# Benchmarking noise extrapolation on a quantum chip with OpenPulse


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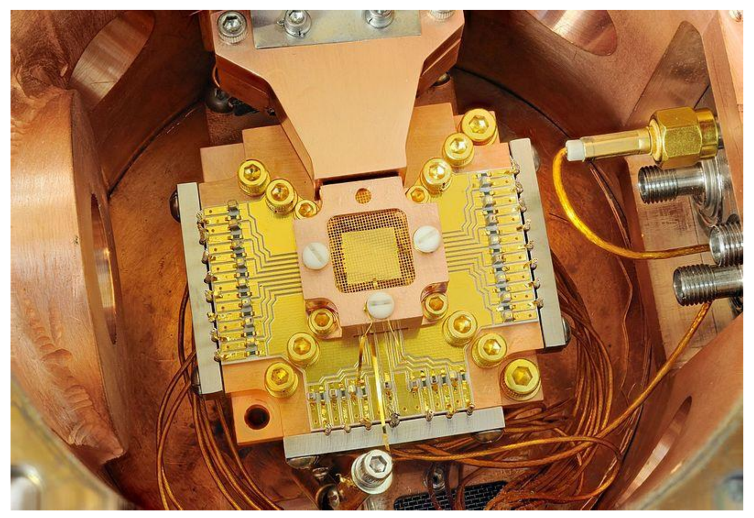
## Abstract

In the Noisy Intermediate-Scale Quantum (NISQ) era we are currently in, computations are often plagued by errors such as decoherence and cross talk. Such errors limit the size of problems we can accurately run on current devices. In this work, we characterize single qubit error rates on IBM's *Johannesburg* superconducting quantum hardware by employing a benchmark (coined Benewop) which analyzes errors accumulated after extended Rabi oscillations. However, we make the important distinction from previous works that we run the benchmark on many qubits in order to characterize the entire chip. Using the results from such a characterization allows experiment designers to choose the set of qubits which maximizes the accuracy of the program being run.

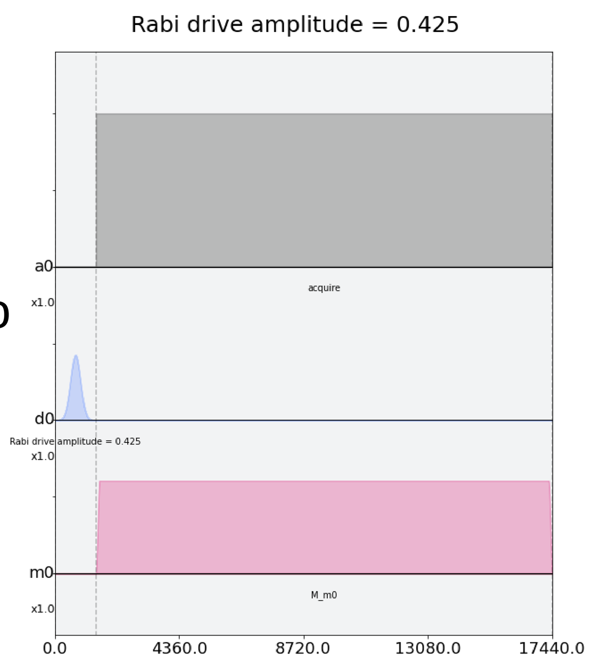

## Background

Physical quantum gates are often abstracted away using libraries such as IBM's Qiskit. In reality, the superconducting qubits are controlled by specific microwave pulses that change the qubits based on the gate being applied to it. An important area of research is improving the quality of these pulses, in turn improving the gates as well as the algorithm being run. An additional research avenue is understanding where noise originates and in what amounts, giving direction to noise mitigation efforts.

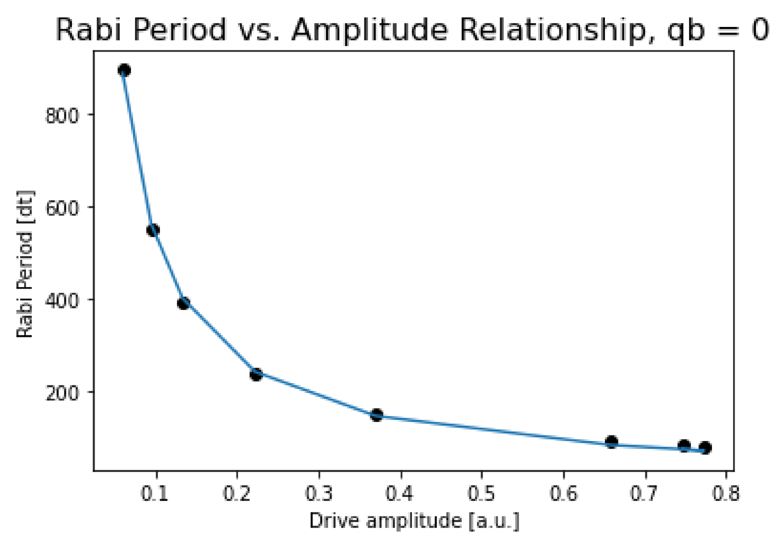


## Methods

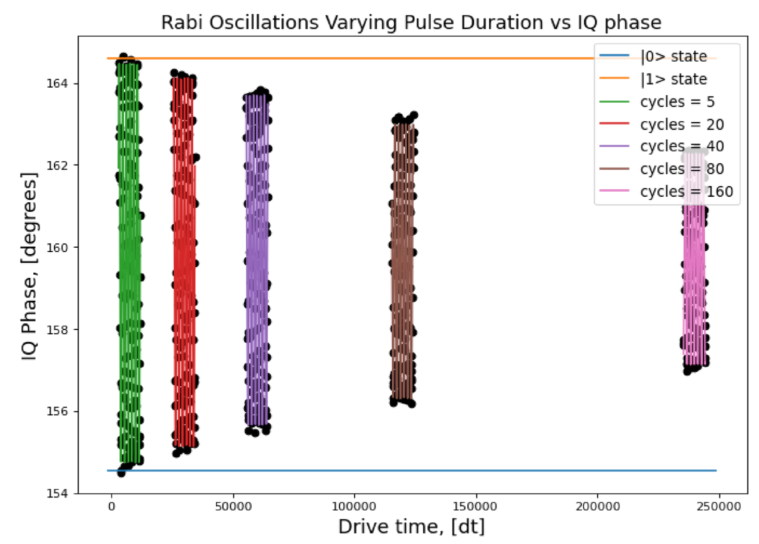
- *Paris* and *Johannesburg* IBMQ quantum hardware have OpenPulse control programmed using the Qiskit Terra package
- Specify microwave pulse parameters such as amplitude, duration, and width, to drive qubits
- Gaussian and square gaussian pulses act like X gates of variable duration
- Find period versus amplitude relationship
- Run Rabi oscillations at a variety of periods for long drive times
- Fit an exponential to the decaying amplitudes



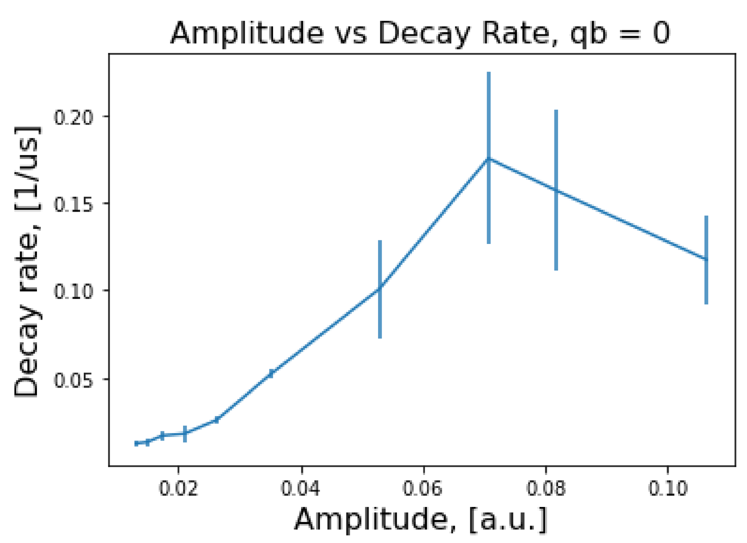

## Results




- Rabi period and amplitude relationship modelled by $\tau(\Gamma) = a\Gamma^b$ where b = -1 inverse power law
- Can be used to create Rabi oscillations of any period




- Rabi amplitudes decay due to decoherence of the qubits
- Fit to an exponential to calculate decay parameter




- Amplitude dependent component of the relaxation rate defined by

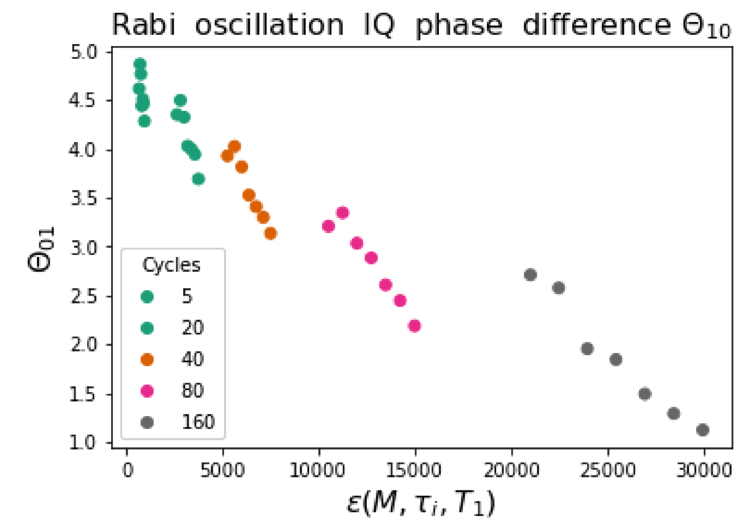
$$\gamma(\Gamma) = \widetilde{\gamma}(\Gamma) - 1/T_1$$

- Line is well fit by linear or exponential fit until amplitude of ~0.07
- Cause for decreasing decay rate reason for investigation

- Generalized, drive dependent, noise expansion parameter

$$\epsilon(M, \tau_i(\Gamma), T_1) = \int_0^{M\tau_i} dt \widetilde{\gamma}(T_1, \tau_i(\Gamma)) = M\tau_i * (1/T_1 + \gamma(\Gamma))$$

- Extrapolate to 0 to determine how to rescale results
- Slope of groupings is of interest and does not match previous results




## Conclusions

- Mitigation benchmarking describes the accuracy of qubits by characterizing gate pulses and quantifying the noise model inherent to current era qubits
- Significant differences in scale exist between different quantum backends
- Slope of amplitude vs decay rate and Rabi oscillation IQ phase difference needs more investigation to discover cause

## Future Research

- Running a modified Benewop benchmark with cross resonance pulses
- Make a comprehensive benchmark that is part of a holistic picture when determining error mitigation techniques


## References

- Garmon, J. W. O., R. C. Pooser, and E. F. Dumitrescu. "Benchmarking Noise Extrapolation with the OpenPulse Control Framework." Physical Review A 101.4 (2020): n. pag. Crossref. Web.



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