Analysis of Commercially Available Electrical Components for Amplification of Quantum Processor Read Out

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Introduction

In quantum processors, quantum readout occurs through spin-selective tunneling of electrons out of a single electron transmitter (SET). The readout signal occurs when a single charge moves approximately **100 nm** in a device. The signal itself consists of a change in current by about **100 pA**.

Image of the four-qubit quantum processor structure

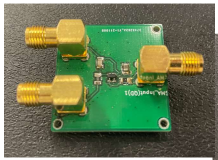
Because the differences in energy between spin-up and spin-down electrons (the computational states of out quantum computer) is so small, quantum processors **must operate at cryogenic temperatures around 10 millikelvin.**

Readout amplifiers must be placed at **850 millikelvin** to:

- Reduce parasitic capacitance
- Eliminate thermal noise

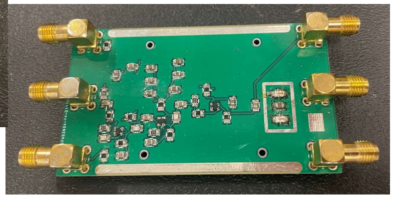
However, classical electrical components do not function as expected at these low temperatures due to **carrier freeze-out.**

Our lab has a two-stage amplification, with the first stage at **1 Kelvin** and the second stage at **4 Kelvin**. [1]



First Stage Amplifier above

Second Stage Amplifier Below



The goal of the project was to test the components that make up the amplifiers to design a better amplifier for quantum readout.

Experimental Setup

For the experiment, components needed to be tested at cryogenic temperatures near **1 Kelvin**. To do this, components were attached to a probe and dunked into an ICEOxford cryostat

- Due to the wiring of the probe, two components were able to be tested together.
- A calibrated temperature sensor was attached to the sample plate to record the temperature of the components throughout the cooldown
- During the cool down process, a computer script was written to collect data from external multimeters and save them to a data frame.

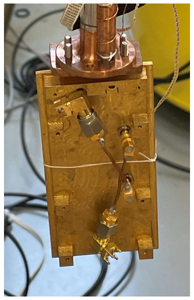


Image of sample plate on probe

Data

A total of six capacitors were tested

- 15 µF 25V JB 0805
- 47 µF 10V JB 0805
- 1 µF 20V TANT 1206
- 10 µF 16V TANT 1411
- 22 µF 10V X7R 0805
- 10 µF 10V X7R 0805

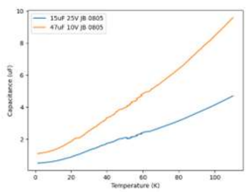
The graphs on the right have the plotted final values of each trial.

Each trial recorded capacitance down to a temperature of roughly **1.5 Kelvin**.

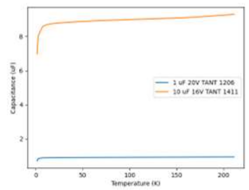
A data table has been included below with key data points for each capacitor

	77 K	4 K	1.5 K
15µF 25V JB 0805	3.03µF	0.52µF	0.50µF
47µF 10V JB 0805	6.16µF	1.14µF	1.09µF
1µF 20V TANT 1206	0.91µF	0.86µF	0.71µF
10µF 16V TANT 1411	8.95µF	8.61µF	7.01µF
22µF 10V X7R 0805	4.58µF	0.90µF	0.83µF
10µF 10V X7R 0805	1.71µF	0.33µF	0.31µF

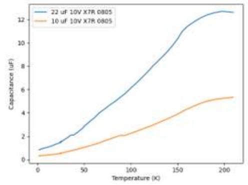
Temperature vs. Capacitance for JB capacitors



Temperature vs. Capacitance for TANT capacitors

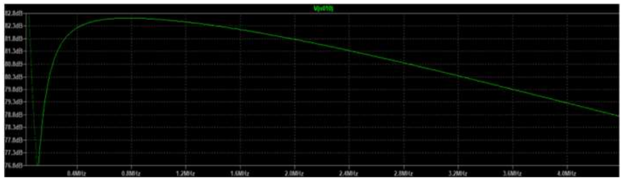


Temperature v. Capacitance for X7R capacitors



Simulation

We used LTSpice to simulate the effects of cryogenic temperatures on the amplifiers. For this project, the only values that were changed were the capacitor values. The reason that resistor values were not changed is due to previous research which measured **resistor values as essentially unchanged** by cryogenic temperatures [2].



The graph of the amplifier's gain from the spice simulation is shown above. Something we noticed is that despite a strong temperature dependence on the capacitance of some of our components, there was **little change** to the gain and bandwidth of our amplifier circuit. At cryogenic temperatures we do see a change in the circuit performance, which is likely due to changes in the transistor at low temperatures.

Future work

In the future, we will test transistors to gather data on more the components that make up the amplifiers.

- For transistors, we will fully characterize thier cryogenic performance to create a comprehensive simulation model of the transistors

This will allow us to **design better amplifiers** specifically meant for cryogenic amplification.

References

[1] T. Vink "Cryogenic amplifier for fast real-time detection of single-electron tunneling, " in Applied Physics Letters, vol 91, 12, doi: 10.1063/1.2783265

[2] H. Homulle "Cryogenic electronics for the read-out of quantum processors," Doctoral thesis, Delft Univ., Delft Netherlands, 2019, doi: 10.4233/uuid:e833f394-c8b1-46e2-86b8-da0c71559538

Acknowledgements

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