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NEW DEVELOPMENT AND TESTING FACILITY FOR HPRF SSA SYSTEM AT LANSCE CCL

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Abstract

A high-power RF test facility developed at the Los Alamos Neutron Science Center (LANSCE) to evaluate components of a RF Solid-State Amplifier (SSA) system operating at 805 MHz and targeted for a final output power of 1.25 MW. The system is powered by a 100 V DC supply and stabilized with a 0.1 F capacitor bank to support transient power demands, capable of storing up to 1.125 kJ of energy. The SSA utilizes Gallium Nitride (GaN) on Silicon Carbide (SiC) high electron mobility transistors (HEMTs) and employs water cooling to manage thermal loads and ensure stable operation under high duty-factor pulsed conditions. Multiple HEMT amplifier modules will be power combined to achieve the full 1.25 MW output, with the aim of enhancing reliability, modularity, and maintainability in accelerator RF infrastructure. Integrated protection procedures allow for secure shutdown of RF drive and DC power in the event of overvoltage, overcurrent, or thermal excursions. This test configuration supports ongoing evaluation of solid-state amplifier performance, thermal handling, and integration with RF passive components under realistic operational conditions.

INTRODUCTION

A new test facility has been developed at the Los Alamos Neutron Science Center (LANSCE) to evaluate solid-state amplifier (SSA) systems operating at 805 MHz, targeting 1.25 MW output for accelerator applications, see Fig. 1. This effort addresses the growing need for RF sources that are modular, scalable, and maintainable—critical for supporting high-duty-factor pulsed operation in modern accelerator infrastructures. The SSA design employs Gallium Nitride (GaN) on Silicon Carbide (SiC) high electron mobility transistors (HEMTs), offering several advantages over legacy vacuum tube-based systems, including improved fault tolerance, lower voltage operation, and reduced maintenance. The modular nature of the system allows individual amplifier units to operate independently, simplifying upgrades, diagnostics, and staged power scaling. A key focus of the project is to demonstrate a path forward for replacing aging RF infrastructure, such as klystron-based sources, which are increasingly difficult to maintain and no longer manufactured. By validating the SSA architecture in a realistic environment, this work supports the transition to modern, solid-state-based RF solutions that align with current safety, reliability, and operational standards. This paper outlines the facility's design, including DC power delivery, amplifier module integration, thermal management, protection mechanisms, and performance characterization under accelerator-relevant conditions.

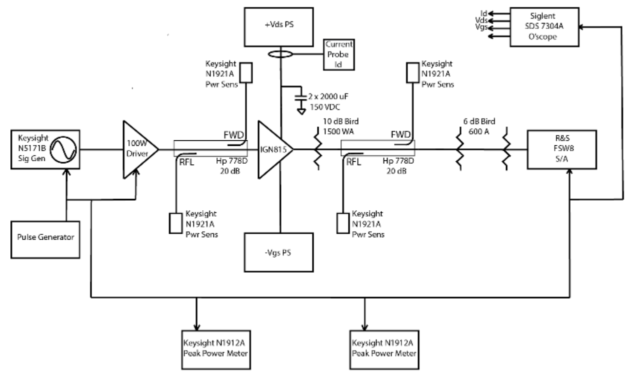

Figure 1: Block diagram of SSA Test System.

POWER ARCHITECTURE

The current generation SSA system replaces legacy klystron-based RF sources that operated at approximately 90 kV DC, representing a significant improvement in lab safety and power handling [1]. Lowering the operating voltage by nearly three orders of magnitude reduces the complexity of insulation, arcing risk, and personnel hazard during maintenance or fault scenarios. The transition to low-voltage, high-current solid-state devices therefore supports not only improved modularity and reliability but also aligns with modern safety standards in accelerator environments.

The DC power for the SSA modules is provided by a TDK-Lambda GEN100-50 programmable supply, operating at 100 V and up to 50 A. The unit is powered from a standard 208 V AC line, simplifying infrastructure requirements and reducing installation constraints compared to traditional high-voltage systems. The power supply features protections for overvoltage. Its compact form factor allows it to be integrated directly into the test stand rack alongside RF and control systems.

Each SSA module also includes onboard 1000 μF capacitors positioned on the drain side of the GaN device. These capacitors are critical for managing fast power transients during pulsed operation, locally stabilizing the supply voltage during high-current draw events. By providing immediate energy buffering at the device level, they mitigate the impact of voltage sag due to cable inductance or distributed impedance on the main DC rail. This localized energy storage enhances pulse fidelity, improves RF output stability,

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and protects the GaN HEMTs from voltage dips that could degrade performance or cause premature failure.

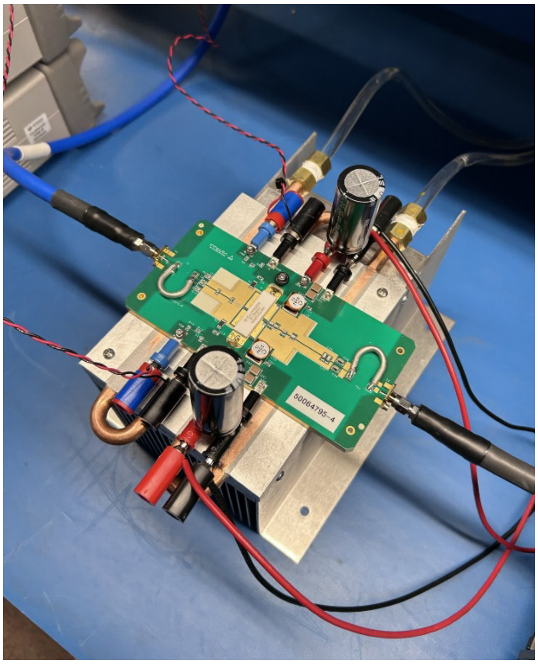

Figure 2: HPRF SSA at Testbench.

THERMAL MANAGEMENT BASED ON SSA DEVICE PERFORMANCE

Thermal management is a critical factor in the successful operation of the SSA system, directly informed by the thermal behaviour observed during SSA device testing, see Fig. 2. The GaN-on-SiC HEMT-based amplifier modules deliver high output power at approximately 74% efficiency under pulsed operation at 805 MHz, generating significant heat that must be effectively managed to ensure device reliability and performance.

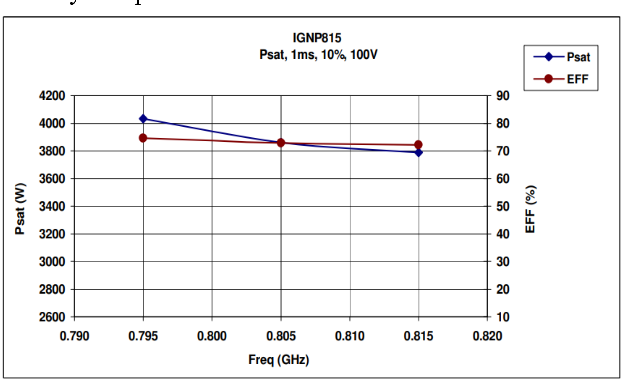

Figure 3: SSA Power Saturation and Efficiency.

As shown in Fig. 3, the output power saturates between 3.9 kW and 4.1 kW, indicating the upper limits of amplifier performance under the given operating conditions. This saturation region corresponds closely with the thermal constraints observed during testing, emphasizing the importance of efficient heat removal to maintain stable device operation at high power levels. In response to these thermal demands, the system incorporates a closed-loop water-cooling solution using a Cole-Parmer Polystat recirculating chiller. This chiller provides precise and rapid temperature control over a broad range (–10°C to 80°C) with ±0.1°C stability, supporting coolant flow rates up to 21 L/min at pressures up to 11.7 psi (805 mbar). Such capacity is essential for effectively dissipating heat generated during pulsed operation at various duty cycles.

Each amplifier module is mounted on a copper cold plate featuring embedded coolant channels, receiving approximately 1.0 L/min of coolant flow per module. The inlet coolant temperature is maintained near 20°C during typical operation, ensuring stable thermal conditions across the array of SSA modules.

The cooling strategy directly addresses the thermal challenges revealed by SSA device results, including managing thermal cycling effects caused by rapid device saturation transitions. This approach reduces mechanical stress at the die-substrate interface and promotes long-term reliability. Additionally, the Polystat chiller's low evaporation design and quick thermal response contribute to system stability during extended testing and operation.

By tailoring the thermal management system to the observed SSA device performance, the SSA amplifier array achieves consistent operation, safeguards device integrity, and supports scalable high-power RF output under demanding accelerator conditions.

SYSTEM INTEGRATION, MODULARITY, AND SAFETY FEATURES

The SSA system is built on a highly modular architecture, comprising multiple independent amplifier modules. Each module operates as a self-contained RF source with its own DC input, RF drive, cooling interface, and monitoring capabilities. This modularity enables scalable power output—achieving the target 1.25 MW at 805 MHz—by combining modules in parallel using a staged RF combining network of broadband hybrid combiners and coaxial splitters [2]. The design ensures phase-coherent signal addition, minimizing power loss across combining stages.

Integration and testing are performed at both the module and system levels. Vector network analyzers, power meters, and directional couplers are used to verify gain balance, return loss, and insertion loss across the combining network. Phase control is implemented at each module to ensure proper signal alignment during power combining, allowing for optimized efficiency, adjustable output levels, and consistent performance across the amplifier array [3].

The modular design directly informs the system's safety strategy. Since each amplifier module operates independently but contributes to the combined output, safety mechanisms must protect both individual modules and the complete array. Currently, basic engineering controls such as cord management and manual disconnection during servicing are employed, suitable for lab-scale operation.

Looking ahead, active hardware protections are planned to enhance safety and fault response. A crowbar circuit is proposed to rapidly discharge stored energy from the capacitor bank in emergencies, minimizing risk to personnel and equipment. While this system remains conceptual at this stage, integrated interlock logic already monitors

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critical parameters—including overvoltage, overcurrent, and overtemperature—at module and system levels. These interlocks trigger staged shutdowns of RF drive and DC input to affected modules, supported by continuous monitoring of coolant flow, RF reflections, and DC bus conditions.

In summary, the SSA's modular architecture not only facilitates scalable high-power RF generation but also drives the development of layered safety features and diagnostic capabilities, establishing a robust and flexible testbed for accelerator system applications.

CONCLUSION

A high-power RF test facility has been successfully developed at LANSCE to evaluate solid-state amplifier (SSA) systems operating at 805 MHz, with a long-term goal of achieving 1.25 MW of RF output power. By leveraging GaN on SiC HEMT technology, the system offers high gain, efficiency, and thermal stability under high-duty-factor pulsed operation. Initial results demonstrate 19 dB of gain across the 795–815 MHz band with 22% efficiency, validating the suitability of this platform for accelerator-class RF applications.

The modular SSA architecture supports phased integration of amplifier modules through a staged power-combining network, enabling scalable and fault-tolerant operation. Integrated thermal management, achieved via a precision water-cooling system, maintains safe device temperatures and supports long-duration testing. System-level diagnostics and RF analysis tools ensure performance verification and streamline commissioning.

This development aligns with a broader push to replace aging and obsolete legacy equipment, including klystrons and high-voltage tube-based amplifiers, which are no longer manufactured or supported. The solid-state approach not only improves maintainability and operational safety but also offers a sustainable, modern path forward for high-power RF infrastructure in accelerator environments.

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