

## MONOLITHIC POWER AMPLIFIERS COVERING 70-113 GHz

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### ABSTRACT

A number of monolithic W-band power amplifiers (PAs) have been developed for local oscillators of the Far Infrared and Sub-millimeter Telescope (FIRST). These PA chips include three driver and three power amplifiers covering most of the W-band, i.e., the frequency ranges of 72-81, 90-101, and 100-113 GHz. Each driver amplifier and power amplifier provides at least 20 and 22 dBm (160 mW), respectively in the frequency range it covers. The 100-113 GHz power amplifier has a peak power of greater than 250 mW (25 dBm) at 105 GHz, which is the best output power performance for a monolithic amplifier above 100 GHz to date. These monolithic chips are fabricated using 0.1- $\mu$ m AlGaAs/InGaAs/GaAs pseudomorphic T-gate power HEMTs on a 2-mil GaAs substrate.

### INTRODUCTION

W-band MMIC power amplifiers (PAs) have been developed for transmitter applications [1]-[2]. These amplifiers can be used as drivers for local oscillator (LO) sources at frequencies into the THz range. The local oscillators for the Far-Infrared and Sub-millimeter Telescope (FIRST) will be comprised of synthesizers and

active multipliers to provide output frequencies of 71-112.5 GHz, PAs to amplify these W-band signals, and finally chains of Schottky diode multipliers to achieve THz frequencies. The motivation of this work is to develop a chip set of W-band MMIC PAs which could be used for the FIRST LO chains.

This paper will present the results of these W-band MMIC PA chips. The chips are fabricated using 0.1- $\mu$ m AlGaAs/InGaAs/GaAs pseudomorphic (PM) T-gate power HEMT MMIC technology on a 2-mil GaAs substrate. Although InP-based HEMT MMICs have demonstrated excellent power performance at W-band [2], GaAs-based HEMT MMIC technology was selected for this project due to the process maturity. The 2-mil GaAs HEMT PAs not only demonstrated good power performance with high yield at W-band (94 GHz) [1], but also showed impressive results from Ka- to V-band [3]-[6]. In this work, three sets of PA chips and their driver amplifiers covering 72-81, 90-101, and 100-113 GHz were designed, fabricated and tested. The three driver amplifiers were designed with a common output gate periphery of 640  $\mu$ m, while the PAs had 1280  $\mu$ m, to fulfill output power requirements. The measurement results indicated each driver amplifier and power amplifier provide at least 20 and 22 dBm (160 mW), respectively, in the frequency range which it

covered. For the first time, the full power data as a function of frequency are presented in W-band and the wide-band capability is demonstrated. Moreover, the 100-113 GHz power amplifier has a peak power of greater than 250 mW (25 dBm) at 105 GHz, which is the best output power performance for a monolithic amplifier above 100 GHz to date.

#### MMIC PROCESS AND DEVICE CHARACTERISTICS

The 0.1- $\mu\text{m}$  power HEMT device development has been reported [7]. The HEMT structure is grown using molecular beam epitaxy (MBE) on three-inch substrates and uses a PM  $\text{In}_{0.22}\text{Ga}_{0.78}\text{As}$  channel. The HEMT device structure is based on a double heterostructure design to achieve a high aspect ratio for 0.1- $\mu\text{m}$  gate lengths. The devices typically exhibit a gate-to-drain breakdown voltage of 6 V measured at a gate current of 0.1 mA/mm, a peak dc transconductance of 600 mS/mm, a maximum current of 600 mA/mm, a unit current gain frequency  $f_T$  of 130 GHz, and a maximum oscillation frequency  $f_{\text{max}}$  of greater than 200 GHz.

#### HEMT DEVICE MODELING AND CIRCUIT DESIGN

The HEMT linear small signal equivalent circuit parameters are obtained from careful fit of the measured small signal S-parameters to 50 GHz. These parameters are consistent with an estimation based on device physical dimensions and parameters. The Curtice-Ettenberg FET asymmetric model was used to describe the HEMT device nonlinear behavior [8]. The nonlinear transconductance coefficients were then obtained from fitting the dc-IV measurement of the devices. The device models have been verified by comparing the measured and simulate on results of simple pre-matched device structures [1].

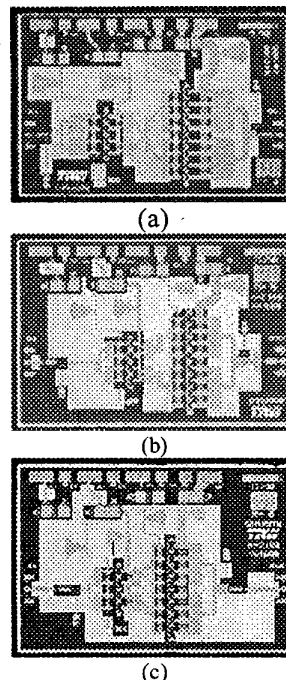


Fig. 1. The photographs of the three W-band monolithic PAs: (a) 72-81, (b) 90-101, and (c) 100-113 GHz. The chip sizes are  $2.3 \times 1.6 \text{ mm}^2$ .

Fig. 1 shows the three PA chips (covering 72-81, 90-101, and 100-113 GHz). All the three PAs follow a common circuit architecture, which is a single-ended two-stage design. The first stage employs four cells of 8-finger, 160- $\mu\text{m}$  HEMT devices and second stage has twice the device periphery with eight HEMT devices. The topology used for the PA designs has been reported in [1]. For these new designs, reactive matching elements were optimized for increased bandwidth and higher frequency performance. EM simulations were performed for all the passive structures using Sonnet [9]. The driver amplifiers also follow a common circuit architecture, which is similar to that of the PAs with half of the gate peripheries for both the first and second stages.

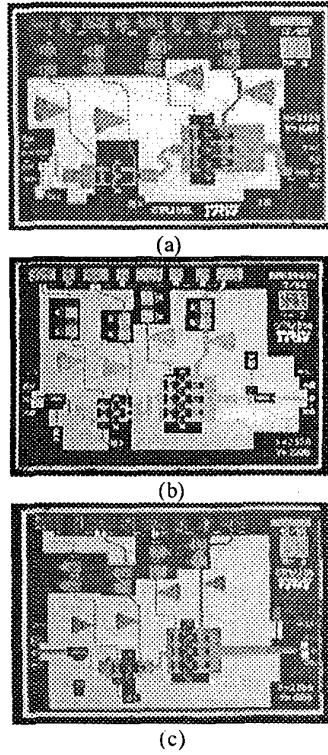


Fig. 2. The photographs of the three W-band drive amplifiers: (a) 72-81, (b) 90-101, and (c) 100-113 GHz.

Fig. 2 shows the chip photographs of the three driver amplifiers. The chip sizes for all of the amplifiers are  $2.3 \times 1.6 \text{ mm}^2$ , in order to facilitate ease of dicing of the wafers.

### MEASUREMENT RESULTS

The PAs and driver amplifiers were first tested for gain using on-wafer small signal measurements. A measured typical small signal gain of at least 8, 7 and 4 dB is achieved at 72-81, 90-101, and 100-113 GHz, respectively at a drain voltage ( $V_d$ ) of 1.5 V with gate voltage set to 0 V for the three PAs as shown in Fig. 3(a). The three microstrip driver amplifiers depict high gain performance of 12, 7, and 7 dB as shown in Fig. 3(b). The chips were then diced and tested in a WR-10 waveguide module (with a pair of

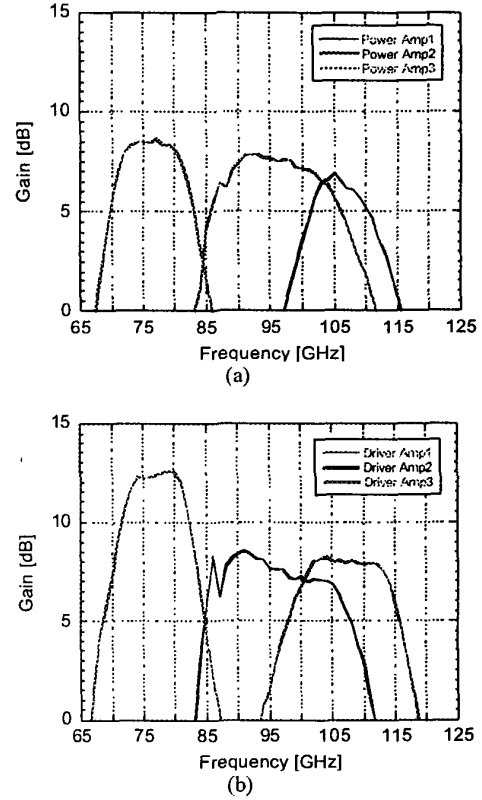


Fig. 3. The measured on-wafer small signal gain vs. frequency of the three W-band (a) PAs, and (b) driver amplifiers.

microstrip-line to waveguide transitions [10]) for small signal response and output power.

Power measurements were performed at  $V_d = 2.5 \text{ V}$  to maximize output power and bandwidth of the chips. The driver amplifiers showed up to 100 mW of peak output power, and the power amplifiers typically exhibited 200 mW of output power. The amplifier modules were then cascaded in order of increasing output stage gate periphery: the driver ( $640 \mu\text{m}$ ) was followed by a power amplifier (1.28 mm). Fig. 4 shows the maximum output power performance vs. frequency at the output of the cascaded modules. Three frequency bands are covered in three separate pairs of modules. Each amplifier chain

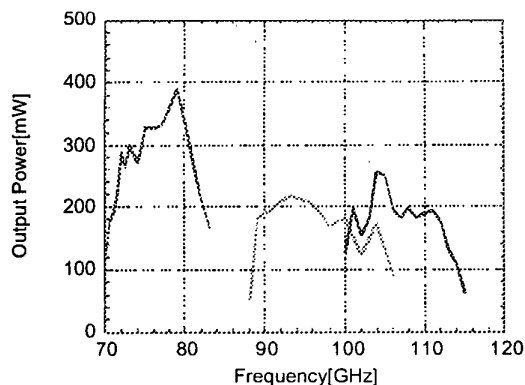


Fig. 4. The output power vs. frequency plot of the three W-band packaged power amplifiers.

demonstrated at least 22 dBm (158 mW) in the frequency range it covers. The 100-113 GHz power amplifier has a peak power of greater than 250 mW (25 dBm) at 105 GHz, which is the best output power performance for a monolithic amplifier above 100 GHz to date. It is also noted that the waveguide transition has an insertion loss of 0.35 dB up to 107 GHz, and 0.5 dB from 107-115 GHz [10]. For the output power results at the MMIC chip end, the numbers mentioned above need to be corrected by this loss factor.

### SUMMARY

We have presented a chip set of monolithic W-band power amplifiers using 2-mil 0.1- $\mu$ m AlGaAs/InGaAs/GaAs PM T-gate power HEMT MMIC production process technology for LO sources which are useful for astronomical telescope applications. Measurement results show that at least 22-dBm output power can be provided for the frequency bands of 72-81, 90-101, and 100-113 GHz. The 100-113 GHz PA and driver amplifiers are the first reported MMIC PAs above 100 GHz.

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