W-Band Gallium Nitride MMIC Amplifiers for Cloud Doppler Radar Arrays

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***Abstract*—We present an effort in developing W-band (75-110 GHz) gallium nitride (GaN) monolithic microwave integrated circuit (MMIC) amplifiers for radar arrays. Due to GaN's high electric field breakdown capability and good 2D electron gas mobility in heterostructure field effect transistors, GaN power amplifiers provide best performance for high output power, high efficiency and small MMIC form factor amplifiers at W-band frequencies. GaN low noise amplifiers can also provide large receiver input dynamic range, reduce receiver noise figure and can be more tolerant of input power leakage from the transmitter without the need of protective limiter circuitry. All these characteristics are crucial for high frequency arrays where design require small circuit spacings, high efficiency to reduce power consumption and heating, and the minimization of circuit components for manufacturability and reliability. We will discuss results of power, driver and low noise amplifiers that we have designed, fabricated and characterized for radar array applications.**

I. INTRODUCTION

THE decadal survey on Earth science and applications recommends for the National Aeronautics and Space Administration (NASA) the Aerosol-Cloud-Ecosystems (ACE) mission that includes an instrument with cross-track scanning multi-frequency radar for measuring cloud droplet size, nucleation height, and cloud height [1]. A key technology that we are developing for enabling one possible implementation of the instrument are MMIC components [2] for a 94 GHz linear radar array [3] that can be electronically scanned in the cross tract direction that is perpendicular to the along-track radar traverse direction. An electronically scannable array will allow for a much greater amount of data to be measured. 94 GHz operating frequency will allow for observation of smaller atmospheric constituents.

The GaN technology we utilized for developing new amplifiers targeting a 94 GHz array radar were based on Raytheon's W-band foundry process and process design kit. Designs were made at both JPL and Raytheon. Raytheon has previously demonstrated a 91 GHz MMIC amplifier with more than 1 W output power and more than 20 % efficiency [4]. Raytheon has also demonstrated a 92 GHz GaN amplifier that produced more than 1 W continuous wave output power with less than 0.1 dB output power ripple for at least 1000 hours. The lifetime of the amplifier at 150 ºC junction temperature was estimated to be greater than 2.5×10^6 hours [5]. Utilizing this same process as these previously reported amplifiers we targeted developing a new set of power amplifiers, driver amplifiers and low noise amplifiers for 94 GHz operation.

II. RESULTS

The GaN MMIC fabrication process we utilized have HEMTs with approximately 0.12 µm gate length, 50 ohm/sq thin film resistors and 300 pF/mm^2 metal-insulator-metal (MIM) SiN capacitors. Transistors, passive components and topside interconnect metal were all built on a 50 µm thick SiC substrate. Metal deposited on the bottom of the substrate provided the ground plane. Thru wafer vias provided ground potential to the topside of the wafer [4].

MMIC circuit designs were done with Agilent ADS using Raytheon's process design kit. Various matching schemes were utilized for the different amplifier types either matching for optimum output power, efficiency, gain, return loss and/or noise performance. Electromagnetic simulations were performed on circuit layouts as needed where schematic models were less certain.

Figure 1 shows a GaN 3-stage driver amplifier. The purpose of this amplifier was to provide enough gain and output power as to saturate a following power amplifier. This driver used a cascaded series of three common source 4x35 µm HEMTs. Wide 50 ohm and short-length microstrip lines were used for interconnecting transistors and RF probe pads to minimize loss. Radial and RF shorted stubs were used for interstage matching and to match the input and output transistors to 50 ohm probe pads. Larger MIM capacitors were placed on chip to improve decoupling for DC bias wiring and future off-chip circuitry for MMIC module packaging. Resistors were placed throughout the MMIC to improve stability.

We will present more amplifiers and new measurements.

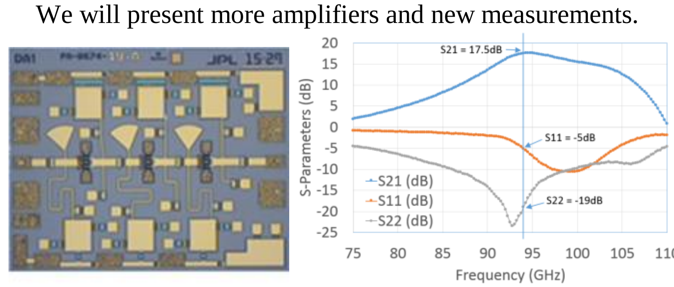

Figure 1 (a) Photo of fabricated driver amplifier. (b) Measured on-wafer S-parameters; 94 GHz data is indicated. Probe tip calibration was done with an off wafer alumina calibration standard substrate. S12 is less than -35 dB and not shown.

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