ECE 6361 Project 2: 5.8 GHz Power Amplifier

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***Abstract*—This paper describes the design of a GaN HEMT power amplifier originally intended for 5.8 GHz. This frequency was recognized as unfeasible, so wide band performance was chosen as the priority. The amplifier achieved a maximum operating frequency only 1 GHz below the original goal.**

I. Introduction

POWER harvesting through RF transmission is gaining more attention these days. The increasing demand of ubiquitous sensor networks accelerates this in an attempt to get rid of the bulky batteries and the problem of charging. To achieve this goal, improvement on both transmitter and receiver systems are essential. For the transmitter, the most critical component is the power amplifier. The aim of this project is to design a power amplifier. In order to increase both maximum output power and power added efficiency, we chose a Gallium Nitride High Electron Mobility Transistor (GaN HEMT). This process features high breakdown voltage, thus it is an optimum choice for high power amplifiers. Our design targets the 5.725 to 5.85 GHz frequency range, which is an unlicensed band under FCC regulation. The paper is organized as follows: Section II introduces the design overview and methodology of the GaN high power amplifier. In Section III measurement results are illustrated, and a comparison of simulation and measurement results is given. A conclusion will be given in the last paragraph.

II. Design Overview

GaN HEMTs are an optimum candidate for high power amplifiers due to their ultra high breakdown voltage. In this experiment, we chose the NPTB0004, provided by Nitronexm, as our power transistor [1]. This transistor features 5 Watt power capability and a 28 V breakdown voltage. However, in the data sheet, it only provides optimum matching impedance up to 3.5 GHz. In order to get an estimation of transistor performance at 5.8 GHz, we used HP ADS circuit simulator along with the foundry provided model to perform circuit simulation before real implementation.

The first step of designing an amplifier is estimating its maximum gain (G_{max}) and maximum oscillation frequency (f_{max}) [2]. The terminology of maximum oscillation frequency for amplifier design is somewhat awkward. However, if we realize that in order to make it oscillate, a feedback loop with correct phase and enough gain is required, the terminology seems reasonable. If it is possible to make an oscillator at such a frequency, then it is possible to make an amplifier for its gain requirement.

The simulation of G_{max} and f_{max} is shown in Fig. 1. Bias conditions were Vg=-1.38 V, Vd=24 V, and drain current was 50 mA. The part functioned well at 5.8 GHz, providing around 13 dB G_{max}, with f_{max} is beyond 10 GHz. However, this estimation did not take into consideration several important issues. First, because we are using a fixed PCB shown in Fig. 2, we need to take all the traces on the PCB into account. The estimated G_{max} and f_{max} after considering the long trace at both input and output ports are shown in Fig. 3.

As we can see, due to the high dielectric loss (tanδ = 0.02) of the FR-4 substrate, the G_{max} degrades to 4.5 dB and f_{max} reduces to 7 GHz. Furthermore, a load pull analysis was performed at 3.5 GHz, the highest frequency with data given in the datasheet. The simulation results are shown in Fig. 4. As shown in Fig. 4, the optimum load impedance is on the real axis. The measurement data given by the datasheet, as plotted in Fig. 5, implies that at 3.5 GHz the drain termination of the HEMT is capacitive, so suitable inductance is needed to resonate out the parasitic capacitance. This is the reason why the optimum load impedance of 3.5 GHz lies in the upper plane of the Smith chart.

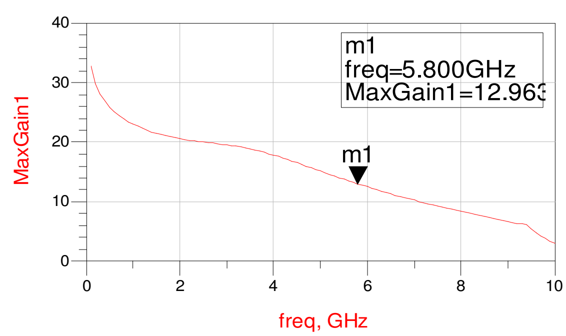

Fig. 1. Simulated Gmax over frequency for NBT0004

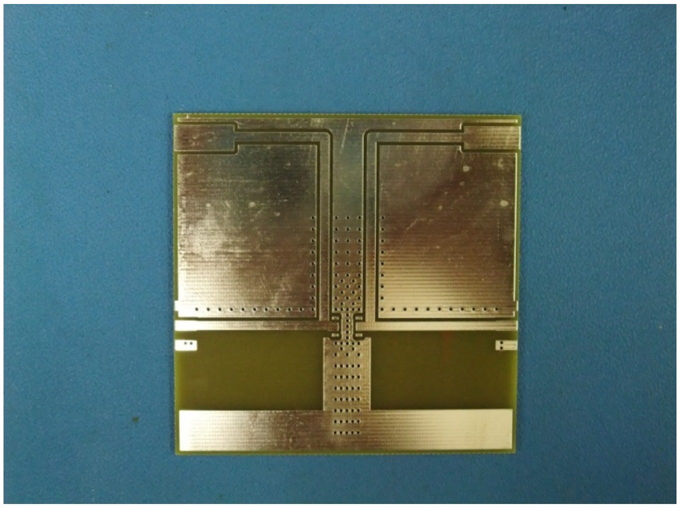

Fig. 2. Board Layout

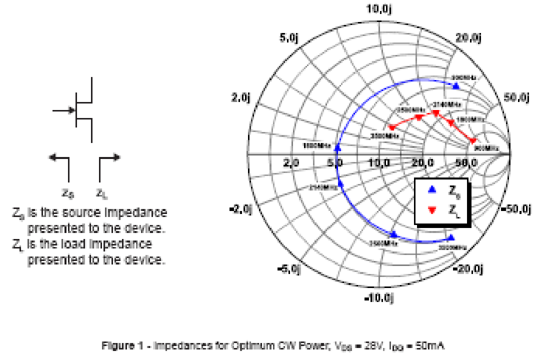

Fig. 5. Optimum load impedance data given in datasheet.

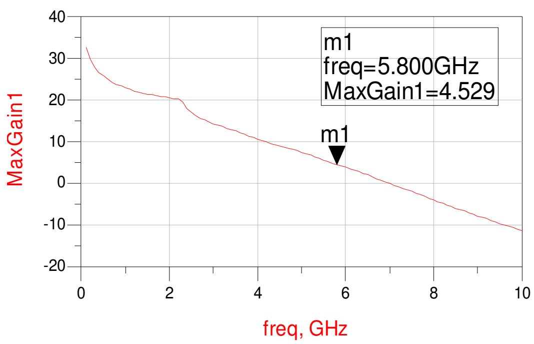

Fig. 3. Simulated G_{max} over frequency for NBT0004 after adding transmission lines on PCB board into consideration.

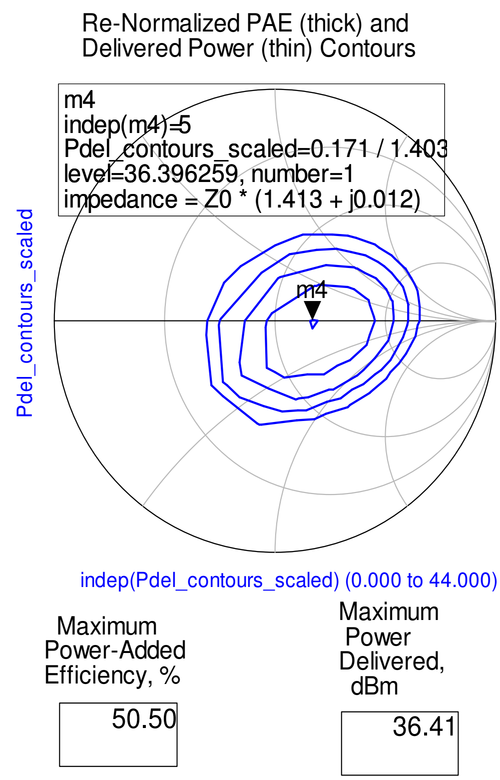

Fig. 4. Load pull simulation result at 3500 MHz plots on normalized Smith chart ($Z_{normalization}$= 10 ohm).

In order to improve the model accuracy, a shunt capacitor of 3 pF was added to model the parasitic capacitance. The new load pull simulation result is shown in Fig. 6, which is in closer agreement with the real measurement data given in the datasheet.

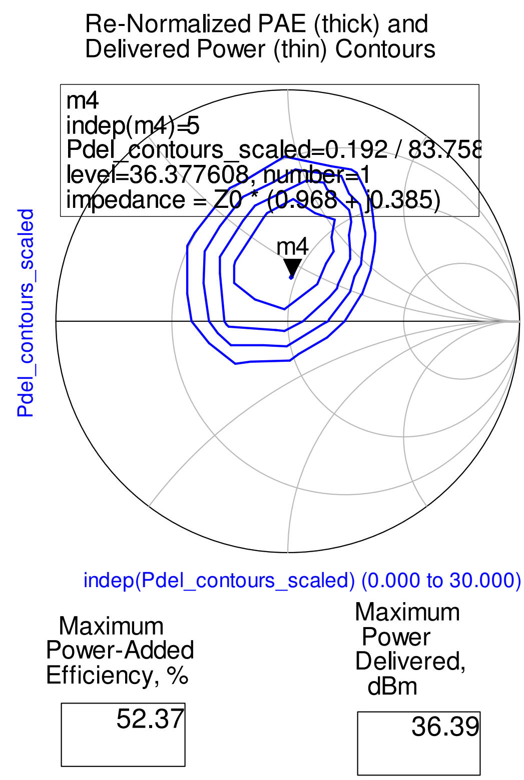

Fig. 6. Load pull simulation result at 3500 MHz plots on normalized Smith chart ($Z_{normalization}$= 10 ohm) after adding a 3 pF parasitic capacitor.

Taking into account the transmission line and package parasitics, the simulated G_{max} is shown in Fig. 7. Here, the G_{max} is slightly higher than that in Fig. 3. However, a gain of 4.5 dB is still too low for power amplifiers. Figure 8 shows the stability factor for the combined transistor and microstrip transmission lines. Although it is stable at our design frequency, to stabilize the transistor at low frequency generally sacrifices a small amount of high frequency gain. Due to all these factors, it doesn't seem feasible to design an amplifier with this HEMT at 5.8 GHz for the specified design criteria. Thus, we decided to change our design goal. Instead of making a narrow band tuned amplifier, we tried to design a wide band amplifier to test its maximum operation frequency.

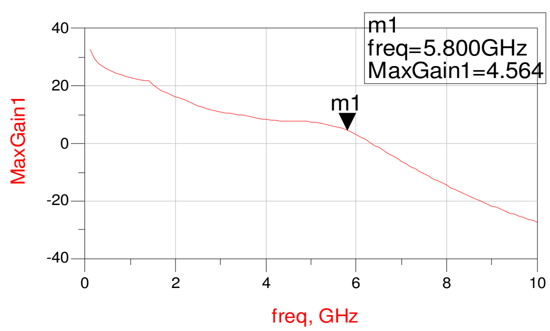

Fig. 7. Simulated Gmax over frequency for NBT0004 after adding transmission lines on PCB board and package parasitics into consideration.

III. Measurement Results

Since the model lacks accuracy, we decided to use the measurement data given in the datasheet [1]. A photo of the completed circuit is given in Fig. 8. We used the same stabilization technique as in the datasheet, a series resistor of 200 ohm at the gate terminal to the biasing. Bypass to ground for biasing nodes were necessary. We put several capacitors with different values to ensure proper grounding for the entire frequency band. For in-band, 12 pF was used. A 100 pF, a 1 nF, and a 1 uF, were put in parallel for bypass grounding at lower frequencies. At the output, a 100 nH inductor was used as an RF choke. DC blocking, or AC coupling capacitors of 12 pF were used at both input and output ports to prevent large current flowing into the measurement instruments, such as the network analyzer, which would be damaged by such a high current levels. In order to make it wide band, no reactive component were used for matching. Such matching techniques can tune out the parasitic at certain frequencies, but they also make the amplifier narrow band.

The most difficult part for designing this wide band amplifier was the stabilization circuit. For example, we started with the gate shunt resistor of 200 ohms, but the circuit was somewhat unstable because the biasing current varied significantly. Also, we saw some return gain for the input port on the network analyzer. We shut off the power immediately, and then replaced the 200 ohm resistor with 100 ohms. We then turned on the power amplifier using the following biasing procedure:

1) Bias the gate to be negative 1.38 V
2) Slightly turn on the drain voltage until it reaches 24 V.

This time the circuit was stable but the gain was low, below 5 dB for the entire band, and the 0 dB bandwidth was also less than 2 GHz. This is because, in this configuration, too much signal current is shunted into the 100 ohm resistor. Thus it was made stable, but the gain was sacrificed to a high degree. To solve this problem, we decided that we could increase the resistor to find the best compromise between 100 and 200 ohm. However, in order to do a shunt resistor to biasing network, the impedance of the power supply and cable must be taken into account, and both are difficult to estimate. Therefore, we put a combination of capacitors to ground after the 200 ohm resistor to ensure proper grounding for the entire frequency band. Several rounds of trial and error were completed. The final measurement results are plotted in figures. 9, 10, and 11. More than 20 dB gain was obtained at low frequency. In addition, the amplifier was able to provide positive gain up to 4.6 GHz.

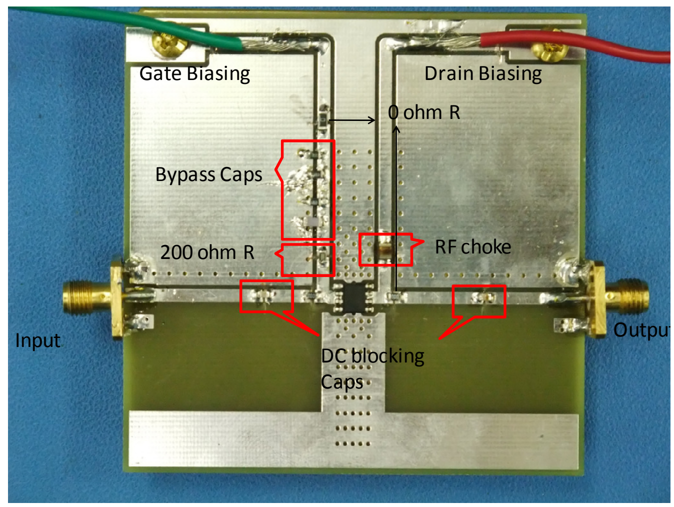

Figure 8. Power Amplifier Photograph

Figure 9. Measured S21 of the power amplifier

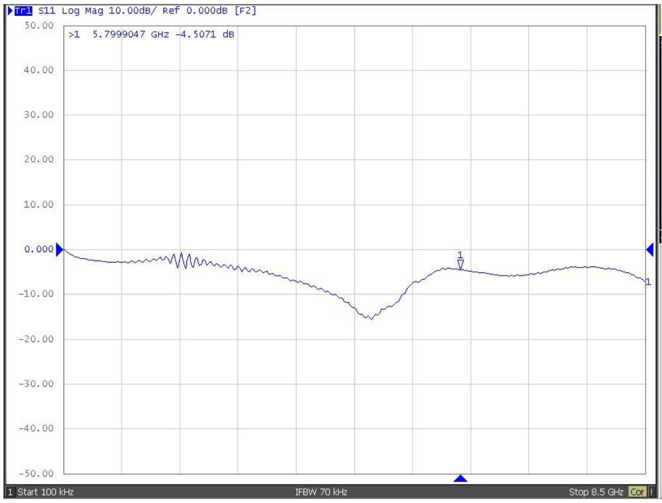

Figure 10. Measured S11 of the power amplifier

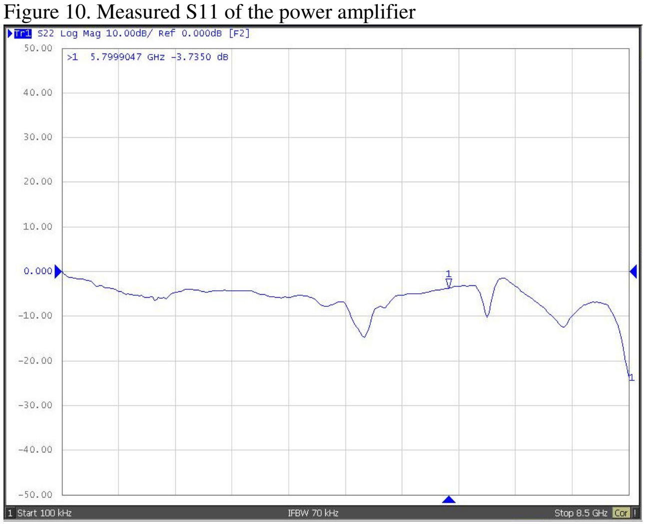

Figure 11. Measured S22 of the power amplifier

IV. Conclusion

A wide band GaN HEMT power amplifier was designed and fabricated. Compared to the original design goal, the amplifiers maximum operation frequency with 0 dB gain is around 4.6 GHz, which is one GHz lower than the design target. Due to parasitics of the package and the long lossy transmission lines on the evaluation board, this amplifier design still needs to be improved to work at 5.8 GHz. The device has the capability to work at 5.8 GHz, but we may need a smaller customized board to reduce the effect of the lossy transmission lines at both input and output.

V. Cost Estimation

We made this work in one time so the total cost is one GaN power transistor. The cost of the device is given in the figure below:

Product Details		Pricing		Order
Part Number:	NPTB0004	1-9	$26.80	Add
Manufacturer:	Nitsuko	10-24	$24.19	No Stock
Category:	Transistor	25-49	$21.89	Est. Delivery: 1 Weeks
Description:	RF Power	50+	$19.94	
Information:	Bipolar NPN	Request A Quote		

Voltage	Current	Type	Case Style
28.0 V		RF Power	

According to this table, our cost for this project is $26.80.

References

[1] Nitronex,“NPTB0004datasheet,”(http://www.propagation.gatech.edu/ECE6361/resources/resources.htm.)

[2] George D. Vendelin and Shih-Chieh Shin, “Applying Fmax, ft, and fmax for microwave transistor designs at microwave and millimeter-wave frequencies,” IEEE Microwave Magazines, vol. 8, pp. 84-87, Jan. 2007.