

K-Band Doherty and Class AB Gallium Nitride MMIC Power Amplifiers for Space Applications

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Abstract: This paper compares the performance of Class AB and Doherty Gallium Nitride (GaN) Power Amplifier (PA) MMICs at 19GHz. The MMICs have been designed in the same process and fabricated on the same wafer to enable the ability for direct performance comparison. Measurements of the AM/AM and transfer curves, Linearity, and Power Added Efficiency have been made for each MMIC PA. Finally an assessment of these performance parameters with respect to output power backoff (OBO) will be presented to help normalize the comparison. To the authors knowledge this is the first time these power amplifier architectures have been compared at these frequencies (2). Additionally, to the best of the author's knowledge the performance for these amplifiers show state of the art PAE for GaN PA MMIC amplifiers at these frequencies.

Keywords: Gallium Nitride, Silicon Carbide, K-band

I. INTRODUCTION

The tradeoff between RF power output, Linearity, and Efficiency is well known among RF power amplifier designers (1). A subset of this discussion centers around the power amplifier circuit architecture. The Class AB architecture has been a prevalent design choice due to its ability to maximize this 3 parameter trade. Recently the Doherty Amplifier architecture has been preferred due to its ability to maintain efficiency in the backoff region of the transfer curve. The essential question when deciding which architecture to use is the performance of these 3 main parameters for a particular application. Other parameters that also enter the trade are MMIC size, bandwidth, gain, and cost.

For applications related to communications the need to optimize RF output power, linearity, and efficiency is key to the system's performance. This trade is based on the response of these 3 parameters with respect to the system's operating point. That is, RF power and efficiency will increase with increasing RF input power, but linearity will decrease. A related consideration with respect to efficiency is the behavior of the DC power (Pdc) with Pin. For power amplifiers biased in Class AB or any other heavily down-biased architecture, due to the self-biasing when driven into compression, the DC power will increase with Pin.

Thus PAE needs to be optimized to minimize Pdc, but the increase when driven into compression could be a factor depending on the PA's operating point. Since linearity may decide where the PA needs to be operated with respect to its

Pin, which is typically backed off from its max efficiency point, the PAE in backoff becomes a major concern. The trade becomes what are the Pdc and Pout levels at the required linearity. For this paper Noise Power Ratio (NPR) (3,4) is used to assess linearity. Although the Doherty shows better Pdc when backed off, you may lose more Pout to reach the same linearity point as the Class AB.

This paper will compare the performance of a GaN Class AB PA MMIC with a Doherty PA MMIC at 19GHz with respect to these key parameters.

II MMIC DESIGN

The designs use a NGAS 0.2 μ m AlGaN/GaN HEMT process. Details of this process have been described previously in the literature (4). Some key points to note are:

Substrate: 100-mm diameter 4H-SiC
Epitaxy: AlGaN/GaN HEMT epitaxial layers grown with 2DEG Densities: 1.0x10¹³ cm⁻²
Room Temp Mobility: 1400 cm²/V-s
Gate structure: 0.2 μ m T-gate, 2 μ m source to Drain spacing, 85nm SiN passivation
Peak transconductance from DC transfer curves: 300mS/mm
ft from S-parameters: 65GHz
Max drain current and 3-term breakdown: 1mA/mm, 90V
Wafer thickness: 100 μ m

Additional NGAS flight process rules are added for this work including 150 pF/mm MIM capacitors (rather than 300pF/mm) and limiting the maximum operating voltage to 24V. Also, all metal traces and TFR are closely monitored for current and power handling rules.

The 2 amplifiers are designed with the same criteria. An operating point was defined by a linearity of NPR = 15dB. The goal was to maximize PAE and Pout for this linearity.

The basic architecture chosen for the amplifiers was a 2-stage design. The Doherty amplifier utilized a class AB design for the Main Arm while utilizing a class B for the Auxiliary Arm. The class AB architecture was designed for deep class AB. Device peripheries and MMIC sizes are listed in Table1.

Table 1 Device Peripheries. The Class AB utilized a 3:1 1st to second stage ratio while the Doherty utilized about a 2:1 ratio.

	O/P Periphery	I/P Periphery	MMIC Size
Class AB	5.76mm	1.8mm	5X4.5mm
Doherty	1.8mm	0.8mm	4.4X2.7mm

Figures 1 and 2 show the chip block diagrams and layouts for the MMICs.

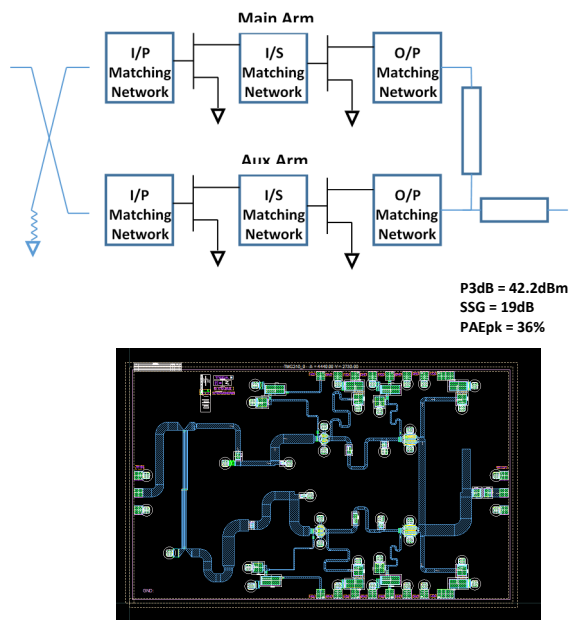


Figure 1 Doherty PA MMIC Chip Block Diagram and Layout. Basic architecture for Doherty PA MMIC is 2-stage Main and 2-stage Auxiliary arms.

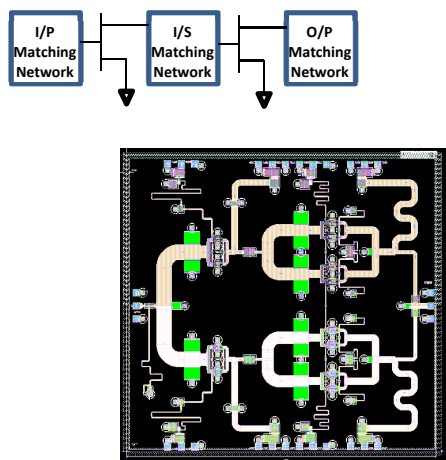


Figure 2 Class AB PA MMIC Block Diagram and Chip Layout. Basic architecture for Class AB PA MMIC is 2-stage.

III MEASUREMENTS/RESULTS

Pout, PAE, Pdc, and NPR were measured for both MMIC types utilizing the same RF set-up to minimize variables in

the comparison. Transfer curves for each MMIC are shown in Figure 4.

For reference the P3dB point is used for comparing parameters in back-off. Thus, a parameter measured at 2dB Output Backoff (OBO) is 2dB lower in output power than the P3dB point. Figure 3 shows the measured results. For the class AB device the PAE decreases by >9% at the 3dB OBO point while the Doherty only decreases <6% for the same 3dB OBO reduction in output power. More specifically for this Doherty design the PAE remains above 25% PAE up to 9dB Input Back-Off (IBO) or 6dB OBO. Additionally, to the best of the authors knowledge, Class AB peak PAE of 36% and Doherty peak PAE of 51% are among the best reported results at K-Band ([4], [5], [7]).

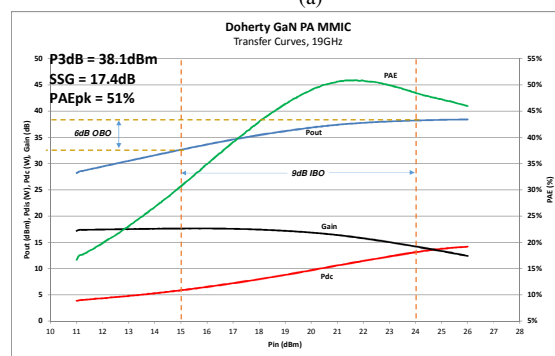
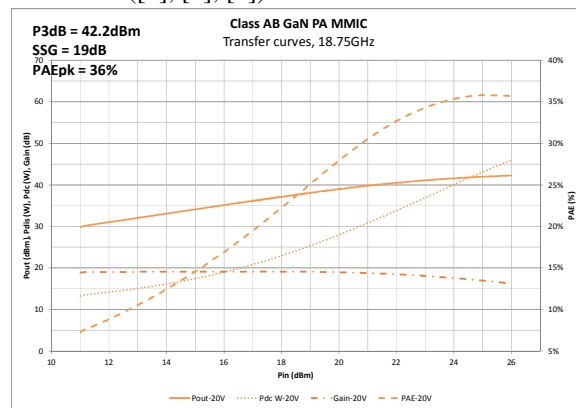


Figure 3 Transfer curves. (a) Class AB (b) Doherty

As shown, the Class AB MMIC PA was designed for higher power than the Doherty. Thus to facilitate the comparison we present the parameter assessment normalized. In Figure 4 we have normalized the PAE to its max value and plotted against OBO. Subsequently for NPR, in Figure 5 we have plotted the value vs. OBO to help normalize the comparison.

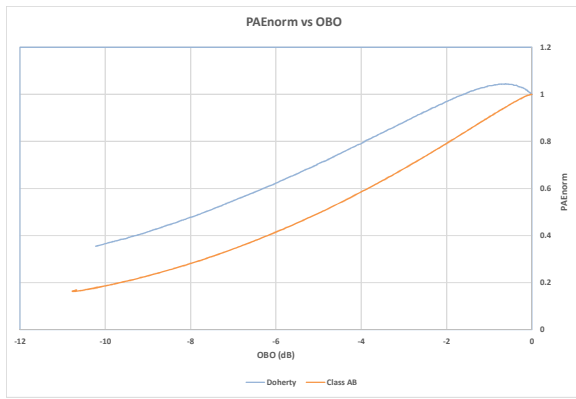


Figure 4 PAE Comparison. As shown the Doherty holds its PAE as the PA output power is backed off.

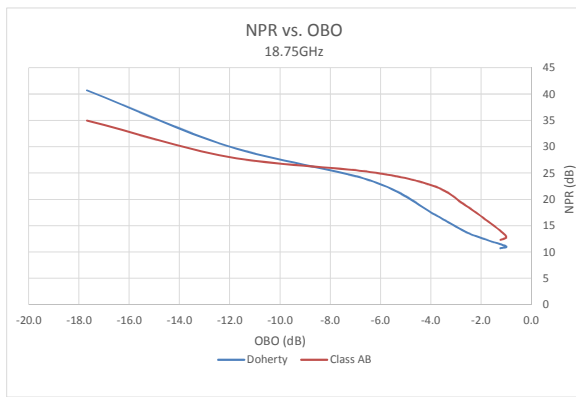


Figure 5 NPR Comparison. As shown the Class AB amplifier gives better linearity close in to saturation than the Doherty.

IV Result Analysis

A comparison of PA performance was chosen by fixing the NPR requirement at 15dB and comparing the PAE's for each architecture. Table 2 below lists the OBO and PAE ratio for each approach.

Table 2. Comparison of Class AB and Doherty PA architectures. The Doherty PA shows slightly better PAE for a given NPR.

Architecture	OBO	PAE Ratio
Class AB	-1.5	0.84
Doherty	-3.0	0.88

Assuming a peak PAE of 40% for each PA, the Doherty would have a PAE of 35.2% while the Class AB would operate at 33.6%. This would give the Doherty the upper hand in applications where PAE in back off is critical to system performance.

To complete this comparison the authors need to mention that factors like bandwidth and gain favor the class AB architecture for performance while chip size and complexity also favor the class AB architecture for chip cost.

The typical Doherty PA requires a quarter wave transformer (6) which limits its BW and increases its size when compared to a Class AB PA. Additionally the need to bias the Main Arm and Auxiliary Arm differently (6) adds to its complexity. This complexity and its larger size typically translate to higher cost.

Table 3 below shows a comparison of this work to recently published GaN PA MMIC results at K-Band.

Table 3 Performance Comparison. This work compares favorably with performance of recently published results for GaN PA MMICs in K-Band

Reference/ Yr/Type	Gate Length	Freq. (GHz)	Pout (dBm)	PAE	Gain (@Pout)	NPR dB
(4) 2017 AB	0.2um	18.75	41	38%		15
(5) 2016 AB	0.25um	18.0	40	32%	13.5dB	Not Reprtd
(7) 2012 Doherty	0.15um	23	37	48%	16.0dB	Not Reprtd
This work AB	0.2um	18.75	42	36%	17.5dB	15
Doherty		19	38.1	51%	17.4dB	15

V SUMMARY

This paper has compared the performance of GaN MMIC power amplifiers in the K-Band frequency range (19GHz). The MMICs were fabricated using a 0.2um GaN HEMT process on the same wafer. Key parameters were normalized to peak performance and/or OBO to facilitate the comparison. The analysis showed that for PAE (Pdc) in backoff the Doherty would be preferred. Additionally, it is pointed out the other factors may favor the class AB approach. Finally, the PAE in K-Band shows state-of-the-art performance when compared to recently published results at K-Band.

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