Design of an X-Band GaN 100W Pulsed Power Amplifier

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Abstract:

This paper describes the RF and DC circuit design of a Gallium Nitride (GaN) based Solid State Pulsed Power Amplifier (SSPPA). This amplifier works in the frequency band of 9.1GHz to 9.5GHz, generating a peak pulsed power of 100W, up to a duty cycle of 20%. This amplifier can be used as a basic building block to realize higher power amplifiers, which can replace microwave tubes.

Keywords: Power Amplifier, GaN, SSPPA

I INTRODUCTION

Transmitters of conventional pulsed RADARs use microwave tubes which are pulse modulated to generate pulsed RF signals [1]. Microwave tubes have disadvantages such as lower duty cycle, very high voltages, long warm-up times, reduced shelf life & periodic maintenance. The development of GaN HEMT (High Electron Mobility Transistor) technology, which operates from higher DC voltages compared to Gallium Arsenide, enables the generation of higher RF power using fewer devices [2]. Thus SSPPAs, designed using GaN devices, can replace the microwave tubes in conventional RADARs.

In this paper, we demonstrate the design and development of an X-band 100W GaN HEMT based SSPPA which works in the frequency band of 9.1 GHz to 9.5 GHz.

II SSPPA DESIGN

The key aspects to be noted while designing an SSPPA module are its operating frequency, maximum duty, pulse width, operating voltage, power gain & saturated output power [3], as shown in Table 1.

Specification	Value
Operating Frequency	9.1GHz to 9.5GHz
Maximum Duty	20%
Pulse Width	0.4µs to 50µs
Operating Voltage	24V DC
Power Gain	10dB
Output Power	50dBm

Table 1 Key Specifications of the SSPPA to be designed

This module consists of two sections, viz. an RF section & a DC section.

III RF SECTION

The high power amplifier consists of a bias network to feed the gate voltage, the GaN HEMT and another bias network to feed the drain voltage [4]. This is shown in Fig. 1.

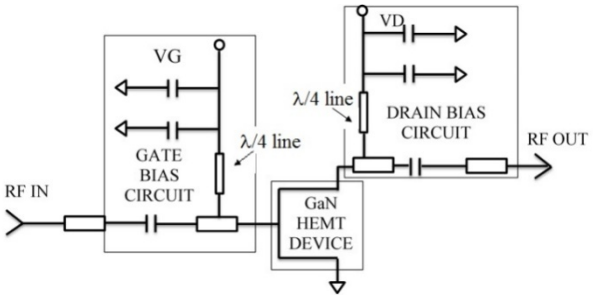

Figure 1 Block diagram of gate and drain bias circuit

The design of the RF section of the SSPPA was done in three stages. First, small signal simulation was done, followed by non-linear simulation using *NI-AWR*'s MWO. Finally, EM simulation for cavity resonance was done using *CST* Microwave Studio.

1 Small Signal Simulation

The small signal simulation of the SSPPA was done using the linear model of the device that was provided by the vendor. The *Touchstone* format file (.s2p) was used to perform the simulation. The substrate used was *Taconic*'s RF35.

The gate bias section was made using multiple quarter wave transformers to get adequate isolation between the RF and DC sections. Fig. 2 & Fig. 3 clearly demonstrate the difference in isolation between a single stage quarter wave transformer and a multi-stage bias tee.

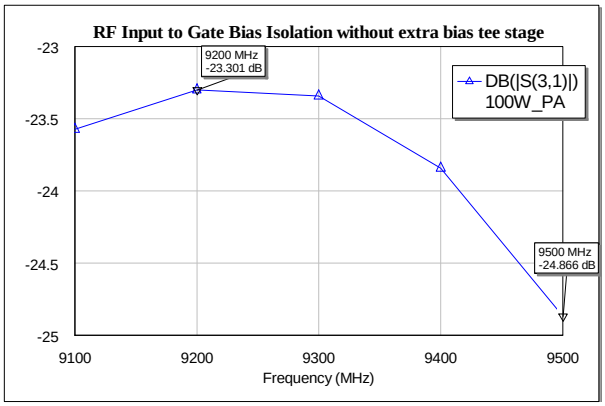

Figure 2 Isolation of one-stage bias network

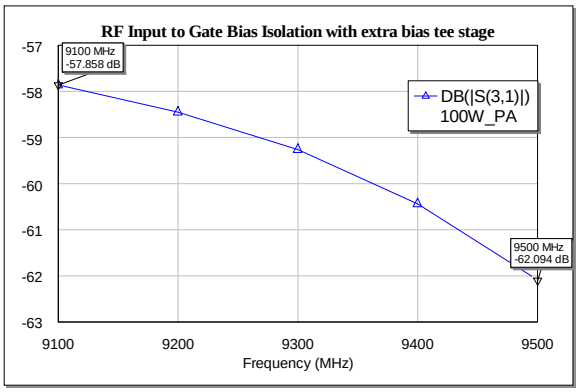

Figure 3 Isolation of multi-stage bias network

Multiple bypass capacitors were used in the bias network to ensure rejection of a wide band of frequencies. Blocking capacitors, with low ESR & high voltage ratings, were selected in such a way that their self-resonance frequencies were way beyond the frequency of operation.

Fig. 4 shows the overall small signal schematic with gate bias, drain bias and the GaN HEMT device. Fig. 5 shows the simulated small signal gain and output return loss.

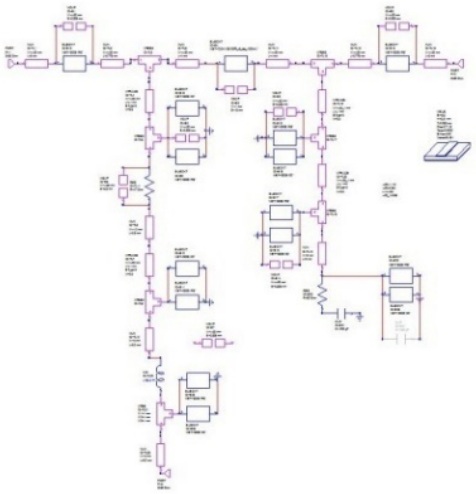

Figure 4 Overall small signal schematic

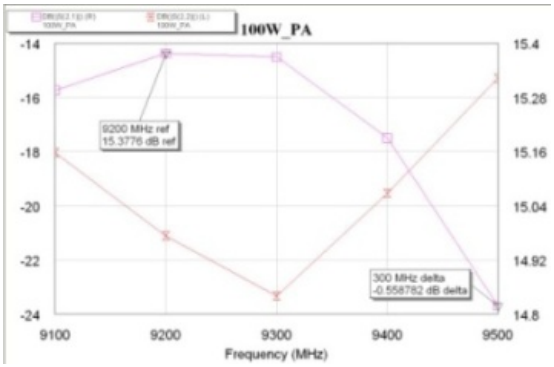

Figure 5 Response and Output Return Loss of the Amplifier

2 *Nonlinear Simulation*

The next step in the design process is to decide the bias conditions of the chosen device using non-linear simulation. Fig. 6 shows the schematic diagram for nonlinear simulation using the large signal model of the device. Fig. 7 shows the plotted IV curves. The drain voltage and the quiescent drain current are chosen as per the datasheet of the device. For this bias condition, the gate voltage value is obtained from Fig. 7.

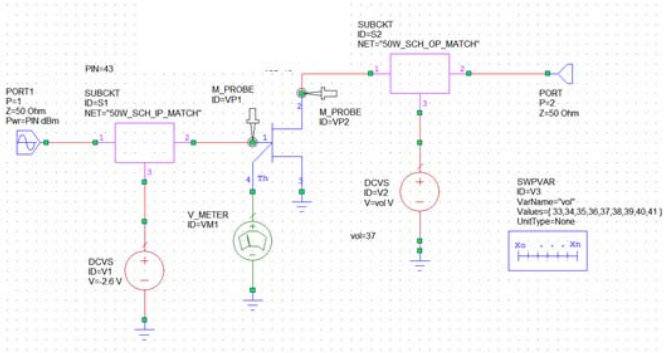

Figure 6 Schematic diagram for nonlinear simulation

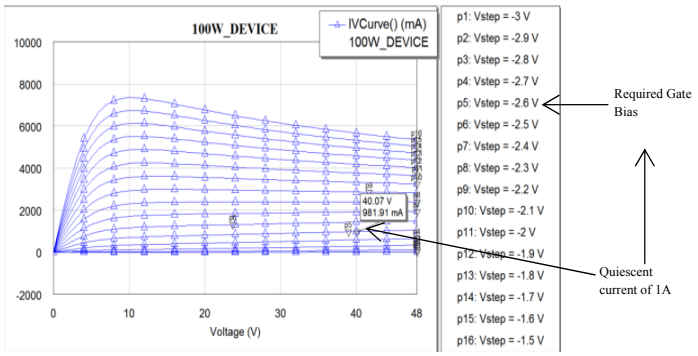

Figure 7 IV curves for the device

Finally, the variation of RF output power with drain voltage for a fixed gate voltage of -2.6V is plotted as shown in Fig. 8. The plot shows that the RF output power can be adjusted by varying the drain voltage.

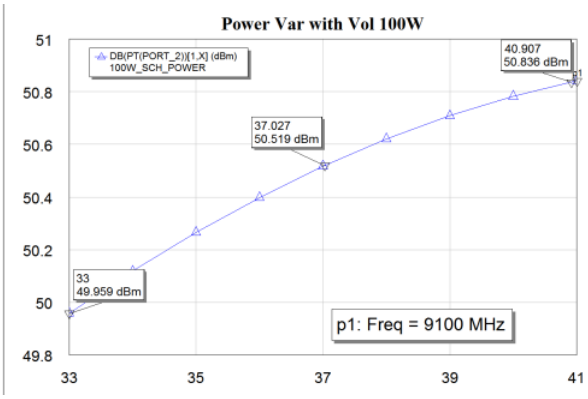

Figure 8 Variation of RF output power with DC voltage

From the simulation, it is clear that a gate voltage of -2.6V, drain voltage of 40V and quiescent current of 1A is sufficient to generate the required RF output power.

The RF output power at different frequencies is plotted for this bias condition in Fig. 9. The result demonstrates that the RF output power requirement is met over the full bandwidth.

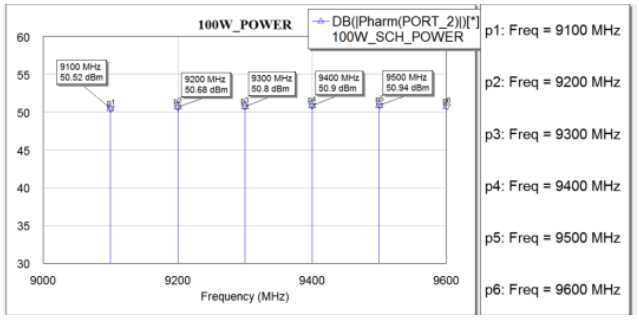

Figure 9 Output Power over the frequency band at a fixed bias

3 EM Simulation for Cavity Resonance

The device and bias sections were enclosed in a mechanical housing. It contained two EMI-filtered feedthroughs which supply the gate and the drain voltages for biasing the device. EM simulation was done to check the cavity resonance frequencies. Without any separator blocks, the cavity showed resonance in the band of interest. Appropriate mechanical block structures (Fig. 10) were incorporated to shift the cavity resonance frequencies outside the band of interest (Table 2).

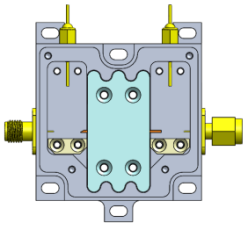

Figure 10 Cavity with the block

Eigenmode solver results:		
Mode	Frequency	Accuracy
1	14.76 GHz	4.016e-009

Table 2 Lowest Resonant Frequency of the Cavity

IV DC SECTION

The DC section of the SSPPA operates from a +24V ± 4V DC input and accepts a TTL cover pulse. The module uses a trimmable DC-DC converter to generate the drain voltage for the high power GaN HEMT.

A GaN DC bias PCB generates the negative gate voltage required for the amplifier. It consists of a sequencing circuit to ensure that the negative voltage is generated before the positive drain pulse is applied. It has a high-voltage, high-current regulator circuit along with an on-board current sensing and limiting circuit, with over-voltage protection. Fig. 11 shows the block diagram of the DC section.

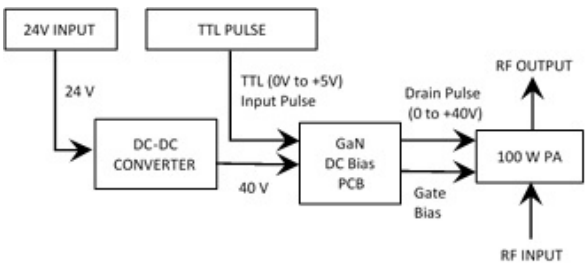

Figure 11 Block diagram of the DC Section

The drain pulses are generated using a power MOSFET that has a low on-resistance combined with fast switching speed for high duty and narrow pulse-width operation. Fig. 12 shows the SPICE simulated results [5].

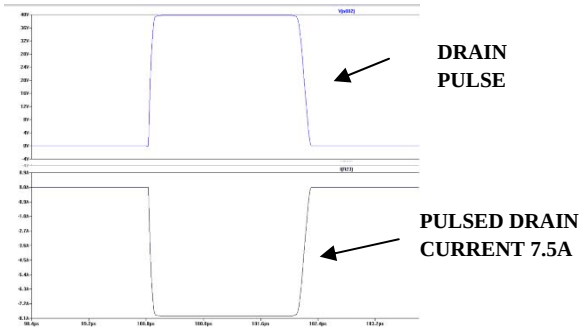

Figure12 SPICE simulated results

Charge storage capacitors are used to achieve an RF pulse droop of <0.8dB for pulse widths up to 50µsec. Aluminium electrolytic capacitors of appropriate value with a low ESR of <0.1Ω were chosen for this.

A temperature sensor module was designed and mounted close to the HEMT flange, to get an analogue voltage corresponding to the temperature measured.

V LAYOUT AND FABRICATION

The RF circuit was fabricated using Taconic's RF35 double layer substrate material, which has low dielectric loss at high frequency. Table 3 presents the substrate parameters [6].

Parameter	RF 35
Dielectric constant	3.5
Substrate thickness	0.508 mm
Metal	Copper
Metal thickness	0.035 mm
Loss tangent	0.0011

Table 3: The substrate parameters

The RF layout and the fabricated RF-section PCBs are as shown in Fig 13 and Fig 14. The DC layout and the fabricated DC-section PCB are as shown in Fig 15 and Fig 16.

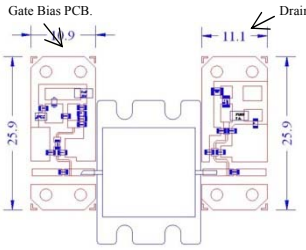

Figure 13 Layout of RF PCB

Figure 14 Fabricated RF PCBs

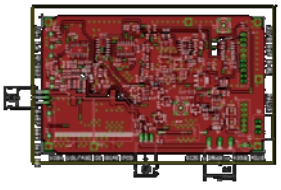

Figure 15 Layout of DC PCB

Figure 16 Fabricated DC PCB

For better thermal management, additional fins were provided on the top cover. The overall test setup is as shown in Fig 17.

Figure 17 Power Measurement setup

VI RESULTS

A pulsed RF input of 10W was fed to the SSPPA. The results for different pulse widths are shown in Fig 18 and Fig 19.

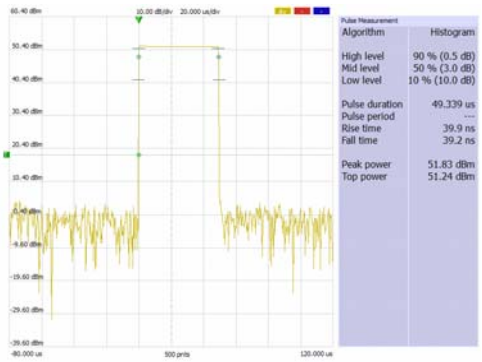

Figure 18: 50us PW @ 20% duty

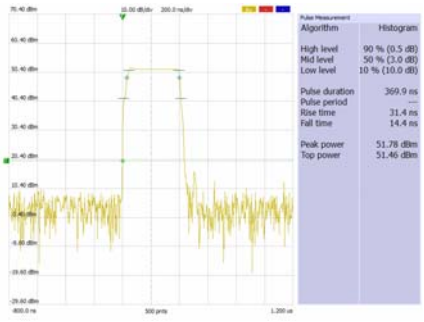

Figure 19: 400ns PW @ 5% duty

Thermal cycling of the amplifier was done for a temperature range of -10 C to +55 C. The results are as shown in Fig 20.

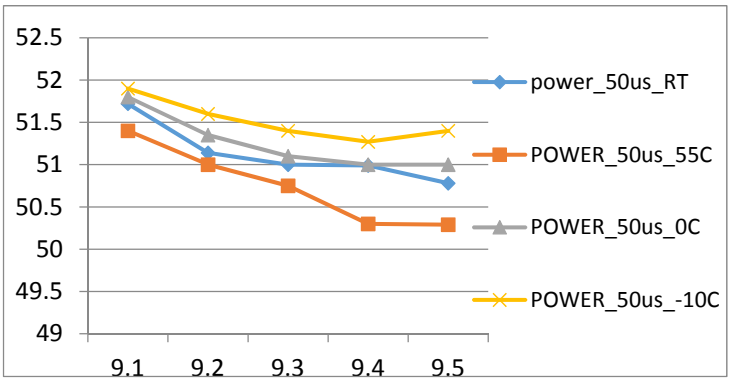

Figure 20: Thermal Cycling plots

CONCLUSION

Next generation RADAR systems require transmitters with high output power, small size, low weight, high efficiency, and high reliability. Using GaN based SSPPAs, miniaturization, weight reduction, and high efficiency can easily be achieved.

In this paper, the realization of a GaN based 100W X-band SSPPA module has been described. The practical results were comparable to the simulated results. The temperature cycling proved that the SSPPA was able to operate over the temperature range of interest. By combining modules, higher power SSPPAs can be realised with graceful degradation (and no single point of failure) for longer RADAR range requirements.

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