# Ultra Wide-Band, High-Power, High-Efficiency GaN Amplifier[1]

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***ABSTRACT* - We report a high-performance GaN amplifier operating from 100MHz to 3,000MHz. The best results included 100W output power, 22dB gain with 40% power-added-efficiency from 100MHz to 3,000MHz. This performance is achieved by tailoring both the device impedance and by using unique wide-band circuit matching topology. Detailed design technique of both device and matching circuit will be presented.**

***Index Terms* — Broadband amplifiers, high-voltage techniques, microwave devices, power combiners, MMICs.**

## I. INTRODUCTION

Wide-Band, High-Power, High-Efficiency Amplifier is a key element in advanced communication systems such as Search-and-Rescue Software Radio for fireman, police, and marine. The traditional technique to achieving wide-band amplification is either using travelling wave approach [1, 2] or designing wide-band matching circuits to transform the device input and output impedances to 50 ohms [3]. If the high-power device output impedance is much different from 50 ohms, the latter approach's output matching circuit suffers from having large dimension, as well as high RF loss. This high RF loss severely degrades the amplifier output power and efficiency.

This paper reports a new approach that adds a new dimension to the wide-band amplifier design. In addition to just using the circuit matching technique, we also tailor the device output impedance to be close to 50 ohms. This way makes the output impedance matching circuit relatively simple and low loss, leading to wide-band performance with high output power and high power added efficiency.

Section 2 outlines the design of the GaN HEMT 30W MMIC PA which serves as a building block for the 100W amplifier. Section 3 describes the topology of the 100W amplifier. Section 4 is the conclusion.

## II. 30W GAN MMIC AMPLIFIER

To achieve more than 100W output power over 100-3000MHz, we power combine four, 2-stage GaN MMIC PA's. Each MMIC has 30W output power with 23dB gain over the desired band. Figure 1 shows the layout of this 30W MMIC PA. The first-stage device size is 2mm, split into two 1mm paths. The second-stage device consists of four, 2x1.12mm HEMT. This 2x1.12mm device is connecting two of 1.12mm unit cell devices both DC and RF in series. We call this configuration HIFET [4, 5, 6, 7]. The DC bias voltage and RF output impedance of this HIFET are both twice that of the 1.12mm unit cell device. By proper choice of the unit cell device size and the number of unit cell devices in series, we can optimize the HIFET optimal output impedance to be close to 50 ohms to achieve wide-band performance. Figures 2a and 2b show the first-stage and the second-stage input and output impedances, respectively. Notice that the second-stage optimal output load impedance at 0.5GHz is fairly close to 50 ohms. This result enables low RF loss wide-band matching, which is important to achieving wide bandwidth with high output power and efficiency. This 50-ohm optimal output impedance is achieved by the proper choice of the unit cell device size and number of devices in series. Because the second-stage has 2 unit cells in series, the DC bias voltage is 60V for the second-stage.

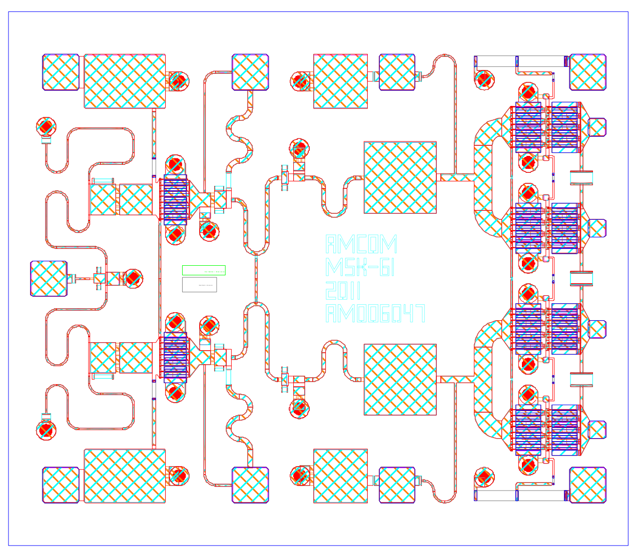

Fig. 1. Layout of 30W GaN HEMT MMIC PA

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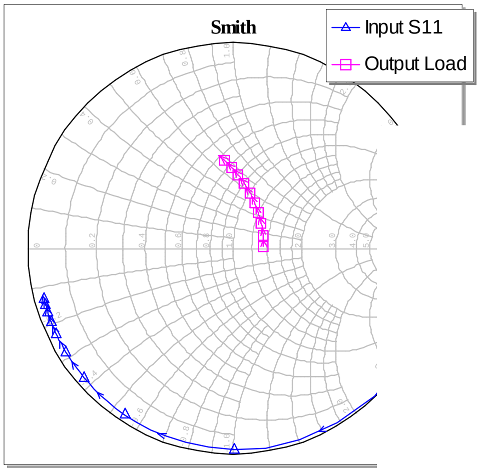


Fig. 2a. . First-stage input impedance and optim
from 0.1-6GHz.

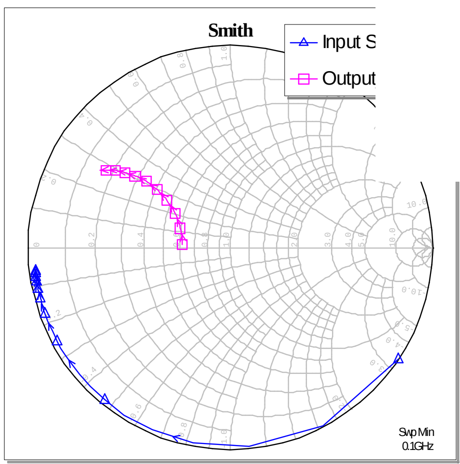


Fig. 2b. Second-stage input impedance and optimal output load from 0.1-6GHz

The input impedance of both stages is capacitive and varies from open circuit at low frequencies (i.e. < 0.5GHz) to almost short circuit at 6GHz. To obtain a good broadband match and flat gain over wide bandwidth, a shunt resistor to ground is used at each gate input to bring the impedance closer to the center of the Smith chart at low frequencies. A small series resistor is also used to bring the impedance close to the center of the Smith chart at the high frequency end of the band. At low frequencies the input device is matched close to 50 Ohms and does not need any further matching. The second stage input is also matched as close as possible to the optimum resistive load of the first stage using the shunt gate resistor. For high frequency, the inter-stage matching uses a series inductor and shunt capacitor to match the output impedance of the first-stage device to the input impedance of the second stage to achieve the optimum power load of the first stage device. The combination of shunt series resistors makes the matching feasible over the entire frequency band, moreover, the gain of each individual stage is lowered at low frequencies using the shunt resistors thus contributing to a flat gain for both stages. Figure 3 shows the circuit schematic of this MMIC PA.

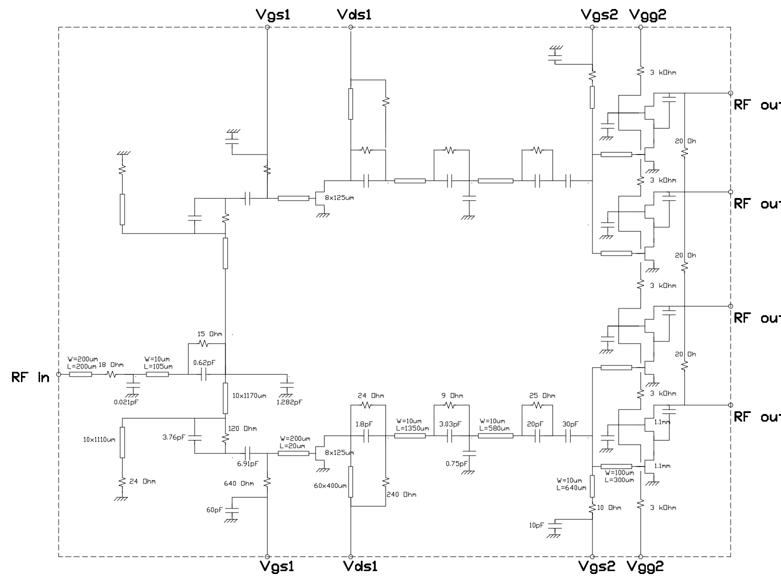


Fig. 3. Circuit Schematic of MMIC PA

Figure 4 shows the performance of this MMIC. It achieves 45dBm (32W) saturated pulsed output power (1mS pulse width with 10% duty cycle) with an average of 45% power added efficiency and 23dB gain over 100MHz-3000MHz.

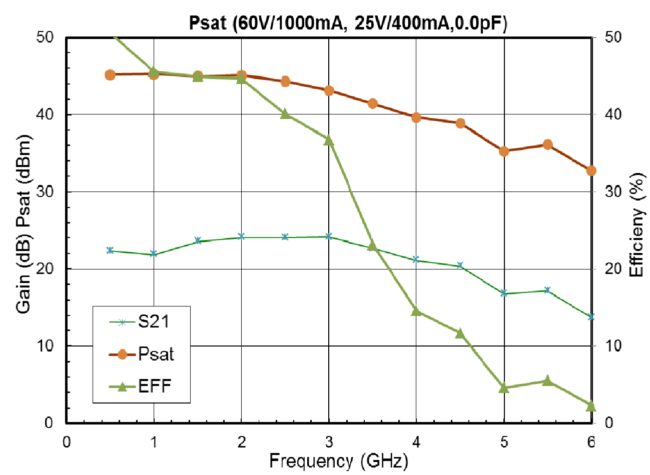


Fig. 4. 30W MMIC performance.

## III. 100W AMPLIFIER

We power combine four 30W MMIC PA to achieve 100W output power from 0.1-3.0GHz by using a low loss push-pull power combiner as shown in Figure 5a. We first direct combine two 50-onm MMICs to achieve 25-ohm output impedance. Than we use a push-pull combiner, which also serves as an impedance doubler, to combine the two 25-ohm amplifiers to achieve the overall 50-ohm output impedance. Figure 5b is the implementation of the 4-way push-pull power combiner.

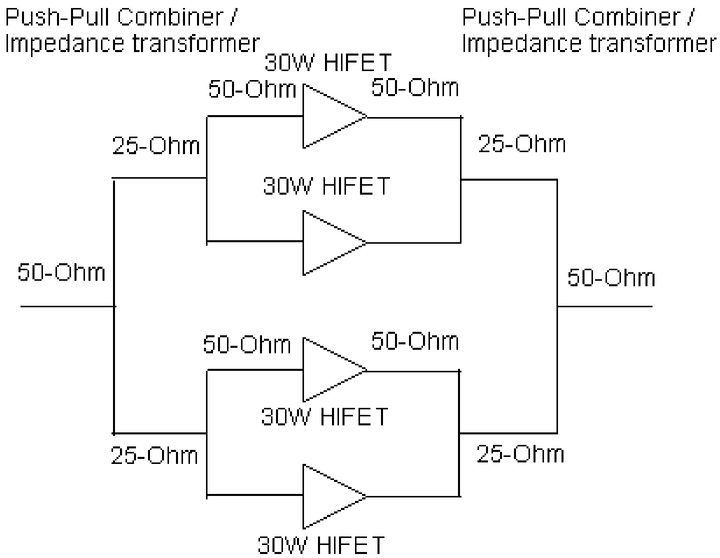


Fig. 5a. Push-pull 4-way combiner.

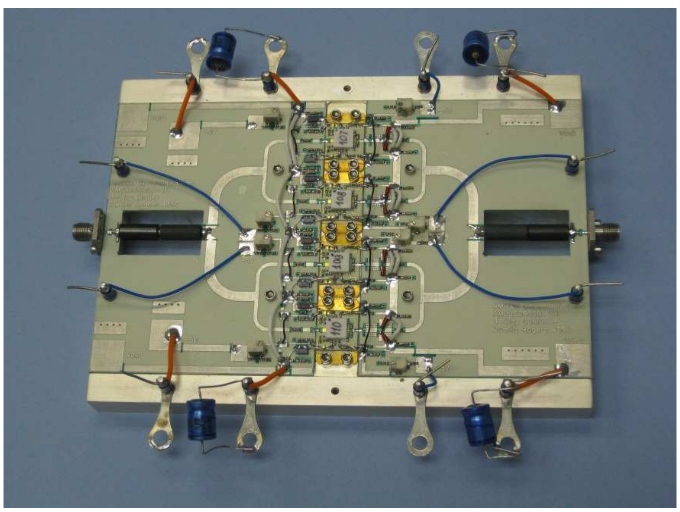

Fig. 5b. Implementation of 4-way push-pull power combiner (Size: 4" x 6")..

Figures 6a,b,c show the performance of this 100W GaN Amplifier. It achieves 51dBm (125W) +/- 0.7dB pulsed output power, with 48% to 25% power added efficiency and 22dB gain from 0.1GHz to 3GHz. The output return loss is -5 to -8dB. The input loss is better than -18dB.

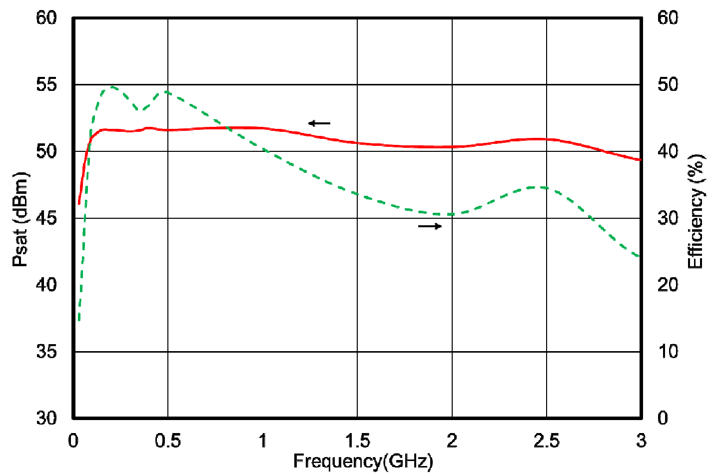


Fig. 6a. Power & Efficiency of 100W PA

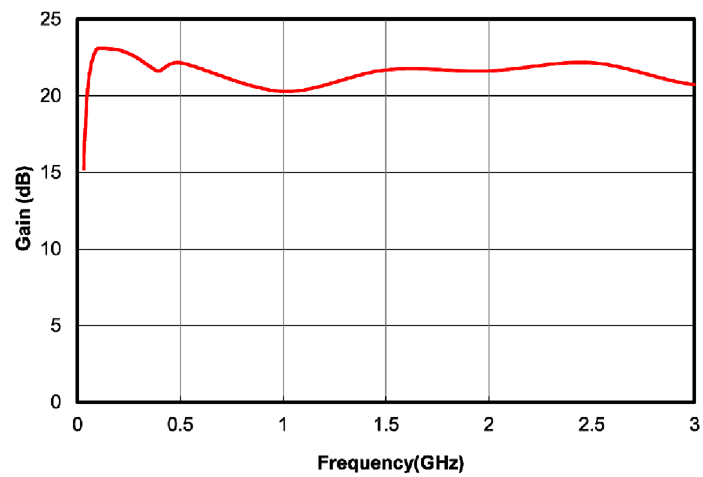


Fig. 6b. Gain of 100W PA

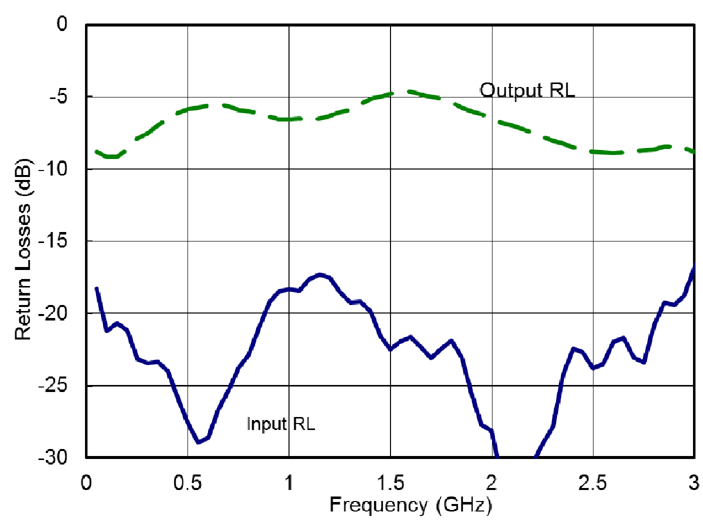


Fig. 6c. Output & Input Return Losses 100W PA

## IV. Conclusion

We report a wide-band, high-power, high-efficiency amplifier using GaN HEMT MMIC. It achieves 50dBm (100W) pulsed output power, 40% efficiency with 22dB gain from 0.1-3.0GHz. We believe that this result is state-of-the-art performance considering achieving the combination of wide bandwidth, high output power, high efficiency, and small size of the amplifier. This performance is achieved by both using a design technique of tailoring the device output impedance to be close to 50 ohms and by applying a unique wide-band impedance matching technique.

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