Learning-Based RF Channel Characterization with Crosstalk Modeling for Optimal Transmon Qubit Control

ECSE 6560 Modern Communication Systems

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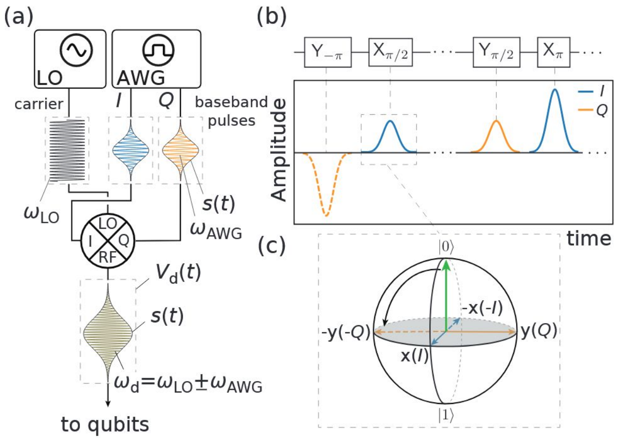
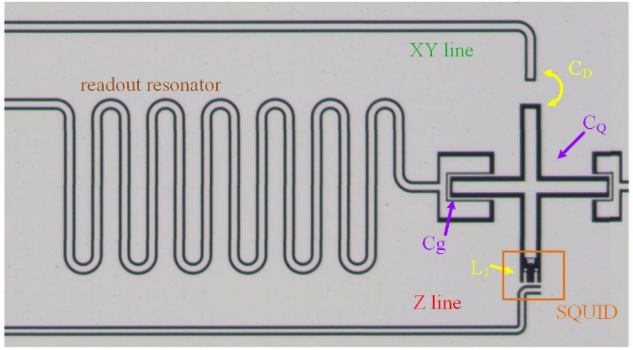
Background: RF Challenge in Quantum Computing

RF pulses drive quantum state

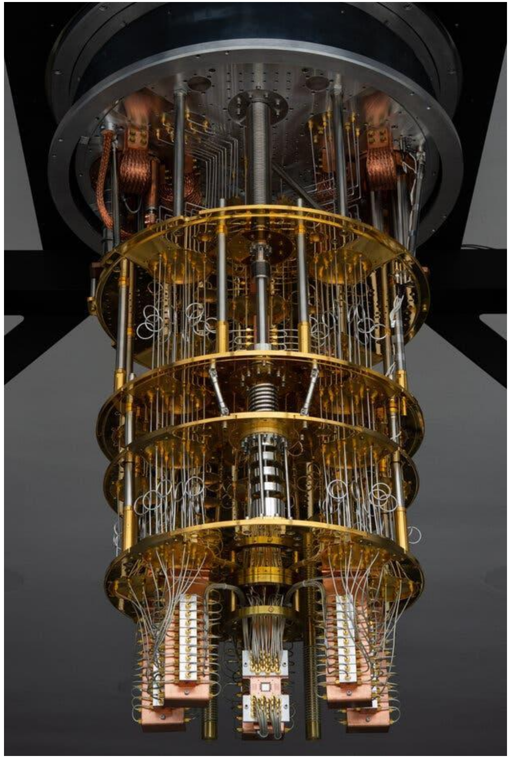
Coax from RT to Cryo stages

Distortion + Crosstalk: requires calibration





(b)



Motivation: The channels aren’t perfect. Go faster?

Impedance mismatch + Qubit Channel Crosstalk -> Calibration… But

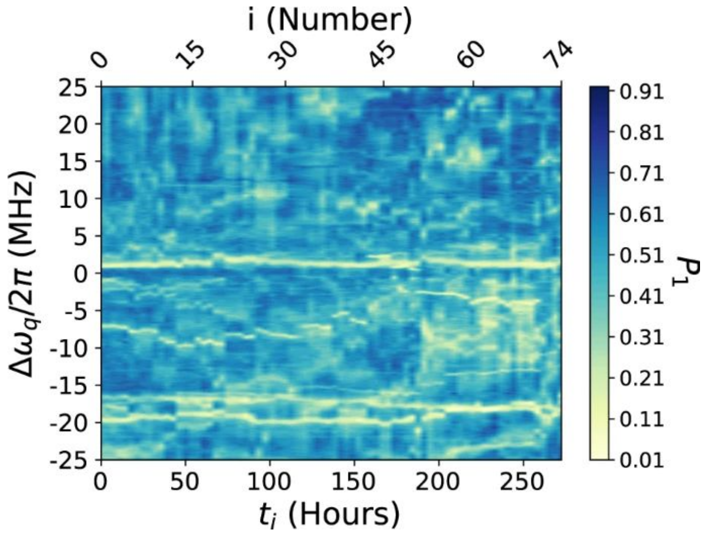
1. One-time calibration isn’t enough

    Environment sensitive; drifting over time

    Need frequent recalibration for small drift

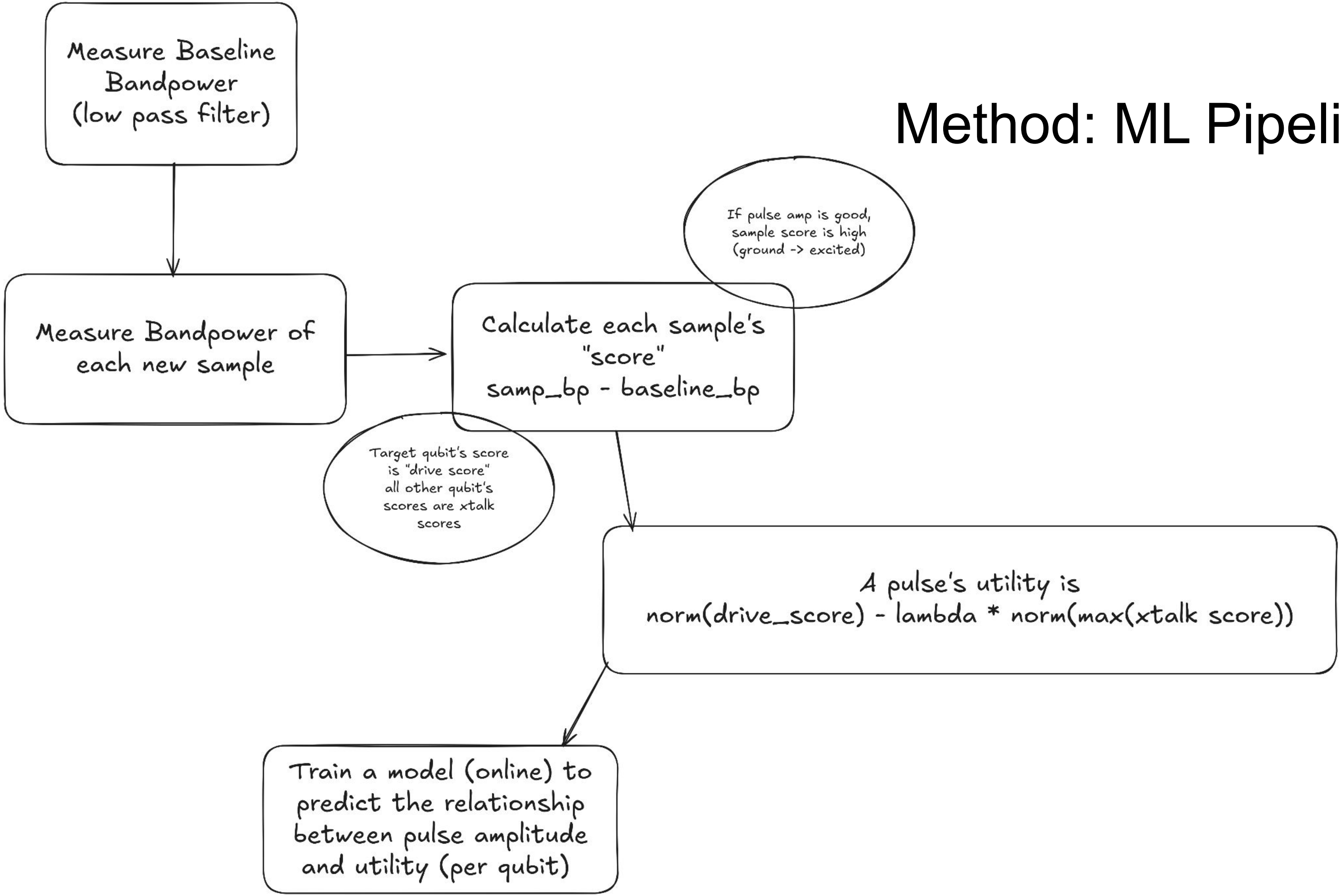
2. Two Q-gates: Pairwise calibration is **slow** on 100+ Qubit System

3. Changing one parameter affects others



Can a ML model tweak this mess as an ensemble?

Method: ML Pipeline



Dataset Collection: Sampled from Real Device on Cloud

Transmit known waveform on drive qubits

Measure response on other qubits

Access low-level IQ Samples from ADC

Sweep parameters

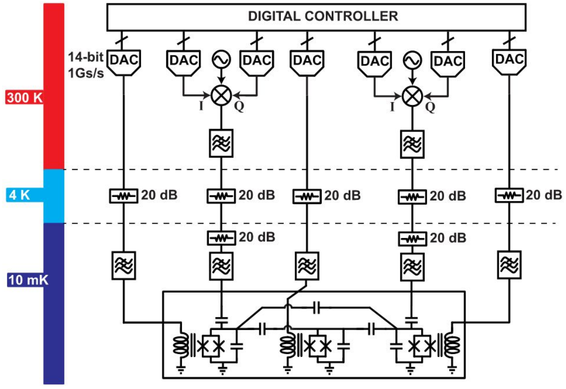
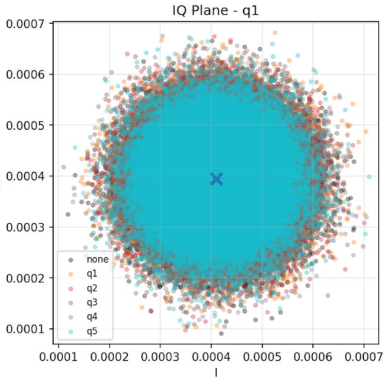
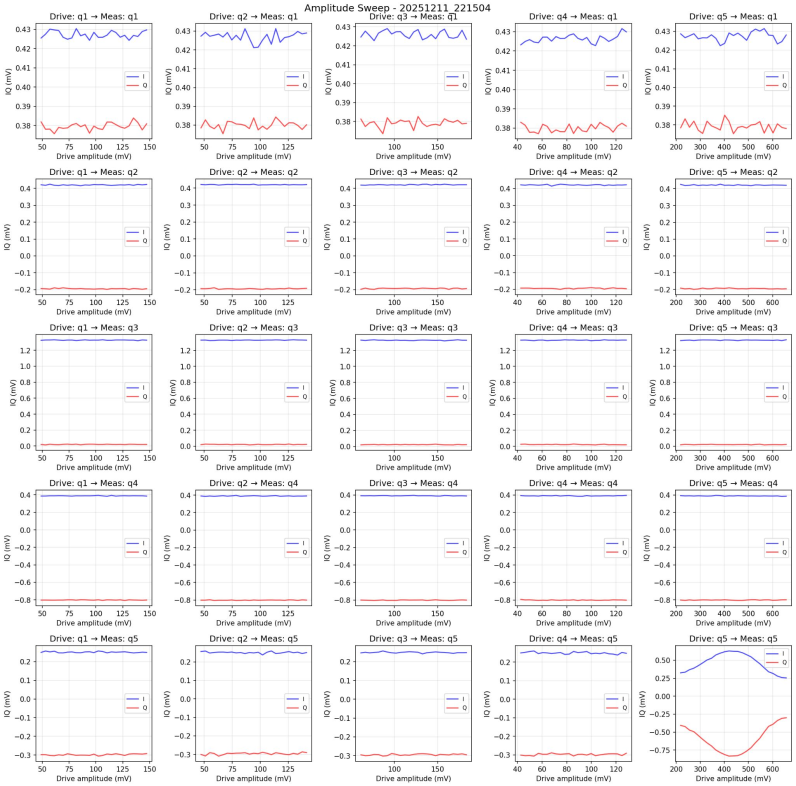


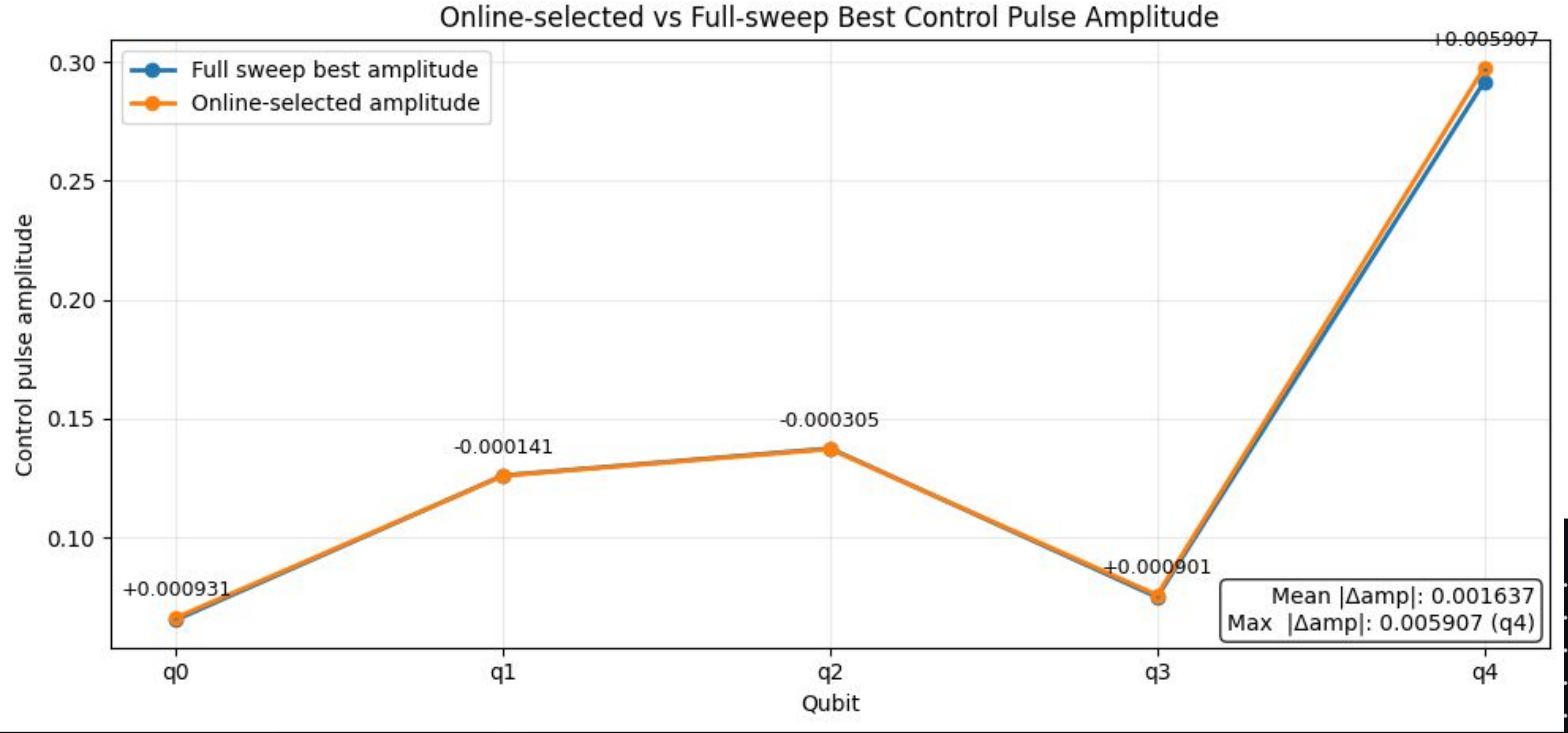
FIGURE 12. Simplified control hardware for a two-qubit transmon-based quantum processor with tunable coupler.





Evaluation: Validate using backtesting

1
2
3

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q0:                                                   .905
q1:                                                   .131
q2:                                                   .283
q3:                                                   .553
q4:                                                   .728
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Contribution, Limitations, Future Work

First work to calibrate qubits as an ensemble

We demonstrated amplitude learning only at this point

- Phase also matters

Next step:

1. Consider phase in our model as well
2. More complicated drive waveform
3. RL for control loop decisions
    a. When to take baseline
    b. When to explore new amplitudes

Reference

J. C. Bardin, D. H. Slichter, and D. J. Reilly, “Microwaves in Quantum Computing,” *IEEE Journal of Microwaves*, vol. 1, no. 1, pp. 403–427, Jan. 2021, doi: 10.1109/JMW.2020.3034071.

P. Krantz, M. Kjaergaard, F. Yan, T. P. Orlando, S. Gustavsson, and W. D. Oliver, “A Quantum Engineer’s Guide to Superconducting Qubits,” *Applied Physics Reviews*, vol. 6, no. 2, p. 021318, Jun. 2019, doi: 10.1063/1.5089550.

E. Chae, J. Choi, and J. Kim, “An elementary review on basic principles and developments of qubits for quantum computing,” *Nano Convergence*, vol. 11, no. 1, p. 11, Mar. 2024, doi: 10.1186/s40580-024-00418-5.