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Medium Power Amplifiers Covering 90-130 GHz for the ALMA Telescope Local Oscillators

L. Samoska, E. Bryerton*, D. Pukala, A. Peralta, M. Hu†, A. Schmitz†

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

*National Radio Astronomy Observatory, Charlottesville, VA 22903

†HRL Laboratories, LLC, Malibu, CA 90265

***ABSTRACT* — This paper describes a set of power amplifier (PA) modules containing InP High Electron Mobility Transistor (HEMT) Monolithic Millimeter-wave Integrated Circuit (MMIC) chips. The chips were designed and optimized for local oscillator sources in the 90-130 GHz band for the Atacama Large Millimeter Array telescope. The modules feature 20-45 mW of output power, to date the highest power from solid state HEMT MMIC modules above 110 GHz.**

***Index Terms* — MMIC power amplifiers, InP HEMT, coplanar waveguide, ALMA.**

I. Introduction

The Atacama Large Millimeter Array (ALMA) [1] is an interferometer array telescope that will operate at millimeter and submillimeter wavelengths for radio astronomy. Its receivers will cover frequencies from 30-900 GHz, and make use of MMIC power amplifiers as local oscillator drivers for diode-based multiplier chains up to 900 GHz. The requirements for the ALMA amplifiers demanded an improvement over the prior state of the art in terms of output power, bandwidth, and frequency of operation for MMIC power amplifiers.

Many articles have been published on monolithic millimeter-wave integrated circuit (MMIC) power amplifier (PA) chips and modules in W-band (75-110 GHz). [2-4]. Such chips typically provide 50-300 mW of output power for 0.6-1.2mm of gate periphery in the transistors. Those chips made use of a microstrip topology which is particularly convenient for large eight-way power-combining networks. For higher frequencies, it may be more beneficial to use a grounded coplanar waveguide topology to avoid the added source inductance required in microstrip to provide a ground for the transistors. A W-band amplifier making use of a four-way power combiner in coplanar waveguide showed great promise with nearly the same power per mm of gate width as the microstrip designs [5]. More recently, medium power (5-20 mW) chips have been published in G-Band (140-220 GHz) [6,7] using InP HEMT and InP HBT technology. The purpose of our work is to increase the frequency of medium power amplifiers beyond W-band, while also increasing the number of transistors to be power-combined on-chip. Towards this end we have designed two chips for the 90-130 GHz band with 300 micron and 600 micron gate periphery, using both two-way and four-way power combining in grounded coplanar waveguide topology, and fabricated the chips in HRL's 0.11 μm InP HEMT MMIC technology.

In this paper, we report on the MMIC modules for the ALMA local oscillator drivers. The two chip designs will be presented, with gains of 15-20 dB and output powers from 20-45 mW. Thus far, these results represent the highest output power from solid-state amplifier modules above 110 GHz.

II. MMIC Design and Chip Photographs

Some of the challenges in designing MMIC power amplifiers above W-band are first, the choice of device technology. InP HEMTs with gate lengths no larger than 0.12μm are the most mature technology available, though InP DHBTs are starting to gain ground. Second, the one must power-combine as many large periphery transistors as possible within the constraints of matching networks at the higher frequencies. The best W-band PAs utilize eight-way combiners for a total gate periphery of 1.2 mm. Since power-combining FETs involves placing source vias between each of the FETs, this limits the compactness of the power-combined structure as the wavelength decreases. Thirdly, if coplanar waveguide is chosen as the design medium to overcome excess source inductance which could substantially limit the maximum available gain of the transistors, the range of impedances available to match large periphery devices is limited by design rules, metal lift-off constraints, and current carrying capability of the transmission lines to be between approximately 23 and 65 ohms. We have designed the chips within these constraints and proven that a four-way coplanar waveguide combiner is still possible to achieve up to 130 GHz.

The two MMIC chip photos are shown in Fig. 1. The chips are designed with 0.11μm gate-length AlInAs/GaInAs/InP HEMT devices grown by MBE. The devices exhibit typical DC transconductances of 1050 mS/mm and breakdown a)

b)

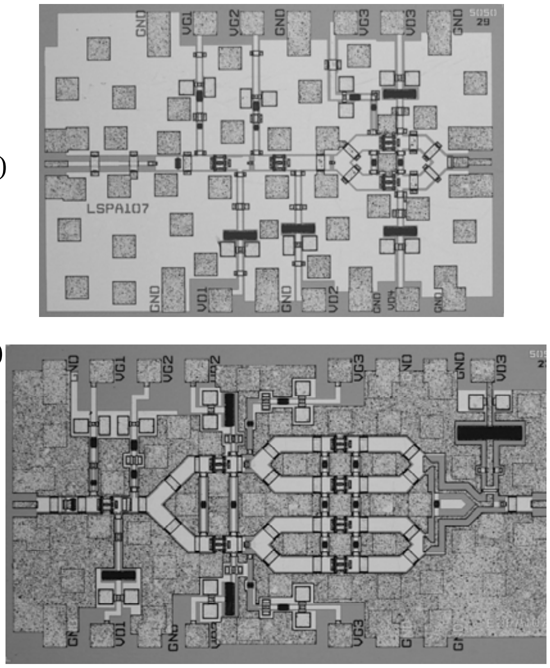

Fig. 1. Chip photos of the two MMIC PAs. Top photo (a) shows Chip 1, with output stage having a two-way combiner for a total gate periphery of 300 μm. Bottom photo (b) shows Chip 2, having three stages with a four-way combiner at the output for a total gate periphery of 600 μm.

voltages of 4V. The devices used four gate fingers 37 microns wide, for a total periphery of 148 μm. The topology used is a grounded coplanar waveguide medium having a 50 μm thick InP substrate. Vias between the top ground planes and backside metal are used to suppress unwanted substrate modes. The design in Fig. 1a (Chip1) incorporates three stages with the final stage employing two power-combined HEMTs for a total gate periphery of 300μm, similar to that in reference [8] The larger chip in Fig. 1b (Chip 2) incorporates three stages with a four-way combiner at the output for a total gate periphery of 600 μm.

III. MEASUREMENTS FROM 90-140 GHz

A. On-wafer S-parameter Measurements

The small signal S-parameters of each chip are shown in Fig 2. We measured the chips on-wafer using Oleson Microwave Labs frequency extension modules for the WR8 waveguide band, as well as GGB Industries WR8 waveguide wafer probes. Both chips exhibit over 10 dB gain from 90-135 GHz. For the four-way combined chip, we mounted the chip on a carrier and assembled off-chip bypass capacitors for each stage to suppress low frequency (~600 MHz) oscillations.

a)

b)

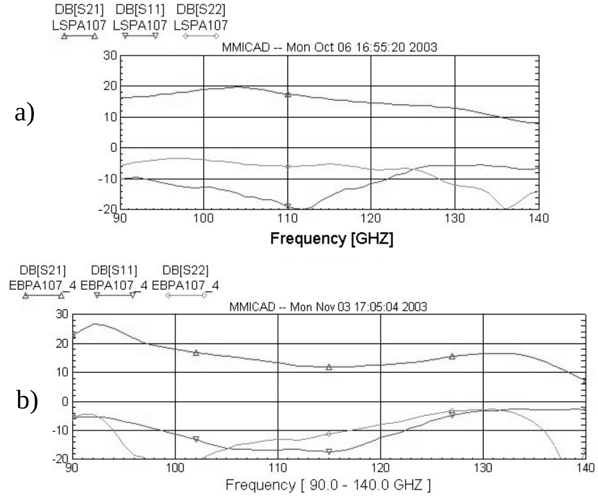

Fig. 2. On-wafer S-parameter measurements of Chip 1 (a) and Chip 2 (b).

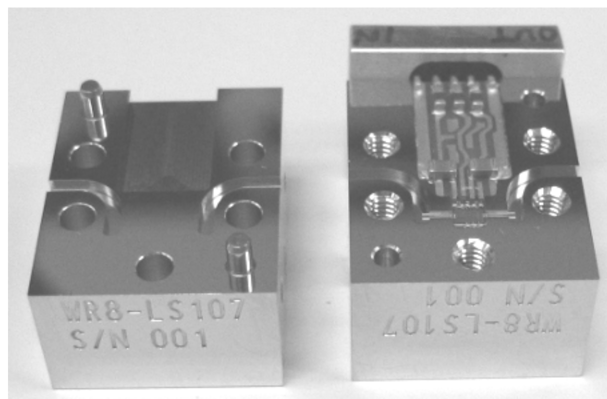

Fig.3. WR8 waveguide split-block amplifier module, opened up to show components. Chip sits in right half module.

B. Power Measurements of MMIC Modules

We have designed and assembled WR8 waveguide modules for the MMICs similar to those in Ref [7]. A photo of the opened split-block module is shown in Fig 3. We used a Gunn oscillator as an input power source from 93-123 GHz and an Erickson power meter to measure output power. The output power as a function of frequency and input power for chip 1 is shown in Figure 4. The chip is biased for Vd=2.4V, Id=200mA, Vg=-0.06V, Ig=-0.3mA, with all drains tied together and all gates tied together. At least 25 mW is obtained over the entire range with several frequencies topping out above 30 mW. The peak power is not surprisingly obtained near the points of highest small signal gain shown

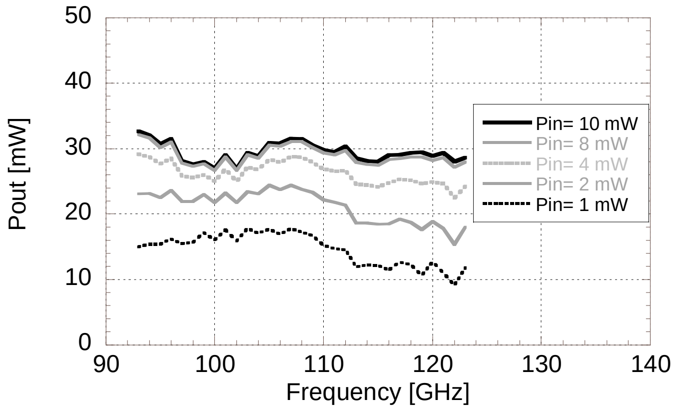

Fig. 4. Output power vs. frequency for five input power levels ranging from 1 mW to 10 mW, for the waveguide module populated with Chip 1.

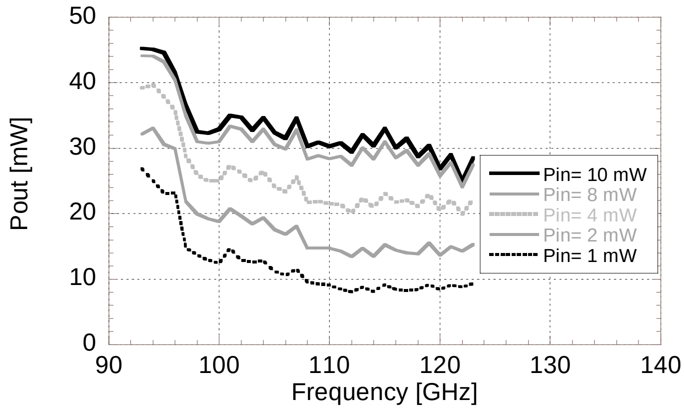

Fig. 6. Output power vs. frequency for five input power levels ranging from 1 mW to 10 mW, for the waveguide module populated with Chip 2.

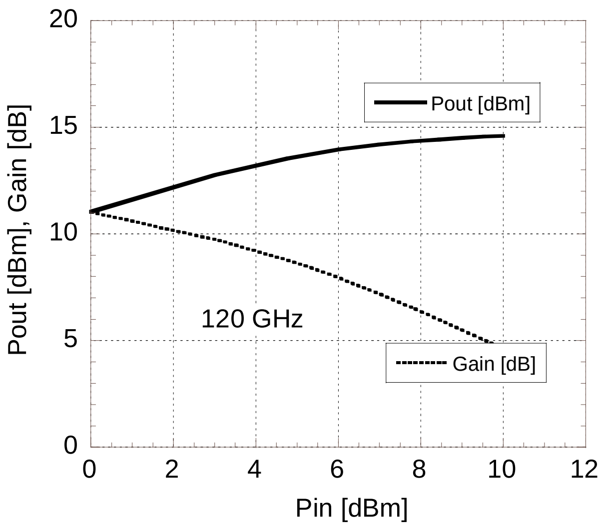

Fig. 5. Pout and associated large signal Gain for the module containing Chip 1, measured at 120 GHz.

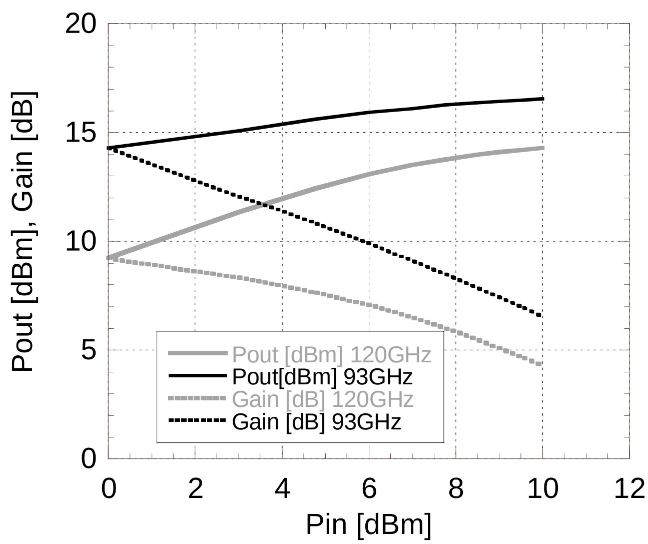

Fig. 7. Pout and associated large signal Gain for the module containing Chip 2, measured at 93 GHz and 120 GHz.

in Fig. 2. The power added efficiency is approximately 4% at 120 GHz. The output power is well-saturated for Pin of 8 mW at all frequencies. We also plot the output power Pout vs. Pin curve at 120 GHz for this module in Figure 5, where the 1 dB compression point occurs approximately for Pout of 12 dBm.

For the module containing Chip 2, we show the output power vs. frequency for various input powers from 1 mW to 10 mW in Fig. 6. Since Chip 2 contains a four-way power combiner at the output stage, the peak output power is higher than that for the module of Chip 1. Once again, the peak output power is obtained near the peak in the small signal gain shown in Fig 2b. Chip 2 is biased for the maximum output power at 123 GHz. The first two stages are tied together while the third stage is biased separately. The conditions used were Vg=-0.07V, Ig=-.42mA, V_{d12}= 2.4V, and I_{d12}=170 mA, while the drain of the final power–combined stage is biased at V_{d3} = 3.3 V and I_{d3} = 190 mA. The power added efficiency is between 3.5% at 93 GHz and 1.7% at 120 GHz. In Fig. 7, we show the Pout vs. Pin curves at 93 GHz and 120 GHz. The corresponding gain curves are also plotted as dashed lines.

VII. CONCLUSION

We have presented our results on two medium power amplifier MMIC modules for the 90-130 GHz band. These modules, each containing a single InP MMIC chip, can obtain 20-45 mW over the band. For MMIC chips and modules above 110 GHz - the edge of W-band - our modules represent the highest output power reported to date. Future work will involve optimizing the output power-combiners for higher frequencies, making use of electromagnetic simulator tools such as Sonnet and HFSS. These amplifier modules will provide the needed power for the local oscillator chains in the ALMA telescope.

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