Characterization and Automation of Quantum Electronics for Qubit-based Dark Matter Detector

Michael Zaidel[1], Rakshya Khatiwada[2], Mohamed Hassan[2], Daniel Bowring[2]

[1]Departments of Physics; Astronomy & Astrophysics, Pennsylvania State University
[2]Quantum Information Science Metrology, Fermi National Accelerator Laboratory

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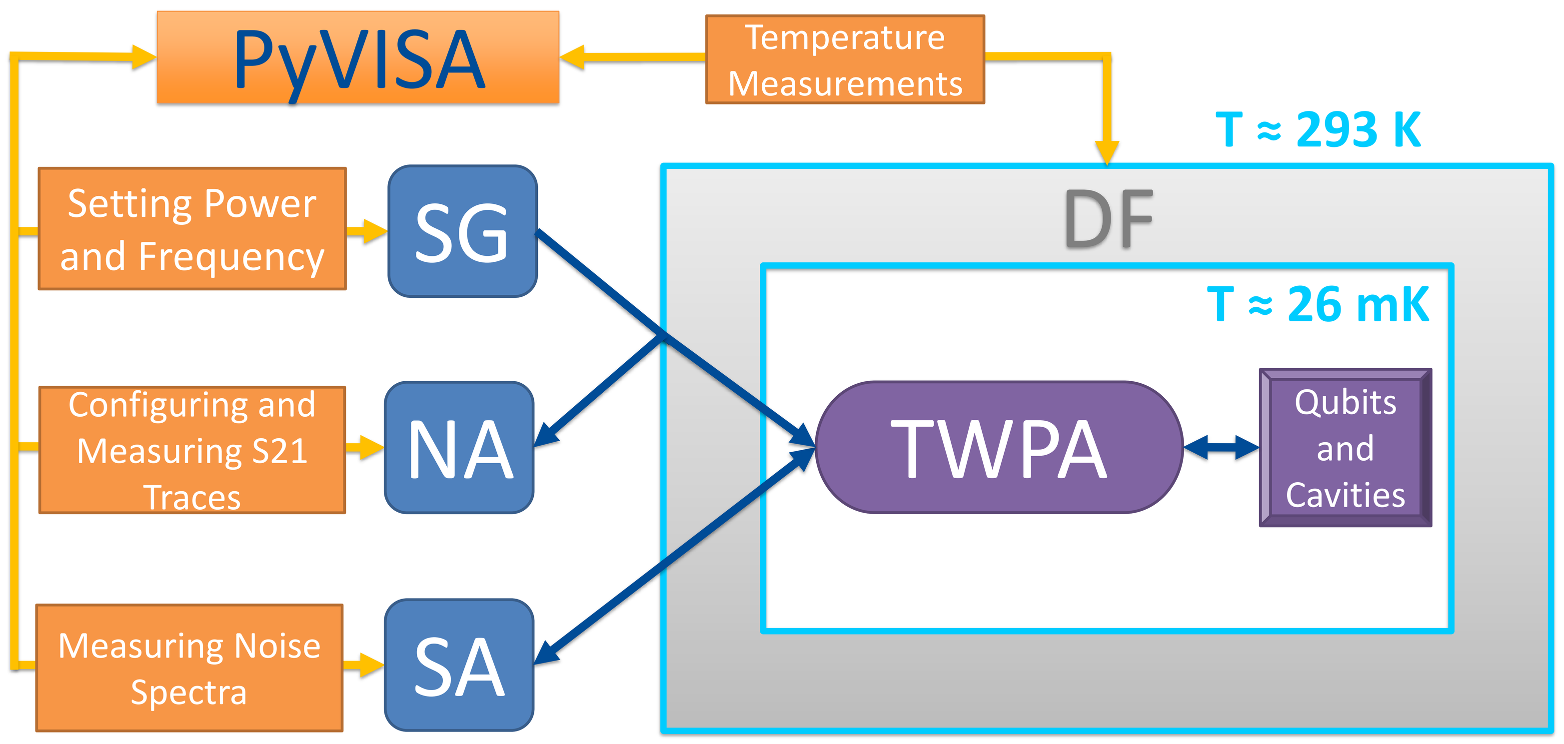
Introduction

The hypothetical axion particle is not only a potential solution to the strong CP problem of quantum chromodynamics but also is a compelling cold dark matter candidate. Searching for axions requires sensitivity that is achievable only with superconducting qubits and other quantum-noise limited devices. This work focuses on the characterization of one such device, a **Traveling Wave Parametric Amplifier (TWPA)**. This was accomplished through developing techniques for remote control and operation of various electronics and the **TWPA** used in qubit-based dark matter searches.

Experimental Layout

The cryogenic microwave electronics within a **Dilution Refrigerator (DF)** including qubits are readout using a **TWPA**. The signal is measured by performing S21 transmission studies with a **Network Analyzer (NA)**. The **TWPA** is biased as a function of pump tone and frequency generated by a **Signal Generator (SG)**. Measurements of **TWPA** noise are made using a **Spectrum Analyzer (SA)**.

The **TWPA** is a high gain, low noise quantum amplifier with high sensitivity specifically equipped for use with qubits in cryogenic environments.



Flowchart of experimental setup and remote operation of electronics accomplished by developed Python functions.

Methodology and Results

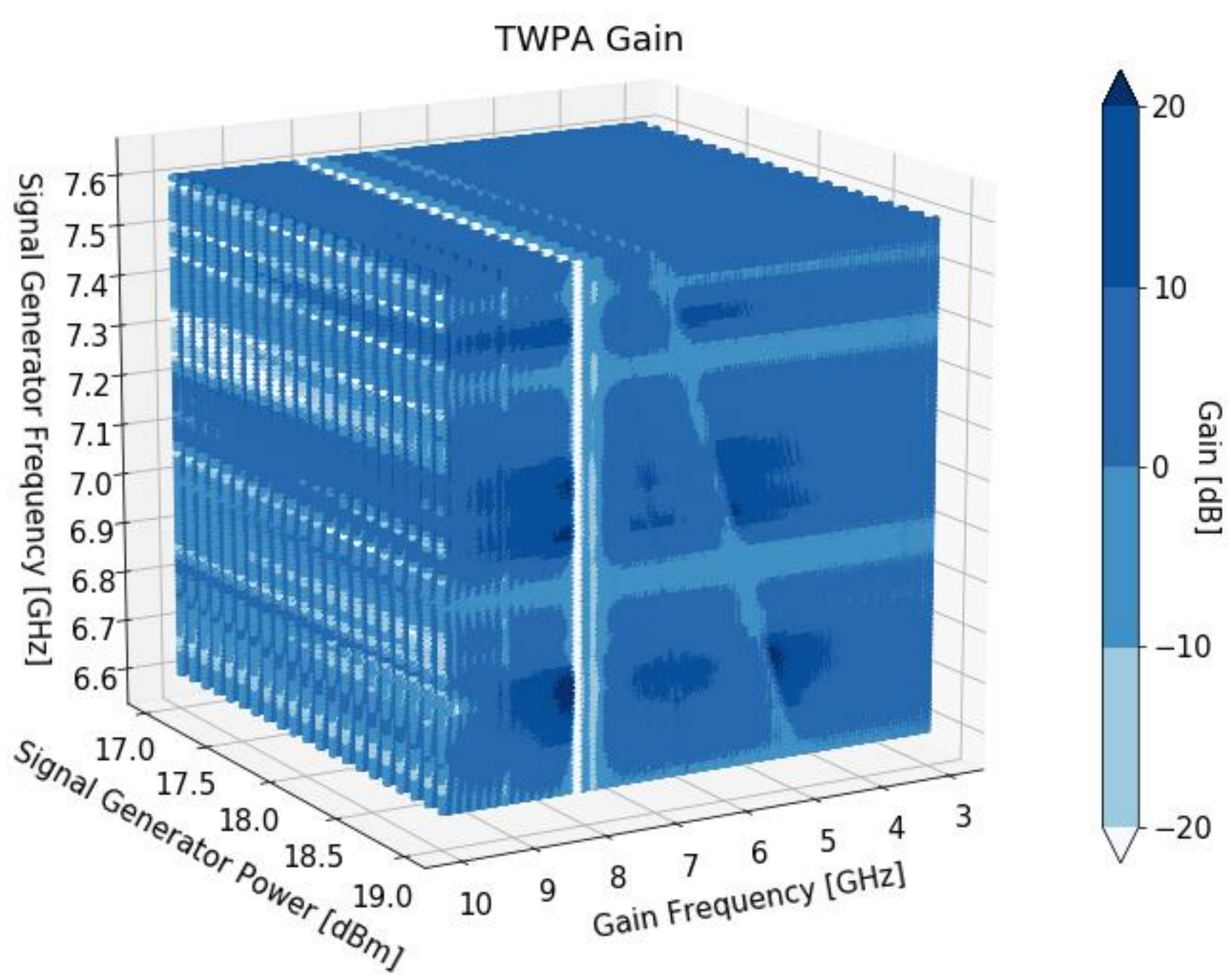
This work involved designing and programming Python routines to communicate with electronics in the experiment via the **Python Virtual Instrument Software Architecture (PyVISA)**, as well as conducting a **TWPA** study of signal gain as a function of device operating parameters.

The remote connection and operation of electronics were implemented in functions that encode instructions in device language to a more easily readable I/O syntax in a standard Python environment. Function operations include:

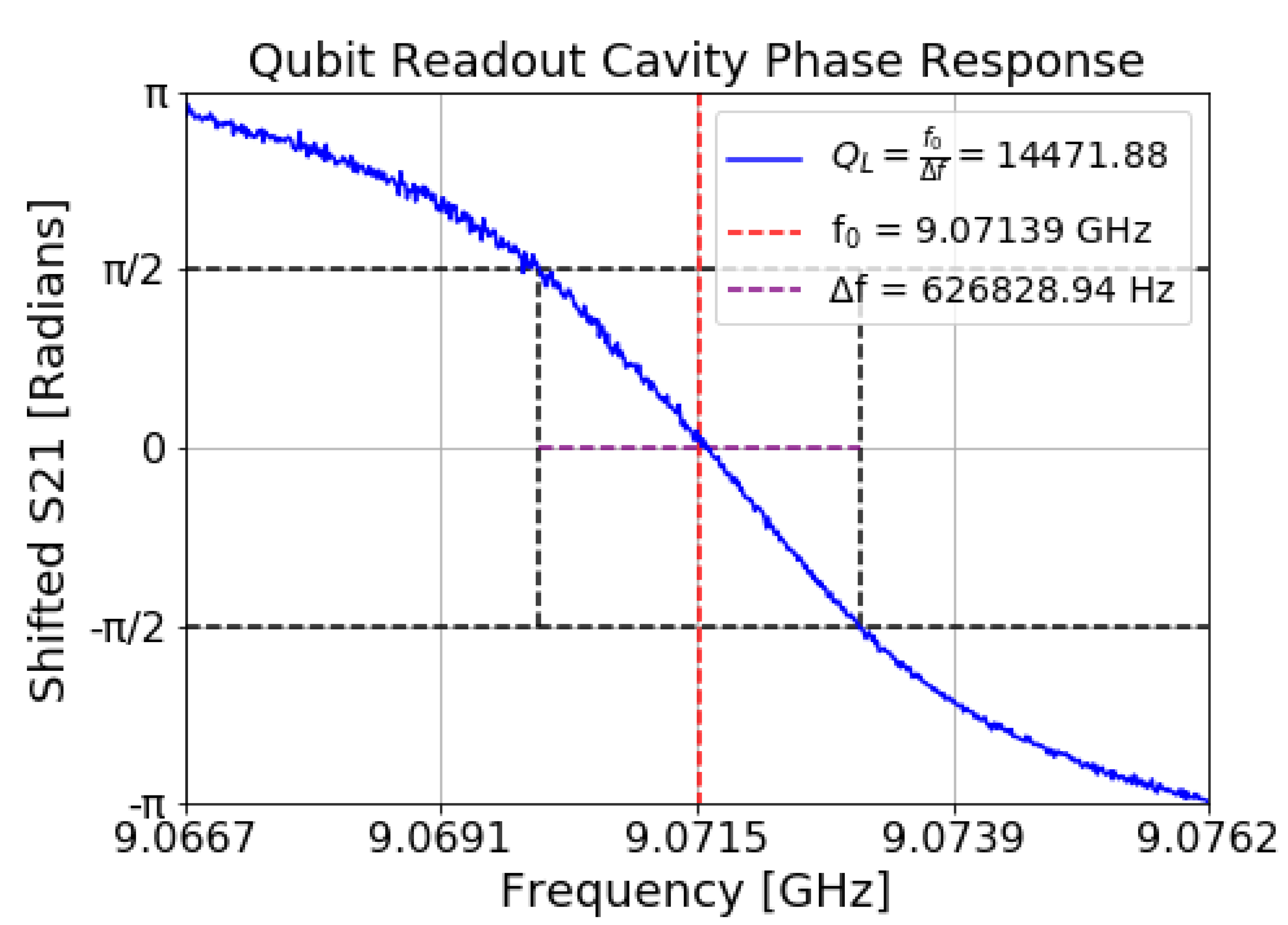
- Reading/setting the state and operating parameters of devices
- Automating data collection of large parameter space sweeps
- Saving measurement data to file
- Producing formatted plots and tables

The gain study aimed to determine the combination of **SG** Power and **SG** Frequency that maximize power transferred through the **TWPA** for values of **NA**/Gain Frequency.

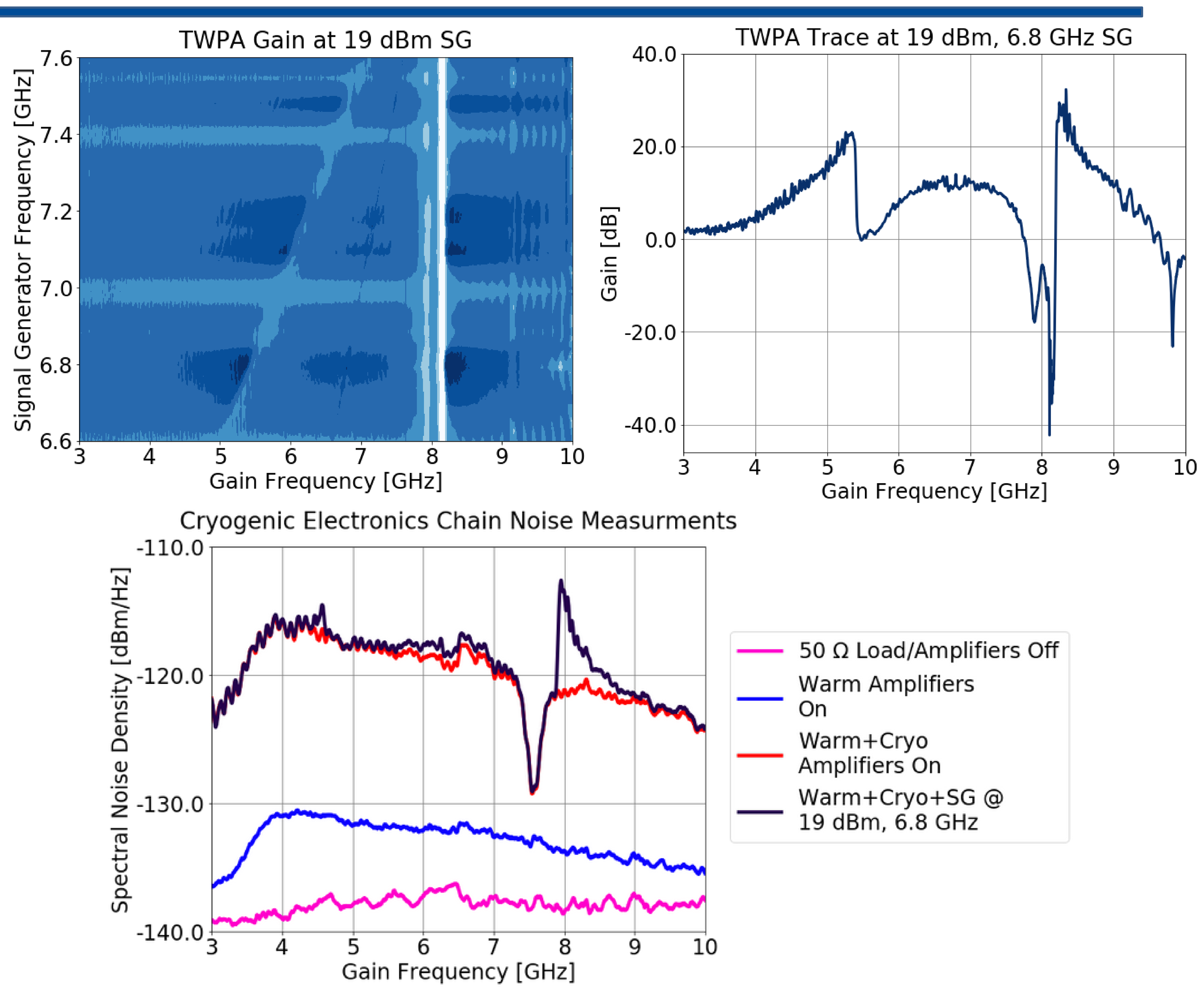
Results of this study are showcased in plots to the right. Regions in darkest blue contain combinations of favorable operating parameters with optimal **TWPA** gain. Subspaces of the study are also shown for parameter values that produce high gain, along with noise measurements with the **SA**. Additionally, the readout cavity frequency of a qubit-readout cavity system is displayed along with its computed quality (Q) factor.



3D plot of TWPA gain study.



Qubit/Cavity system readout frequency and Q-factor.



Top: 2D plot of high-power regime of TWPA gain; 1D trace of highest gain. Bottom: TWPA noise measurements with and without various amplifiers.

Conclusions

This project establishes a methodology for automating the tuning and characterization of electronics involved in qubit-based axion dark matter searches. The development of Python programs for the remote control of experimental devices provides a streamlined operational framework for data acquisition and other laboratory functions. The complete characterization of the **TWPA** provides insight on the most optimal configuration of device parameters to precisely measure signals from supercooled quantum devices. This work not only speeds up the quantum electronics characterization process but also significantly reduces the time it takes to do qubit spectroscopy which is essential in developing an ultra-sensitive axion dark matter detector.

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