Pulsed Low-Noise Amplifiers for Quantum Information Systems

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***Abstract*—This report summarizes the research progress on developing pulsed low-noise amplifiers (LNAs) for quantum information systems, focusing on time-domain noise characterization and low-power cryogenic amplifier design. A novel transient noise and gain measurement methodology was proposed and experimentally validated with 5 ns resolution and $<$ 0.3 K noise uncertainty. Using this methodology, a modified cryogenic HEMT LNA was optimized for pulse operation, achieving a recovery time of 35 ns while maintaining sub-2 K noise temperature. This work demonstrates the feasibility of duty-cycled amplifier operation for superconducting qubit readout, potentially reducing average LNA power consumption by one orders of magnitude.**

***Index Terms*—Cryogenic, InP HEMT, low-noise amplifier, pulsed operation, low power, qubit readout.**

I. INTRODUCTION

S The rapid scaling of superconducting qubits in quantum computing is challenged by the limited cooling power of dilution refrigerators, especially at the 4 K stage where cryogenic HEMT LNAs are located [1]. These amplifiers, typically consuming several milliwatts, contribute to the thermal budget and potentially degrade qubit fidelity via backaction. While transistor and circuit-level optimizations have achieved power reductions to 100 μW [2], a further breakthrough is needed to enable million-qubit-scale architectures.

This project explores pulsed operation of the HEMT LNA, leveraging the inherently pulsed nature of qubit readout. By synchronizing amplifier biasing with qubit measurement windows, it is theoretically possible to reduce average power consumption by a factor proportional to the readout duty cycle ($<$ 10 %) without compromising gain or noise performance. However, implementing such a scheme requires a precise understanding of LNA transient behavior—a largely unexplored domain prior to this work.

II. PROJECT OUTCOMES

A. Time-Domain Noise and Gain Characterization

A novel methodology was developed for direct time-domain measurement of LNA noise and gain during bias transitions. The setup, illustrated in Fig. 1, employs a calibrated noise source at the input of the device under test (DUT), and a high-speed oscilloscope to record the output waveform. By segmenting the transient output voltage into short time windows and applying discrete Fourier transform (DFT) to each segment, the power spectral density (PSD) was obtained. From the PSD data under ‘hot’ and ‘cold’ noise source conditions, the time-resolved noise temperature and gain were extracted using the Y-factor method. This approach enables simultaneous nanosecond-scale resolution in both noise and gain, providing critical insight into the dynamic behavior of pulse-operated amplifiers [3]. A 3D plot of both gain and noise recovery over time and frequency for the pulse-biased cryogenic HEMT LNA is shown in Figs. 2(a) and (b), respectively, highlighting the amplifier’s transient performance and recovery dynamics across the 3–9 GHz band.

Analytical expressions linking noise variance to system parameters were derived and validated, which provided theoretical insight into the trade-offs between time resolution, frequency averaging, and measurement stability in time-domain noise characterization, as shown in Eq. (1) [4].

$$\begin{aligned}Var_{ns}(T_{e,m}) =& \frac{2\cdot(T_{hot}+T_e+\frac{T_{osc}}{G})^2(T_{cold}+T_e+\frac{T_{osc}}{G})^2}{(T_{hot}-T_{cold})^2}.\\ \approx& \frac{2}{(T_{hot}-T_{cold})^2}\cdot(T_{hot}+T_e)^2(T_{cold}+T_e)^2.\end{aligned} \tag{1}$$

Cryogenic measurements were then performed using a setup at 10.6 K, incorporating a low-loss cryogenic attenuator and band-pass filters. The system achieved 5 ns time resolution and $<$ 0.3 K standard deviation across 3–9 GHz. Static and transient results showed excellent agreement with conventional NFA measurements.

B. Pulse Operation and Fast Recovery Biasing

The developed methodology was applied to characterize a modified 4–8 GHz InP HEMT LNA under gate-pulsed operation. Using an initial square-wave gate bias, the LNA exhibited a recovery time of approximately 120 ns, limiting its suitability for fast qubit readout. To enhance performance, a fast-recovery gate bias strategy was proposed and optimized using a genetic algorithm. The optimized waveform significantly improved the transient response, reducing the effective recovery time to 35 ns while maintaining a noise temperature below 2 K and gain above 40 dB across the C band. The full transient noise and gain behavior under this optimized biasing condition is illustrated in Fig. 3.

Additionally, real-time drain current monitoring confirmed that the average power consumption scaled proportionally with

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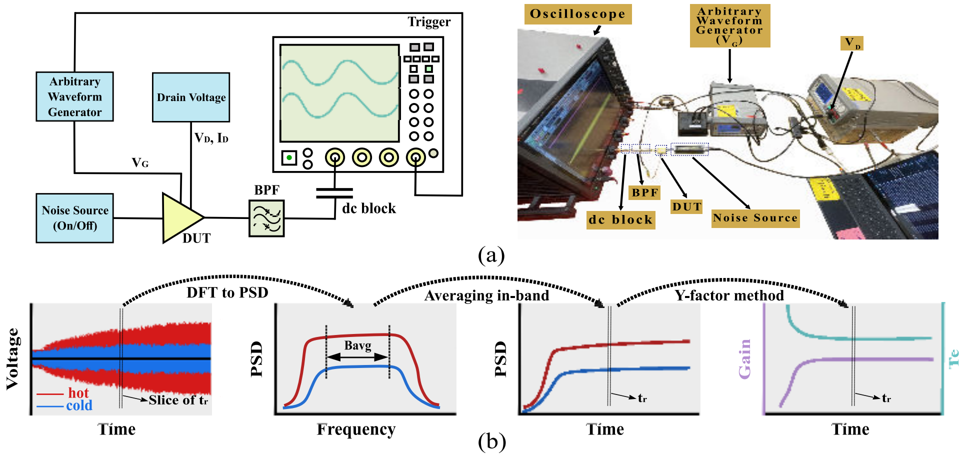
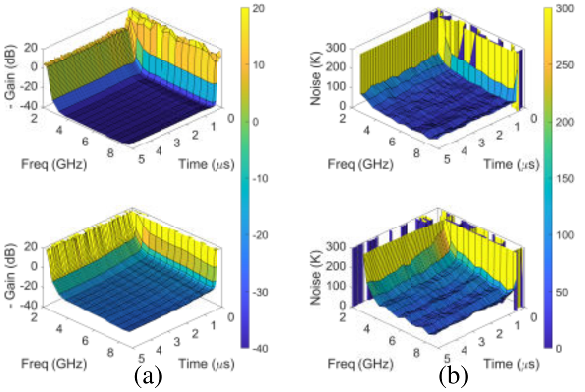


(a)

(b)

Fig. 1. Proposed time-domain noise characterization (a) setup schematics and real test environment, and (b) data processing procedures.



(a) (b)

Fig. 2. 3D plot of (a) negative gain and (b) noise transient in time and frequency domain. Top row: V_G = -92 mV and bottom row: V_G = -244 mV. Each frequency point averaged 0.5 GHz nearby bandwidth PSD.

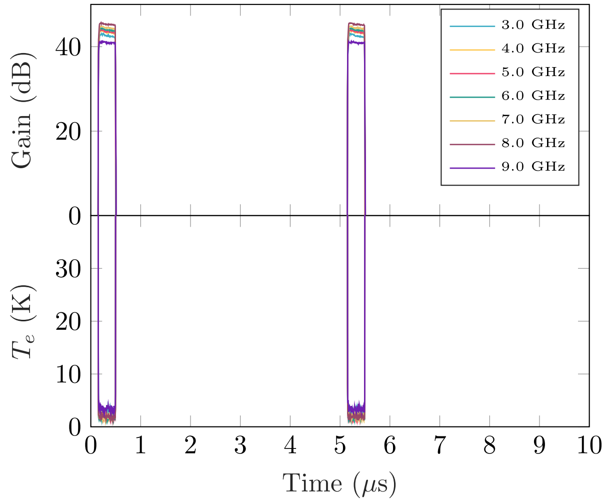


Fig. 3. Gain and noise transient of DUT with optimized fast recovery V_G waveform in two 5 μs period with 500 ns pulse width.

the readout duty cycle, achieving 10 % of the static bias power consumption under representative qubit readout conditions. This pulsed operation scheme demonstrates a practical and scalable solution to mitigate thermal bottlenecks in large-scale quantum computing systems.

III. CAREER PLAN AND FELLOWSHIP IMPACT

The MTT-S Graduate Fellowship enabled me to establish a new measurement methodology and demonstrate its utility in advancing quantum cryogenic microwave electronics. This experience has deepened my commitment to developing scalable quantum hardware, combining rigorous microwave engineering with system-level quantum needs.

In the future, I aim to transition into industry R&D while maintaining strong ties to academia. I am particularly interested in cross-disciplinary collaborations at the interface of quantum systems, RF electronics, and cryogenic technologies. The fellowship not only accelerated my research but also broadened my professional network. Attending IMS 2024 in Washington, D.C. allowed me to engage with leading experts and gain inspiration from cutting-edge research, which I will carry forward in my career.

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