with 5 dBm output power and 2 dB conversion loss.[6]

We now report on a MMIC chip which has achieved 15-25 mW of output power, greater than 10 dB small signal gain and 7 dB of large signal gain, measured on-wafer from 140-170 GHz. Preliminary results on this chip and issues associated with packaging MMICs above 100 GHz were reported elsewhere [7,8]. We now discuss the chip and module's power performance in the 140-170 GHz band.

The MMIC chip is designed in a grounded co-planar waveguide topology with vias between the upper ground planes and the 50 μm thick InP substrate(backside metallized), to suppress unwanted substrate modes, and incorporates three stages with the final stage employing two power-combined HEMTs [Fig.1]. Small signal gain was relatively flat over 145-170 GHz (10-12 dB), and peak output power occurred between 150-152 GHz. The saturated output power is 25 mW (14 dBm) at 150 GHz for the chip measured on-wafer with GGB Industries WR5 waveguide wafer probes and an Anritsu power meter. Pout vs. Pin curves reveal that the 1 dB compression point occurs at approximately 10 mW (10 dBm) at 150 GHz.

We have designed, packaged, and tested the 140-170 GHz chip in a WR5-band (140-220 GHz) waveguide housing. [Fig 2,3,4]. E-plane probe transitions were used to interface the grounded cpw chip to the waveguide. Biasing of the module was accomplished using bypass capacitors to suppress low frequency gain (<100 MHz) and prevent low frequency oscillations. We tested the module using a backward wave oscillator (BWO) and commercial frequency doubler to achieve 2-5 mW input power into the module between 140-170 GHz. The module can provide 20 mW (13 dBm) of saturated output power at 150 GHz, and at least 10 mW (10 dBm) from 148-160 GHz. The power-added efficiency is 3%, and 0.4 W of DC power are dissipated. The small size (0.75" by 0.75" by 0.5") makes the module particularly convenient for interfacing with other waveguide test equipment, such as BWOs or Gunn oscillators, diode-based frequency multipliers, and even wafer probes to test subsequent circuits, such as frequency doublers or digital circuits, which may require a high power source at the RF probe tip.

While packaging the module in a waveguide medium introduces between 1-3 dB of RF loss, it has the advantage of ease of use with other commercially available test equipment. We have made two such modules and they are easily cascaded to achieve gain up to 18 dB at 150 GHz. The modules may also be power-combined using waveguide magic tees for more output power. These amplifier modules are an important step towards higher frequency sources and are easily integrated into test systems or wafer probe stations. To our knowledge, this module represents the highest output power to date for a solid state HEMT MMIC amplifier at 150 GHz.

[1] "A 427 mW, 20% compact W-band InP HEMT MMIC power amplifier," Ingram, D.L. *et.al*, *IEEE RFIC Symp Digest*, 1999, pp. 95–98.
[2] "Power-amplifier modules covering 70-113 GHz using MMICs," Huei Wang; L. Samoska., *et.al*, *IEEE Trans MTT*, Vol. 49: 1, Jan 2001 pp. 9–16.
[3] "Compact W-band solid-state MMIC high power sources," D.L. Ingram, *et.al*, *IEEE MTT-S IMS Digest 2000* Vol. 2, pp. 955 -958.
[4] "65-145 GHz InP MMIC HEMT medium power amplifiers," L. Samoska, Y. C. Leong; *IEEE MTT-S 2001 IMS Digest*, Vol. 3, 2001 pp. 1805 -1808
[5] "Advanced HEMT MMIC Circuits for Millimeter and Submillimeter Power Sources," L. Samoska., A. Peralta, J. Bruston, *Proceedings of the Far Infrared, Mm and Submm Detector Workshop*, Monterey, CA April 2002. Manuscript on-line at http://www.sofia.usra.edu/det_workshop/papers/session4/3-18samoska.pdf
[6] "164 GHz MMIC HEMT Doubler," V. Radisic, *et al*, *IEEE Microw.Wireless Comp. Lett*, Vol. 11, No. 6, June, 2001, pp. 241-243
[7] "InP HEMT MMIC Chip Set for Power Sources Covering 80-170 GHz," L. Samoska, *et al.*, *Proc. of the Twelfth International Symposium on Space Terahertz Technology*, Dec. 2001, pp. 477-484.
[8] "Packaging of microwave integrated circuits operating beyond 100 GHz," E. Daniel, *et al.*, *Proc. of the IEEE Lester Eastman Conference on High Performance Devices*, 2002, pp. 374–383.

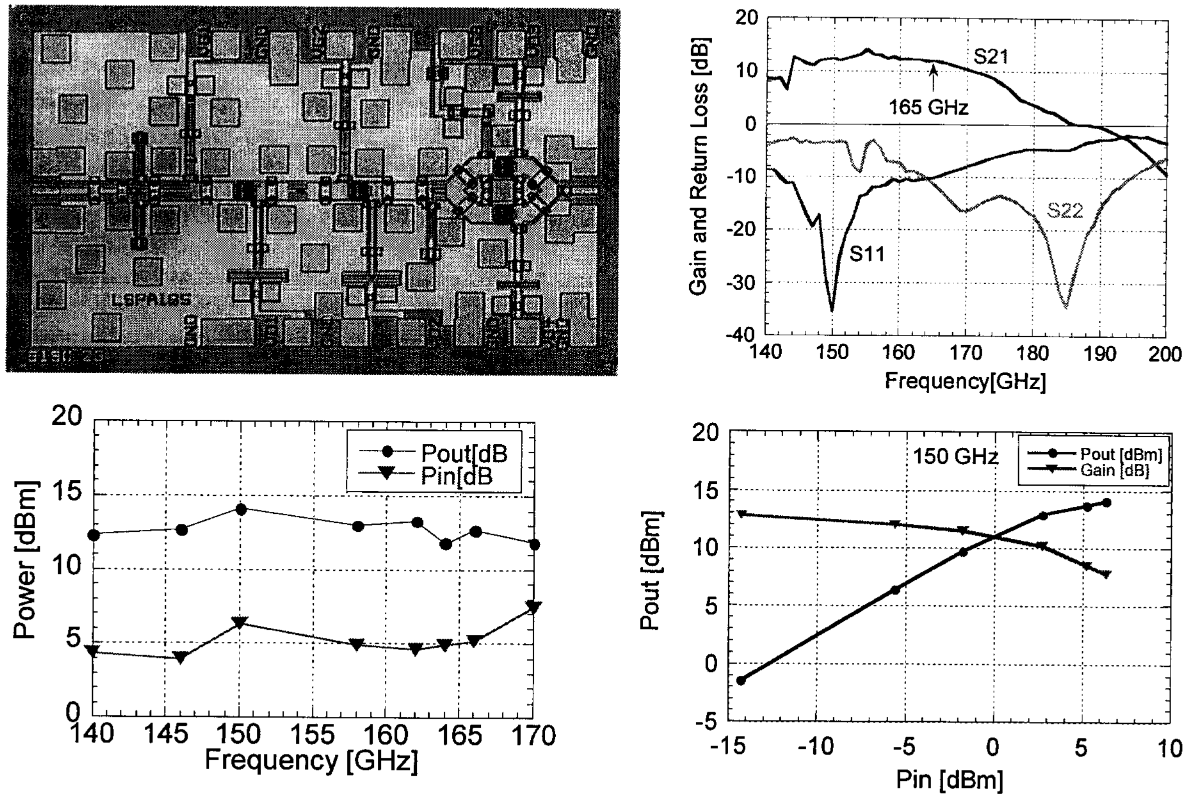
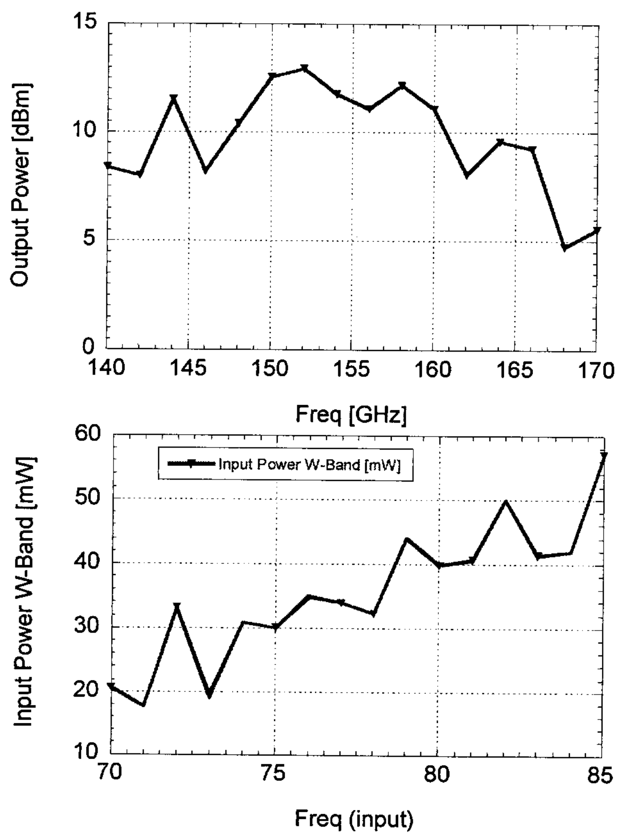


Figure 1. Top photo: Chip Photograph of LSPA165 power amplifier chip, designed at JPL and fabricated at HRL Labs. Upper Right graph: S-parameters showing over 10 dB gain of the amplifier chip from 145-170 GHz. Lower Left graph: Pout and Pin measured on-wafer for the chip. Lower Right graph: Pout vs Pin showing P_{1dB}~10dBm

---



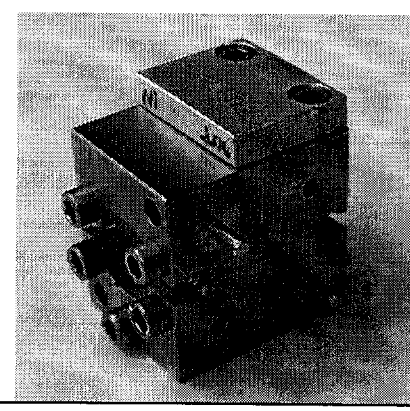
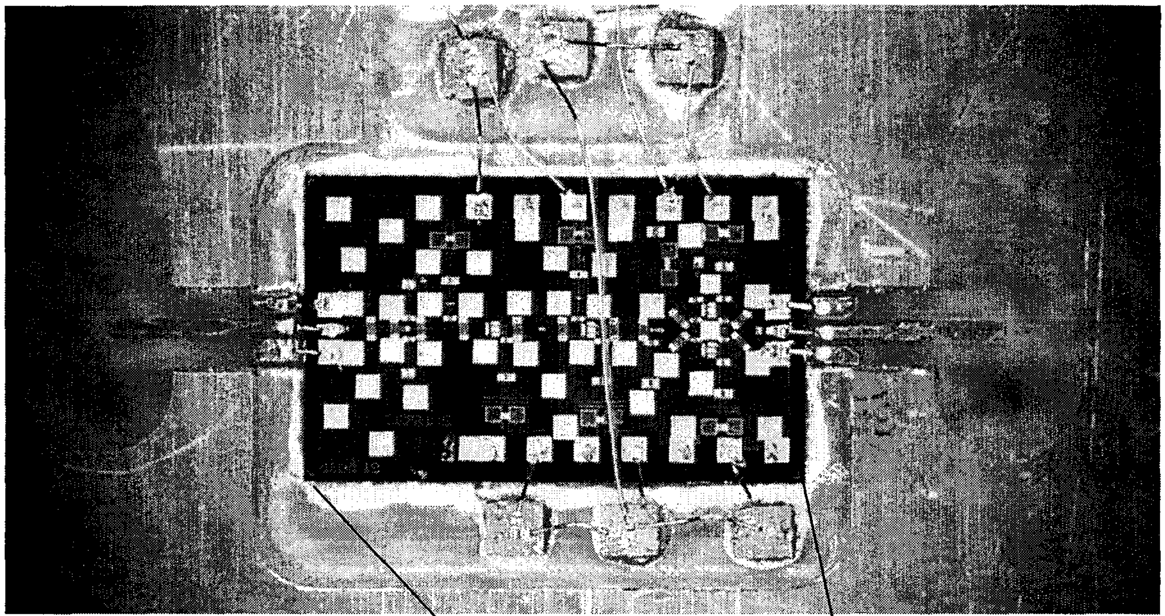


Figure 2. Upper left: Output power of waveguide module as a function of frequency, showing 20 mW (13 dBm) around 150-152 GHz. Lower left: Input power measured at the input to a commercial doubler between 70-85 GHz, which was used to double the frequency to reach the 140-170 GHz power amplifier module. Some of the variation in output power is a result of the input power variation at W-band. Above, right: WR5 waveguide module (longest dimension of the block is approximately .75 inches)



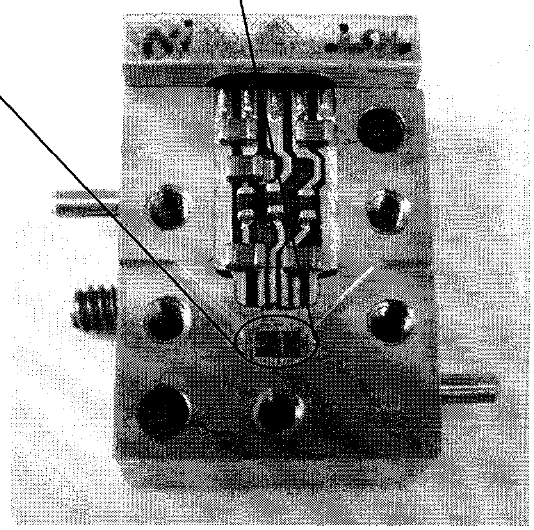


Figure 3. Top photo: LSPA165 chip packaged in a WR5 waveguide module, with alumina E-plane probes for RF input and output, and 50pF bypass capacitors on gate and drain lines to control low frequency oscillations.
Bottom right: Module opened up to show chip and DC circuitry. Large (0.1μF) bypass capacitors were used on gate and drain lines to suppress low frequency (<100MHz) gain. Ferrite beads were also used in series in the bias lines to isolate the chip from the power supply used, to prevent low frequency oscillations.

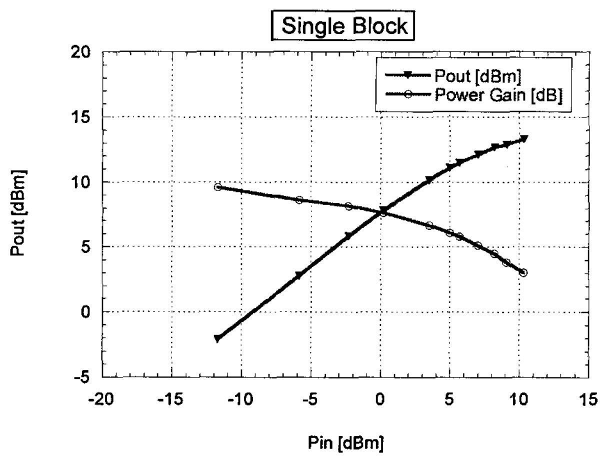


Figure 4. (left) Pout vs. Pin curves for the waveguide module at 150 GHz. 13 dBm is the saturated output power (20 mW) at 150 GHz. The module's small signal (and power) gain is lower than that measured for the raw chip because of the waveguide, probe transition and wire-bond losses, estimated to be 2-3 dB end-to-end.

This work was carried out in part by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.The authors would like to acknowledge support from DARPA under contract number F33615-99-C-1512 under Dr. Edgar Martinez.