Optimization of the Travelling Wave Parametric Amplifier Performance and Noise Handling for Qubit Readout

Joshua Millman

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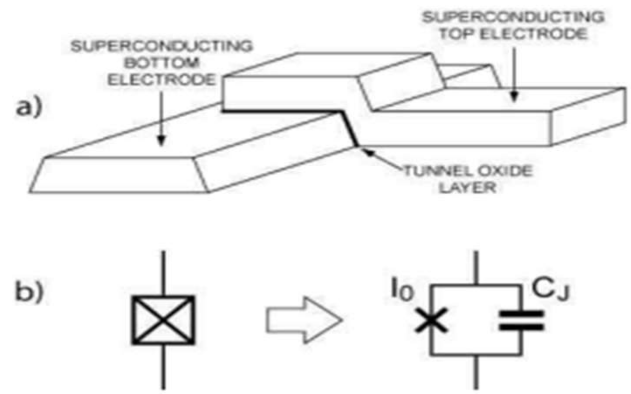
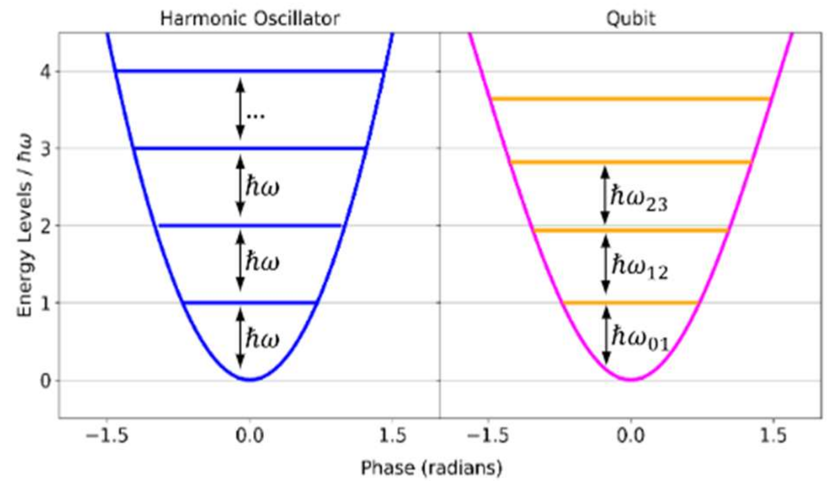
Qubit Background

- Qubits are computer bits that can be 0, 1, or a superposition of both.
  - $|\psi\rangle = c_0|0\rangle + c_1|1\rangle$
- Our qubits are constructed using Josephson junctions.
  - This junction creates an anharmonic oscillator with addressable energy levels.
- Coupled to harmonic resonators for readout purposes.
- Promising candidate for axion detectors
  - Issues with spatially correlated errors.
  - Physicists working at NEXUS are trying to find the source of these errors.



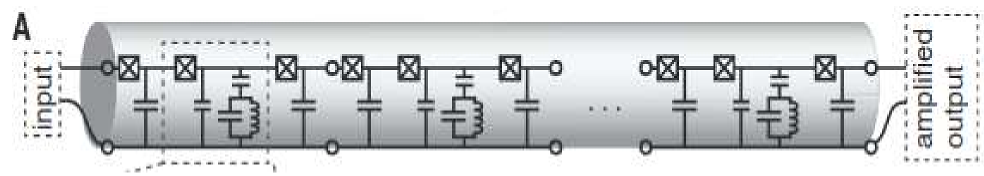


Top: Diagram of a Josephson junction (Devoret *et al.*, 2008)

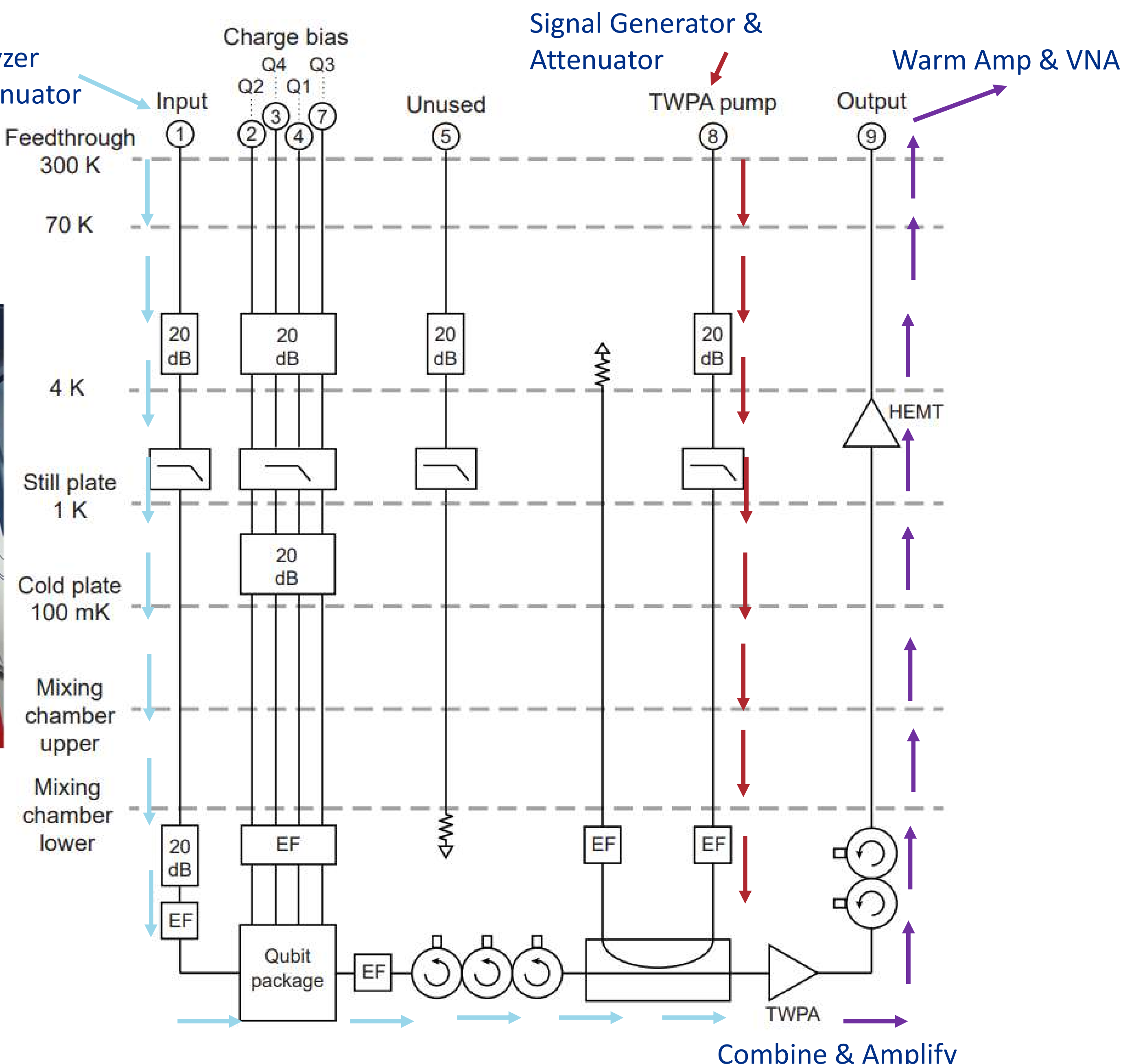
Bottom: Energy Levels of Harmonic Oscillator and Qubit

The Travelling Wave Parametric Amplifier

- The Travelling Wave Parametric Amplifier (TWPA), is the first amplifier the signal encounters after the qubit package.
  - Improves gain and SNR of signal.
  - A near quantum limited amplifier; adds little noise.
- Constructed from a series of Josephson junctions, capacitors, and inductors.
- Requires a specific driving signal from TWPA pump.
  - Comprised of a signal generator and attenuator.
- **My task**: Find this specific driving signal.

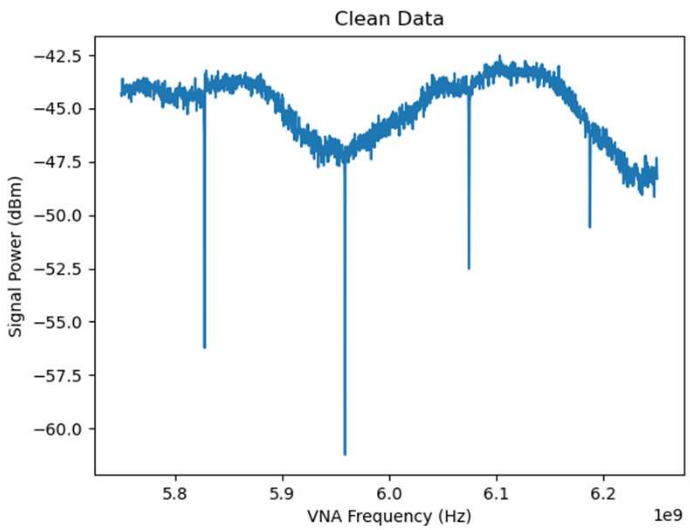


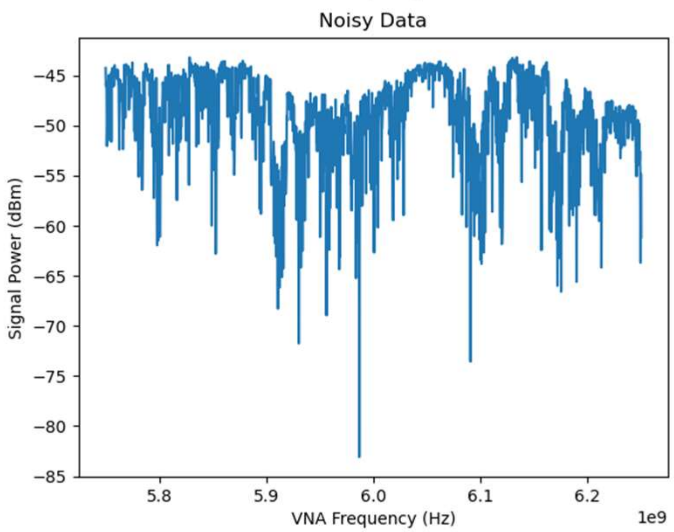
Circuit representation of the Travelling Wave Parametric Amplifier (TWPA)(Macklin *et al.*, Science (2015)).



Vector Network Analyzer (VNA) & Variable Attenuator
Charge bias
Q4 Q3
Q2 Q1
Input
Unused
Signal Generator & Attenuator
TWPA pump
Warm Amp & VNA
Output
Feedthrough 300 K
70 K
4 K
Still plate 1 K
Cold plate 100 mK
Mixing chamber upper
Mixing chamber lower
1
2
3
4
7
5
8
9
20 dB
EF
HEMT
Qubit package
TWPA
Combine & Amplify

Noise Within the System





- Significant change in noise present in our signals.
  - Caused by vibrations of the fridge.
- Random.
- Frequent.
- Dominates signals where it appears.
- **Task**: Develop a noise detecting/handling procedure which can clean data collection.
  - Presently, noise issue is resolved, but procedure can still be handy in the future.

New Code

Five new programs created:

- Signal generator control code
  - Grants control of signal generator
- TWPA Pump code
  - Combines signal generator and attenuator
- TWPA Pump Sweep code
  - 1D and 2D Sweeps of Frequency and Power
- Noise Detector code
  - Indicates if noise is present
- Analysis/Plotting code
  - Calculates gain and SNR and plots on 2D color graph

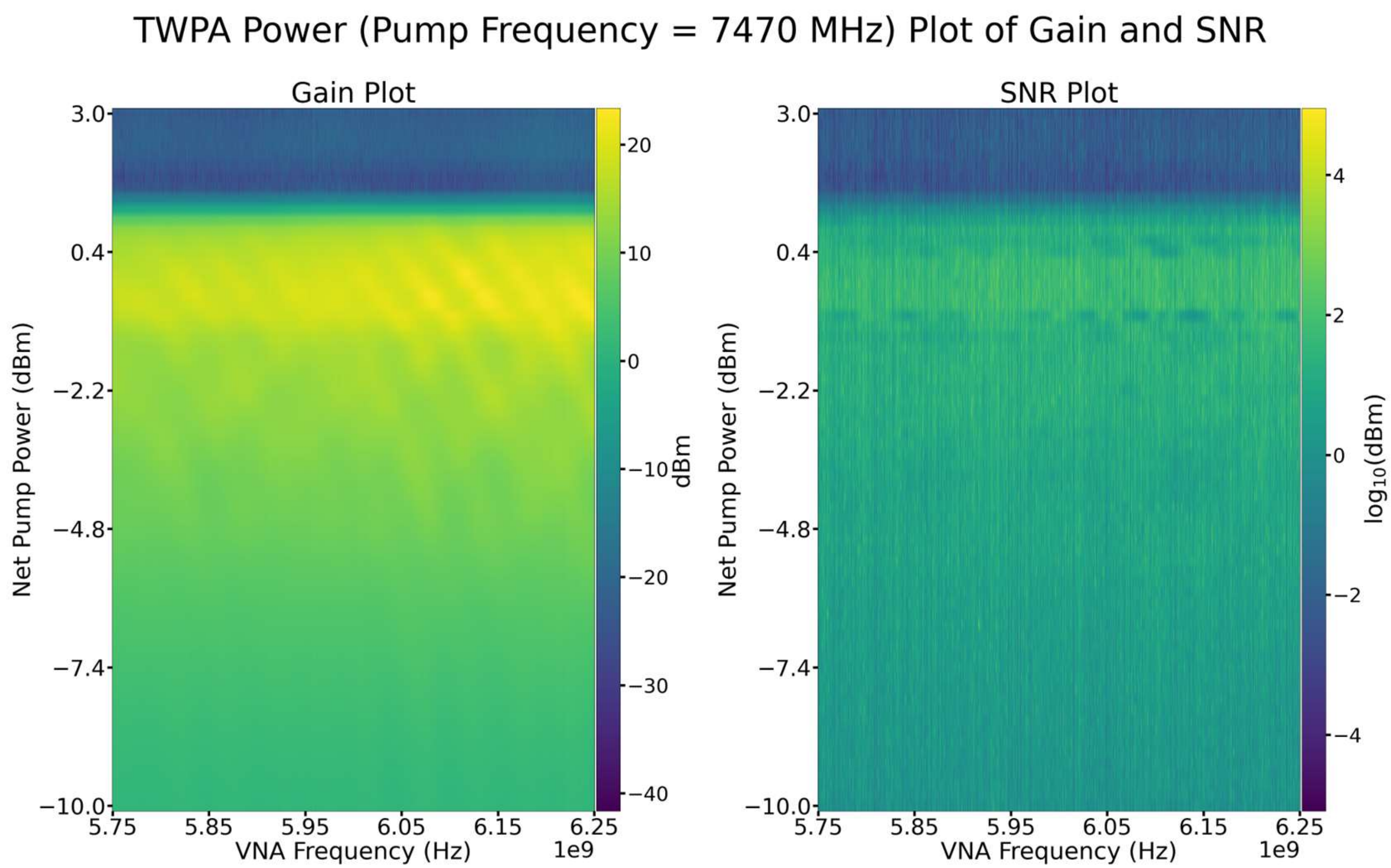
$$Gain = Amp(TWPA_{on}) - Amp(TWPA_{off})$$

$$SNR = \frac{Var(TWPA_{off})}{Var(TWPA_{on})}$$

Optimizing the TWPA

- Objective: Find pump parameters that maximize the gain and SNR.
- First step, narrow the search window with 1D sweeps.
  - This saves a lot of time and avoids accidentally damaging the TWPA.
- Next step, perform a 2D sweep of frequency and power in new search window.
  - This step will reveal the optimal TWPA pump configuration.

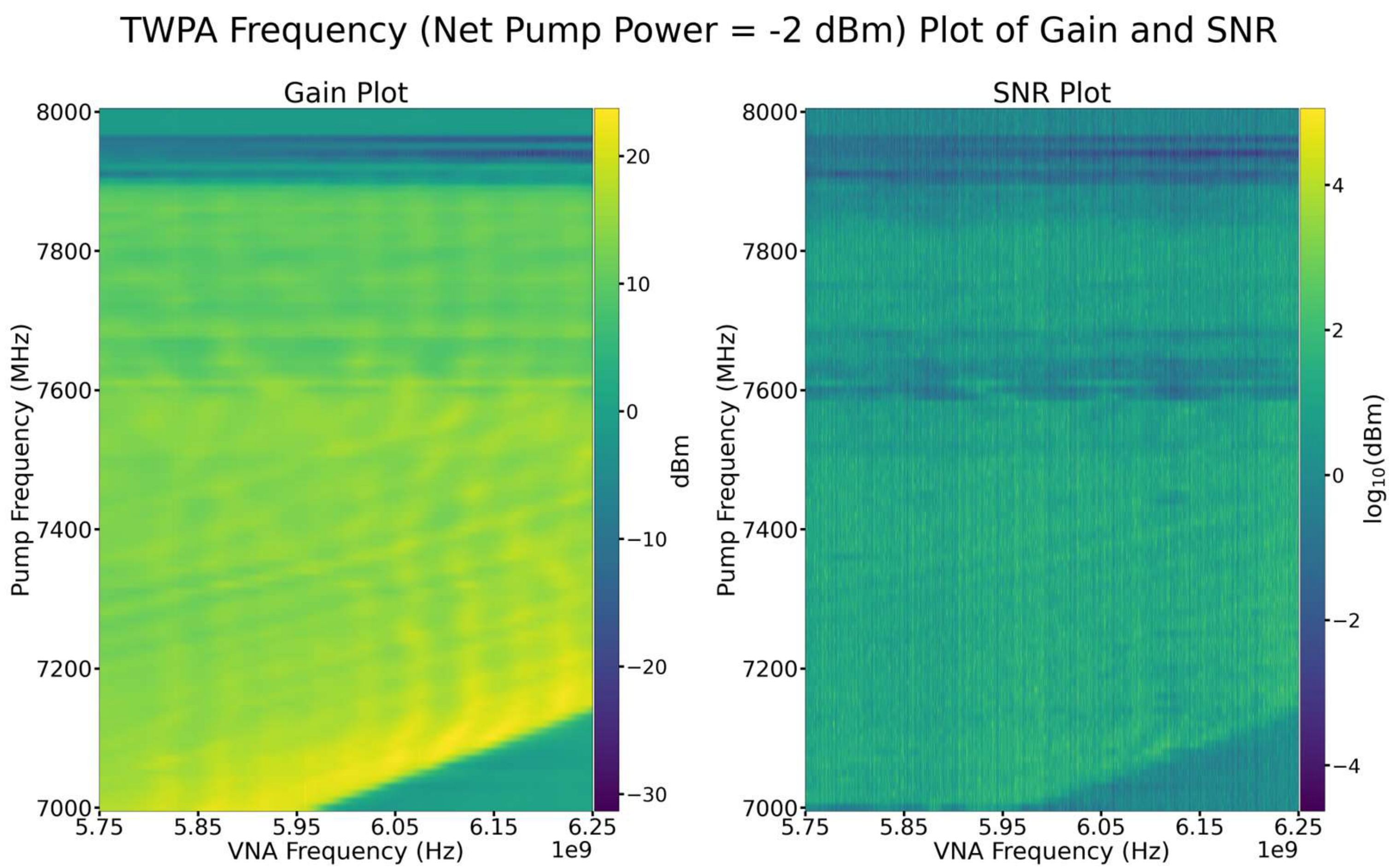
1D Power Sweep



1D pump power plots of gain and SNR.

Drop off clearly visible, don't go further than 1 or less than -10 net dBm.

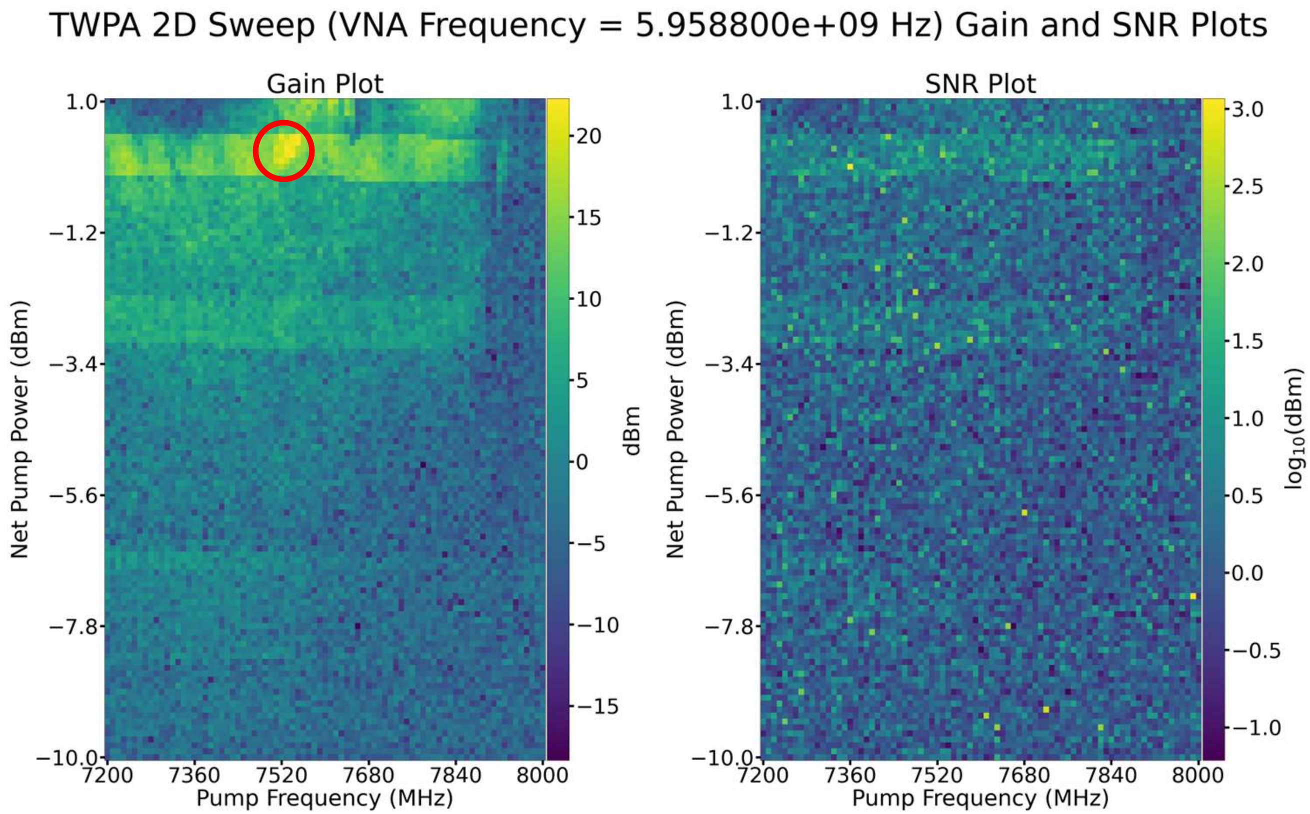
1D Frequency Sweep



1D pump frequency plots of gain and SNR.

Triangular feature is not optimal, don't go below 7200 or above 8000 MHz.

Results/Analysis of TWPA Optimization



- Performing a 2D scan of the TWPA pump produced the following plot.
- The optimal parameters for the TWPA is located where the gain and SNR are consistently the highest.
  - Small fluctuations in the TWPA pump should not drastically change TWPA performance.

Discussion/Conclusion

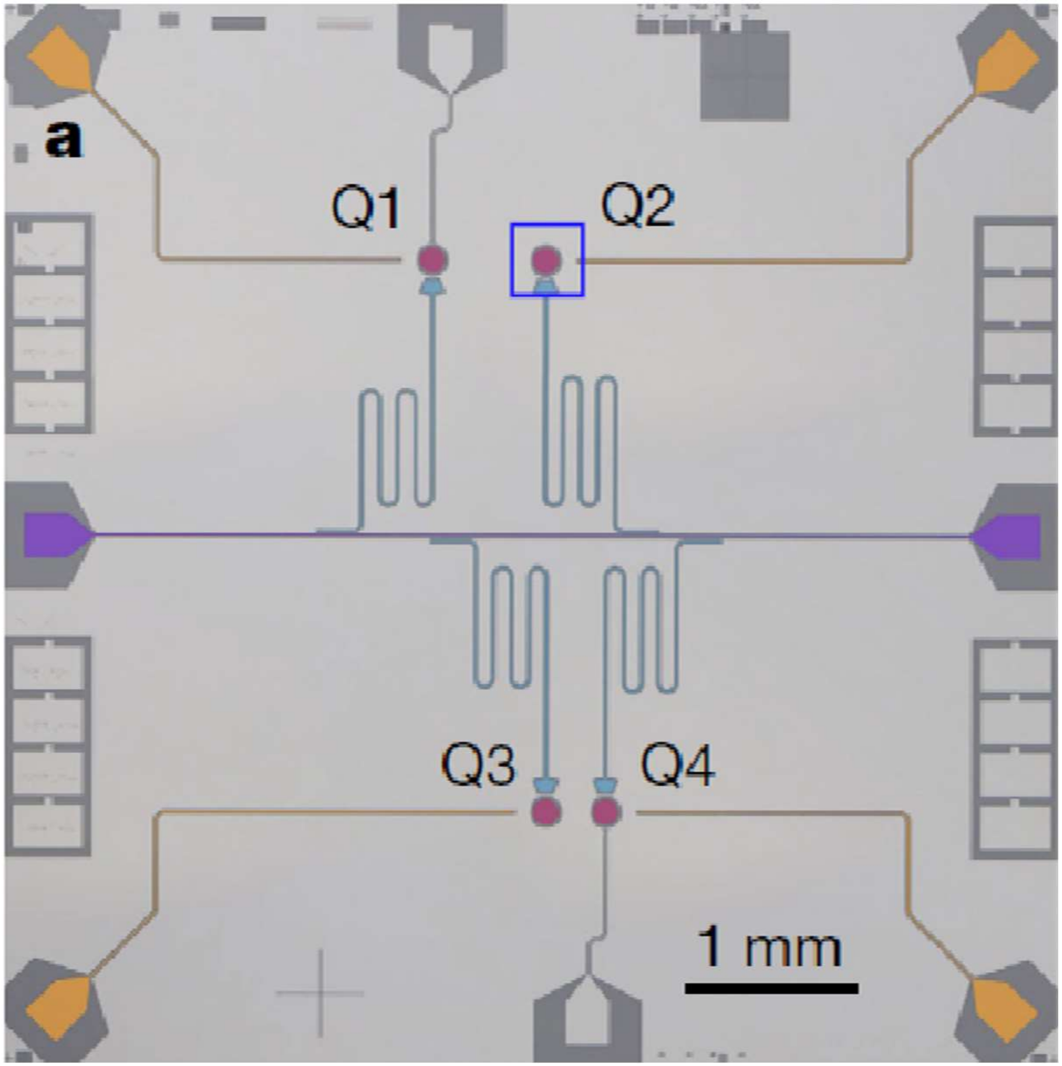
- Knowing where the optimal performance point of the TWPA is, we can now:
  - Provide optimal amplification to the qubit readout signal.
  - Create a clean signal with an optimal SNR.
- We can now use the TWPA to perform qubit measurements/collect data.
- The code written is importable to other programs in the future.
  - Enables noise detection
  - Control of the new signal generator and TWPA pump

Questions?

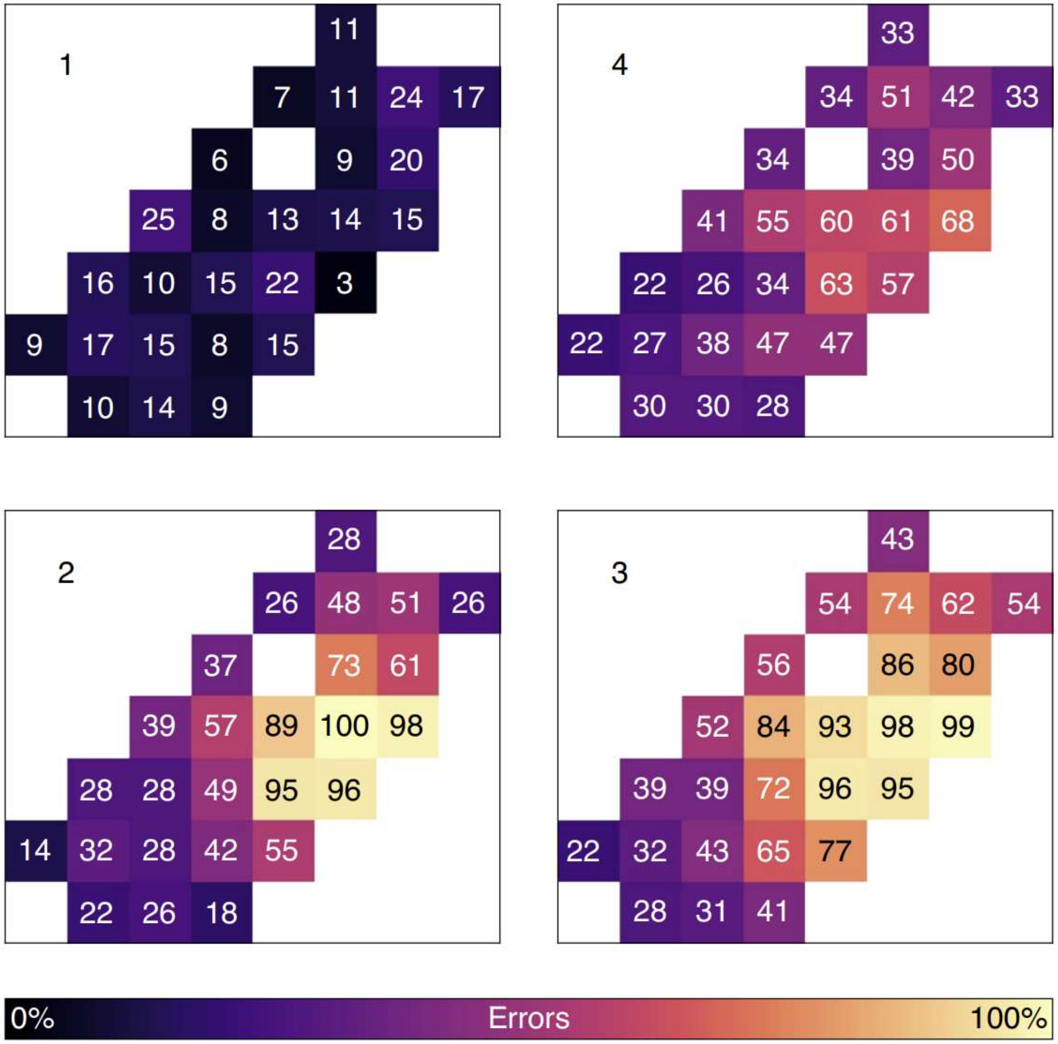

HOW'S YOUR
UANTUM COMPUTER
ROTOTYPE COMING
ALONG?
GREAT!
Dilbert.com
DilbertCartoonist@gmail.com
THE PROJECT EXISTS
IN A SIMULTANEOUS
STATE OF BEING BOTH
TOTALLY SUCCESSFUL
AND NOT EVEN
STARTED.
© 2012 Scott Adams, Inc.
CAN I
OBSERVE
IT?
THAT'S
A TRICKY
QUESTION.

Partnerships

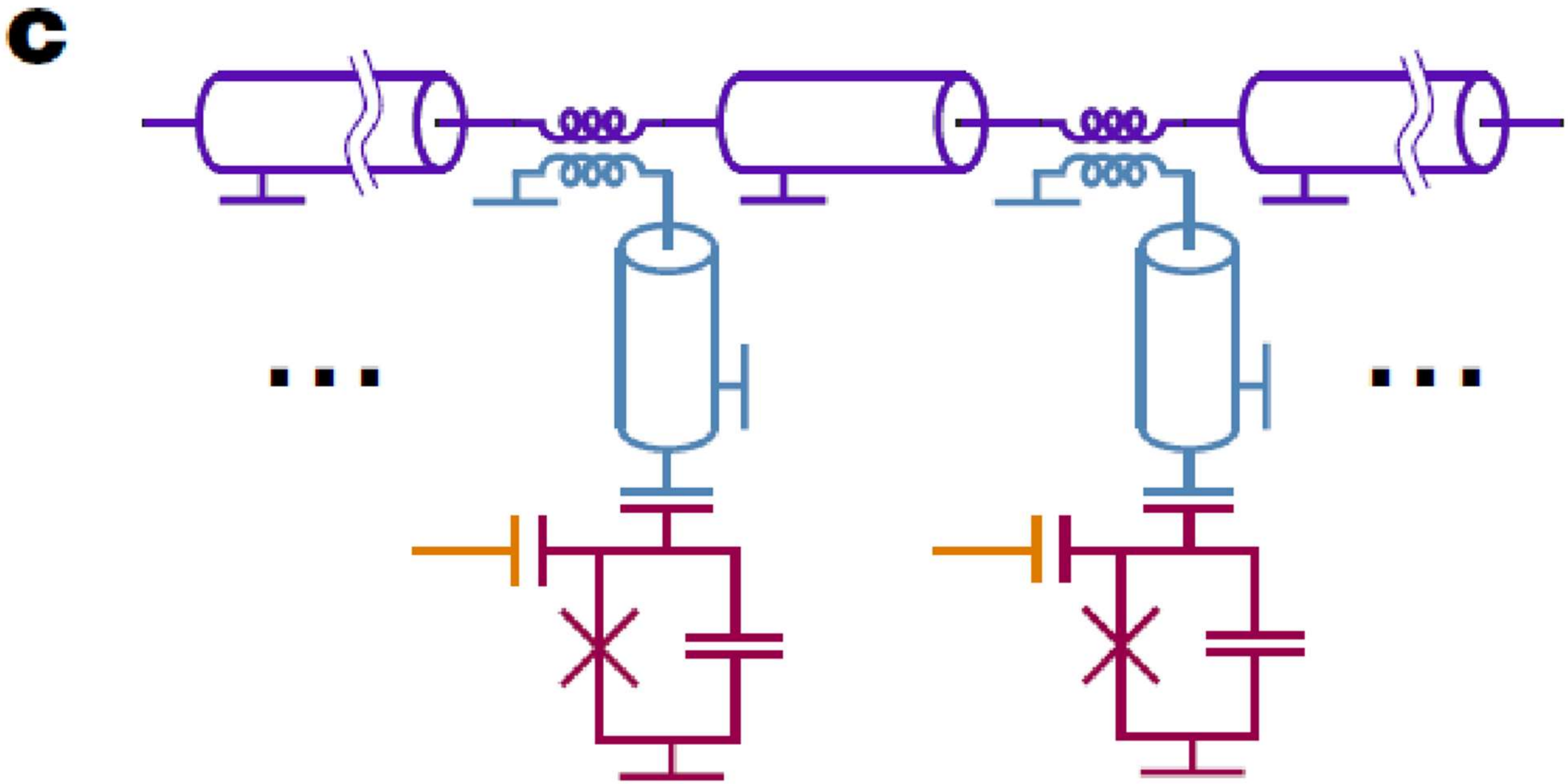
Multi-Qubit circuit layout (Wilen *et al.*, 2021)



Spatial Correlation (McEwen *et al.*, Nature (2022))



Circuit Representation of two Qubits (Wilen *et al.,* Nature (2021))



dBm formula and Jaynes-Cummings Hamiltonian (Naghiloo 2019)

$$x = 10 \log_{10} \frac{P}{1\,\mathrm{mW}}$$

$$H_{\mathrm{JC}} = \omega_c(\hat{a}^\dagger \hat{a} + \frac{1}{2}) - \frac{1}{2}\omega_q \sigma_z - g(\hat{a}^\dagger \sigma_- + \hat{a}\sigma_+)$$