

E-Band GaN MMIC Power Amplifier for Vehicular Radar for Lunar Surface Mobility

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Abstract—In this paper we demonstrate a high efficiency, E-band (76 to 81 GHz) GaN HEMT three-stage MMIC based power amplifier (HPA). The measured output power (P_{out}), Gain, and power added efficiency (PAE) are presented. The results indicate that at about the center frequency (79.0 GHz) the saturated output power (P_{sat}) and the small signal gain are on the order of 29.0 dBm (0.8 W) and 16.5 dB, respectively. The PAE at P_{sat} is 20.2 %. The intended application of the power amplifier is for an obstacle detection frequency modulated continuous wave (FMCW) radar on a lunar terrain vehicle (LTV).

I. INTRODUCTION

In the next decade, NASA is planning on deploying lunar terrain vehicles (LTVs) near the south pole region of the Moon [1]. The LTV will enable astronauts to explore the lunar surface, collect samples, transport science instruments, and conduct scientific research. The LTV will also enable the astronauts to travel much further than they could on foot to collect samples from diverse regions, thereby increasing the science return. However, the LTV must withstand the extreme conditions (temperature and radiation) prevailing at the south pole region of the Moon. Gallium nitride (GaN) high electron mobility transistors (HEMTs) that are epitaxially grown on silicon carbide (SiC) wafers when subjected to space qualification tests including radiation hardness tests have demonstrated sufficient reliability for space applications [2]. Additionally, from microwave performance point of view, the GaN-on-SiC technology imparts several significant advantages over prior gallium arsenide (GaAs), indium phosphide (InP), silicon germanium (SiGe) and silicon complementary metal-oxide-semiconductor (Si CMOS) technologies. These include higher operating voltage, higher output power density, and higher channel operating temperatures [3].

This paper builds on our prior and ongoing investigations of Ka-band GaN HEMT MMIC based high power amplifiers (HPAs). Recently, we demonstrated a prototype of a switched wideband GaN HEMT based MMIC HPA that operates across the 25.25 to 31 GHz frequency band for user spacecraft terminals to support interoperability with multiple commercial SATCOM networks [4]. Additionally, we investigated the benefits offered by GaN HPA's performance characteristics for user spacecraft cognitive radio platforms that can learn from the environment in which they are operating and adaptively and dynamically change the operating parameters [5]. Furthermore, we demonstrated a prototype GaN HPA that operates over the 23.15 to 23.55 GHz frequency band for

future lunar proximity communication forward links that are planned between assets located in the lunar orbit and lunar surface, cross links between lunar relays, and links to science mission spacecraft [6]. Moreover, we demonstrated a prototype HPA, based on a waveguide 4-port magic-tee as a 2-way power combiner to combine the output from two GaN MMIC power amplifier (PA) chips [7].

Recently, Raytheon has reported the performance of E-band high power, high efficiency, GaN MMIC amplifiers [8]. In this paper, we extend our investigations to the characterization of the above E-band amplifiers over the 76 to 81 GHz frequency range, which is designated for terrestrial vehicular radar. The main motivation for this investigation is to conceptualize the design of a compact, low power, LTV FMCW radar. The radar will enable the astronauts to detect and track obstacles in the proximity and in the path of the LTV and thus provide safety while traversing the uneven lunar surface. The rationale for choosing a millimeter wave radar over an optical Lidar instrument is guided by the discoveries made by NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft. The instruments onboard the LADEE spacecraft discovered that the major components of the lunar exosphere are fine dust particles floating in a thin atmosphere of helium, neon, and argon gases that are supplied by the solar winds and radioactive decay of rocks [9]. Additionally, the dust particles when charged by the Sun's ultraviolet light levitates and floats above the lunar surface [9]. Research has shown that millimeter-wave signals can penetrate deeper than optical signals in a dusty environment.

II. E-BAND HIGH POWER, HIGH EFFICIENCY GAN MMIC AMPLIFIER

A. GaN E-Band Power Amplifier MMIC

The GaN semiconductor process, device structure, and MMIC design methodology are presented in [8]. The modules housing the power amplifier MMICs are shown in Fig. 1.

B. GaN E-Band Power Amplifier Measured Characteristics

1) *Output power (P_{out}), gain, and PAE as a function of the input drive power (P_{in}):* The measured output power and gain at about the center (79 GHz) are presented in Fig. 2. The corresponding PAE is presented in Fig. 3. A similar set of results have been obtained at the band edge frequencies of 76 GHz and 81 GHz.

2) Saturated output power (P_{sat}) and compressed gain as a function of the frequency: The measured saturated output power and compressed gain as a function of the frequency range of interest (76 to 81 GHz) are presented in Fig. 4. The corresponding PAE is presented in Fig. 5.

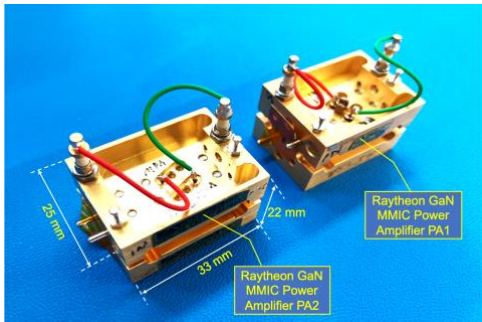


Fig. 1. The modules housing the power amplifier MMICs have WR-10 waveguide as input/output ports.

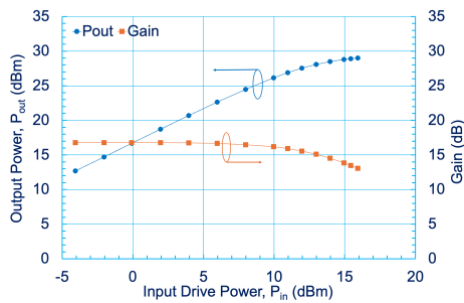


Fig. 2. Measured P_{out} & Gain vs. P_{in} of power amplifier module at 79 GHz. $V_d = 12.5$ V and $V_g = -2.65$ V.

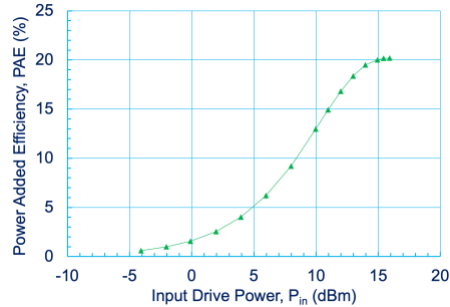


Fig. 3. Measured PAE vs. P_{in} of power amplifier module at 79 GHz. $V_d = 12.5$ V and $V_g = -2.65$ V.

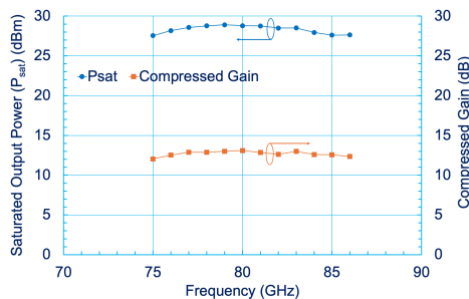


Fig. 4. Measured P_{sat} and compressed Gain vs. frequency. Input drive power (P_{in}) is 15.5 ± 0.45 dBm, $V_d = 12.5$ V, and $V_g = -2.65$ V.

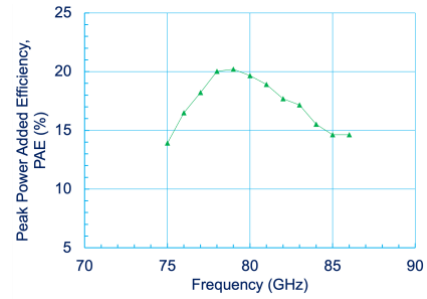


Fig. 5. Measured PAE vs. frequency. Input drive power (P_{in}) is 15.5 ± 0.45 dBm, $V_d = 12.5$ V, and $V_g = -2.65$ V.

III. CONCLUSIONS AND DISCUSSIONS

The advantages of GaN for space applications, GaN semiconductor process, device structure, and MMIC design methodology are highlighted. The measured P_{out} , Gain, and PAE as a function of the input drive power and frequency are presented. The E-band GaN MMIC amplifier has high output RF power, good linearity, and PAE and can serve as a power amplifier for a compact obstacle detection FMCW radar on an LTV.

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