High-Power GaN MMIC PA Over 40-4000MHz[1]

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Abstract — We report a high-performance GaN MMIC power amplifier operating from 40MHz to 4,000MHz. The MMIC achieved 80W pulsed (100us pulse width and 10% duty cycle) output power (P5dB) with 54% efficiency at 40MHz, 50W with about 30% efficiency across most of the mid band, and gradually decreases to 30W with 22% efficiency at 4000MHz. Power gain is 25dB across the 40-4000MHz band. This ultra wideband performance is achieved by both tailoring the device output impedance, and using a unique wide-band, circuit-matching topology. Detailed design techniques of both the device and the matching circuit will be presented.

Index Terms — Broadband amplifiers, high-voltage techniques, microwave devices, GaN MMIC PA.

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 coast guard. The traditional technique to achieving wide-band amplification is either using travelling wave (TW) approach [1, 2], or designing wide-band matching circuits to transform the device input and output impedances to 50 ohms [3]. The TW technique uses multiple devices to simulate a 50-ohm transmission line to achieve wide bandwidth. The wide band matching approach has the advantage of small size. However, if the high-power device output impedance is much different from 50 ohms, the output matching circuit of this approach 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 applies the technique of stacking FET in series to maximize the power from the PA [4-9]. Also the size of the power stage device is optimized to synthesize an optimum output impedance close to 50 ohms. This approach makes the design of the output impedance matching circuit relatively simple, and results in low RF loss in matching circuit, leading to wide-band performance with high output power and high power-added-efficiency.

II. GaN MMIC PA Design

To achieve more than 20dB power gain which is a nominal spec in many applications, a two-stage configuration with inter-stage matching was selected, based on Triquint's 0.25um GaN HEMT process. Fig. 1 shows a photo of the 50W MMIC PA. The first-stage device size is 2.4mm, splitting into two 1.2mm paths. The second-stage device size is 16.8mm which consists of four, 3 in-series 1.4mm HEMT. The 3x1.4mm HiFET device is three 1.4mm unit cells both DC and RF in series (Fig. 2). The DC bias voltage and RF output impedance of this HiFET are both three times that of the 1.4mm unit cell device, particularly at low frequencies. By proper selection of the unit cell device size, and the number of unit cell devices in series, we can optimize the HIFET output impedance to be close to 50 ohms to achieve wide-band performance.

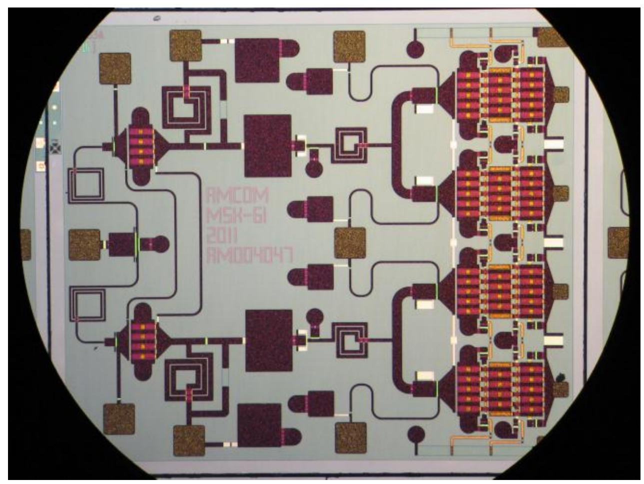

Fig. 1. Photo of 50W GaN HEMT MMIC PA (3.45x3.00mm)

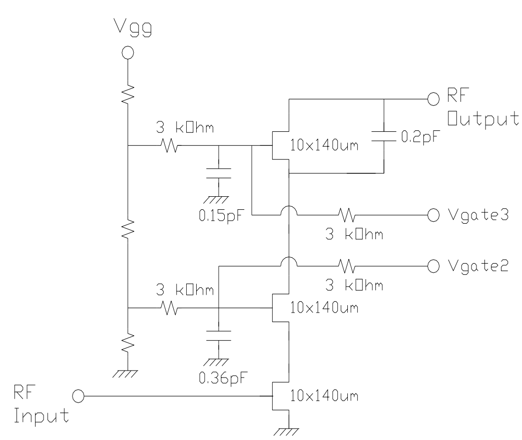

Fig. 2. Schematic of 3 x 1.4mm in-series HiFET Cell

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Figures 3a and 3b show the device input impedance and optimum output load for the second-stage and the first-stage devices, respectively. Notice that the second-stage optimal output load impedance at low frequency 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. The 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 3 unit cells in series, the DC bias voltage is 90V. In order to conserve the GaN real estate, which currently is still expensive, the output matching circuit was implemented off chip (see Fig.4a).

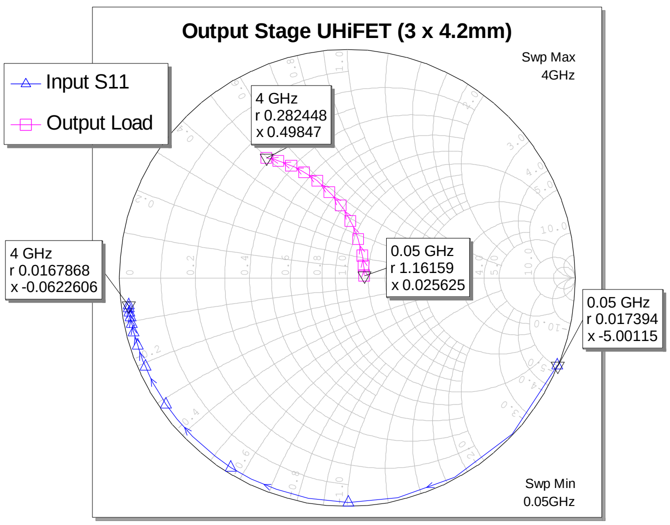

Fig. 3a. . Second-stage input impedance and optimal output load from 0.05-4GHz.

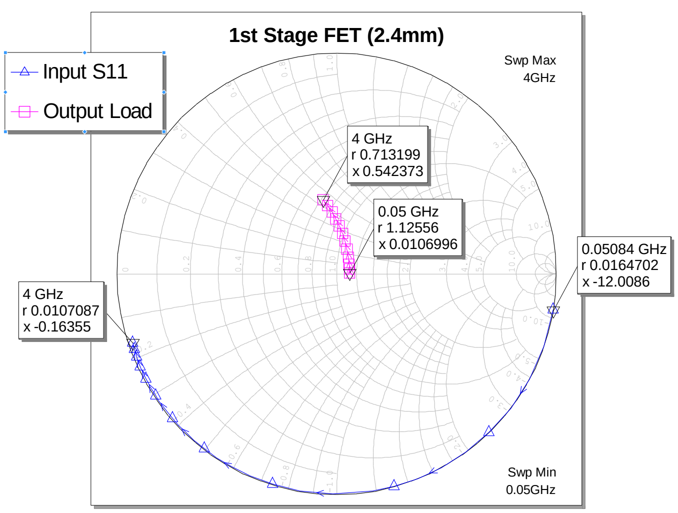

Fig. 3b. First-stage input impedance and optimal output load from 0.05-4GHz

Figs. 4a, b, c, d show the circuit schematic details of the MMIC PA. The input impedance of both stages is capacitive (see Figs. 3a & b) and varies from open circuit at low frequencies (i.e. < 0.5GHz) to almost short circuit at 4GHz. 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. To achieve a good impedance match at the high frequency, several small series resistors are also used. At low frequencies, the device is matched close to 50 ohms, and thus, no further matching is needed. In the inter-stage matching, the input to the second stage is matched as close as possible to the optimum resistive load of the first stage using the shunt gate resistor. For high frequencies, 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 and 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 resulting in a flat gain response for both stages.

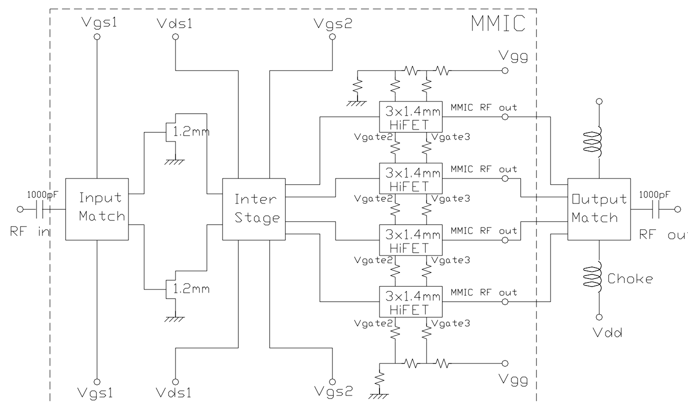

Fig. 4a. Circuit Schematic of MMIC PA

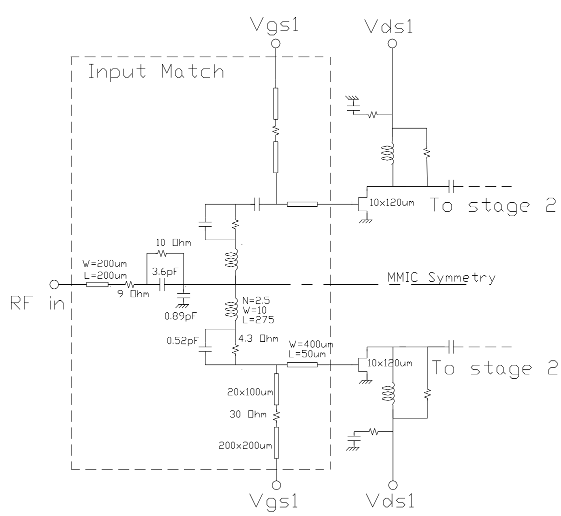

Fig. 4b. Input Matching Circuit

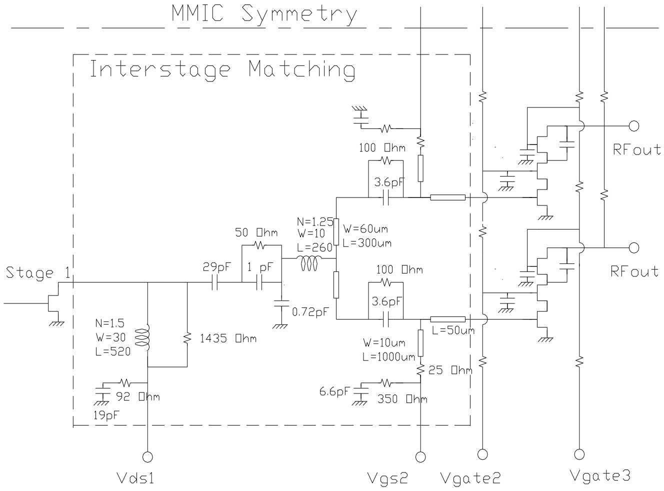

Fig. 4c. Inter-stage Matching Circuit

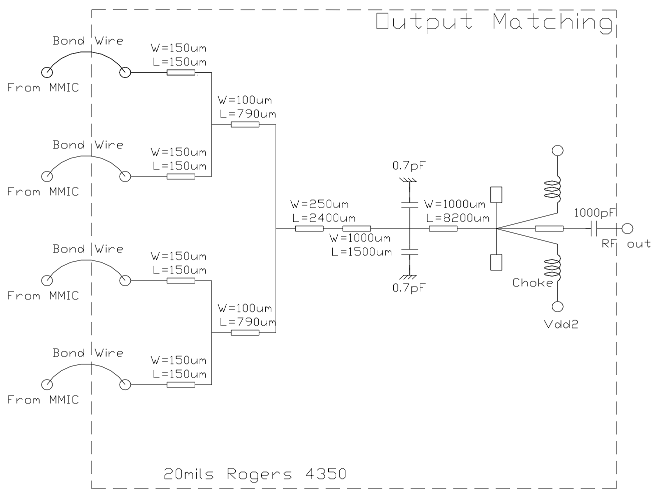

Fig. 4d. Hybrid Output Matching Circuit

The off-chip output matching circuit is implemented on the PCB. At low frequencies (i.e. < 1.5GHz as shown in Fig. 3a) the optimum impedance is close to 50Ohms. The circuit shown in Fig. 4d is used as a 4-way combiner and as a matching circuit to transform the optimum load of the MMIC second stage at high frequencies to 50 ohms. The 4-way combiner acts as a series inductor followed by 2 low-pass sections of transmission lines with shunt capacitors. The inductive portion of the transmission lines had to be as narrow as possible to act as pure inductors without affecting the loss of the matching circuit. Fig. 5a and 5b show the simulated small-signal gain, and output power as a function of frequency. The predicted small signal gain is 26dB from 40-4000MHz with an output return loss of -5dB. The input return loss is better than -20dB from 40-4000MHz. The predicted output power is 48dBm ±1dB. The predicted power-added-efficiency is 62% at 40MHz, and it drops to 28% at 4000MHz.

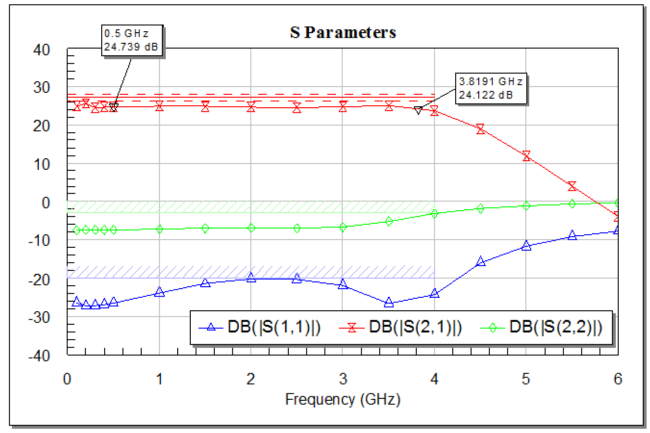

Fig. 5a. Predicted Linear Gain & Return Losses of Externally-matched MMIC (0.04-4.0GHz)

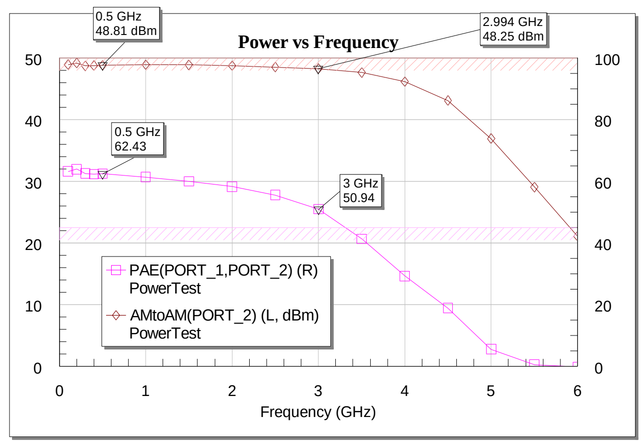

Fig. 5b. Predicted saturated output power and efficiency of externally-matched MMIC (0.04-4.0GHz)

Fig. 6 shows the implementation of the output matching circuit on 20mils Rogers 4350 material, which is mounted on a copper carrier (pallet). A second portion of the matching circuit is implemented on the test fixture in Fig. 7.

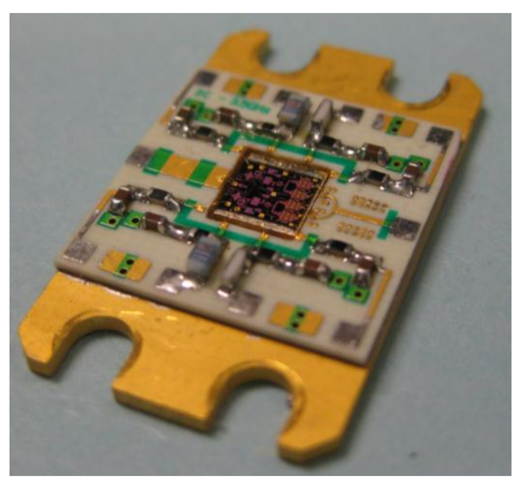

Fig. 6. Photograph of 50W GaN MMIC assembled on a copper carrier for testing. (Size: 12.7mm x 21mm)

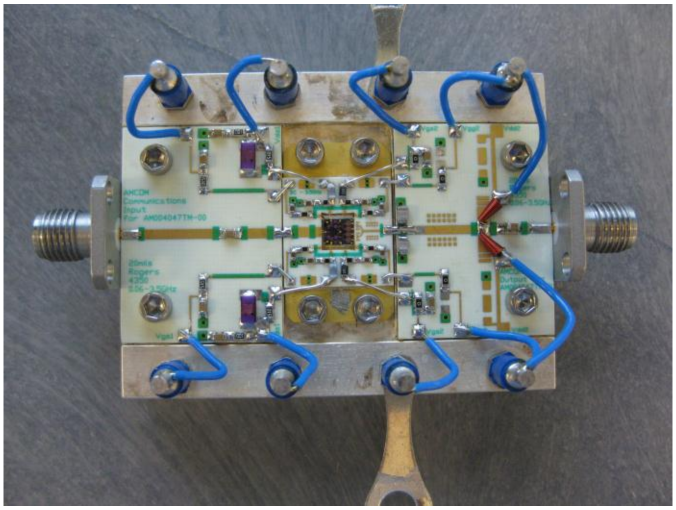

Fig. 7. MMIC pallet assembled on a test fixture

III. Measured Results

The MMIC copper carrier (Pallet) is assembled on a test fixture for testing as shown in Figure 7. The test fixture has a large DC blocking capacitor and a large conical inductor to provide bias to the output stage. Broadband biasing to the input stage is also implemented on the MMIC test fixture. The output matching and biasing circuits PCB are implemented using 20mils 4350 Rogers material.

Figure 8 shows the measured results (100µs pulse width and 10% duty cycle). The saturated (P5dB) output power is 49dBm (80W) with 54% efficiency at 40MHz, 47dBm (50W) ±1dB with about 30% efficiency across most of the mid band, decreases to 45dBm (30W) with 22% efficiency at 4GHz. The small signal gain is 30dB with a power gain of 25dB across the 40-4000MHz band. This measured result is fairly close to the predicted performance.

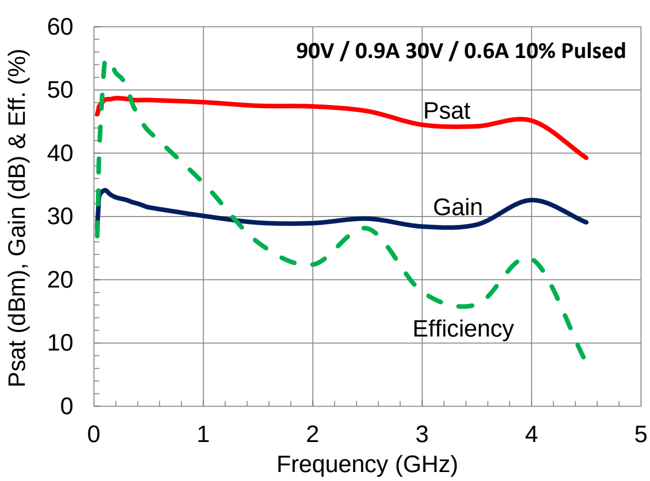

Fig. 8. Measured output Power (Psat), Small signal Gain, and Efficiency of 50W GaN MMIC.

IV. Conclusion

We report a wide-band, high-power, high-efficiency MMIC PA using 0.25µm-gate GaN HEMT. It achieves saturated (P5dB) output power of 49dBm (80W) with 54% efficiency at 40MHz, 47dBm (50W) ±1dB with about 30% efficiency across most of mid band, and 45dBm (30W) with 22% efficiency at 4GHz. The small signal gain is 30dB with a power gain of 25dB across the 40-4000MHz band. We believe that this result represents one of the best reported MMIC performances, considering the combination of wide bandwidth, high output power, high efficiency, and small size of the amplifier. This performance is achieved by applying a unique wide-band impedance matching, and by using design techniques of selecting the size of the GaN device unit cells operating with DC and RF in series, for optimal output impedance close to 50 ohms. Besides broadband applications, the small size, generic GaN PA MMIC also offers selected frequency usage for a wide range of general applications.

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