Q-Ctrl Challenge Summary

When experimenting with the idealized NOT and Hadamard pulses we found that while they behave well with ideal qubits, they do not perform anywhere near as well with simulations of non-ideal, real-world qubits. In order to optimize our pulses for these non-ideal qubits we decided to use robust control schemes. Initially, we tried using the band limited pulse methods with bounded slew rates, considering a Hamiltonian with time dependent alpha 1 and alpha 2 signals, as well as a slow time-varying stochastic dephasing noise. We tested this methodology under various parameters, including segment_count, duration, max_slew_rate, and alpha_max. After running the bounded slew rate optimization, we decided to test the chopped random basis optimization, as it would decrease the search space size. Specifically, we experimented with smoothing via linear filters on control signals and chopped random basis (CRAB) optimization. We found that these both performed well on non-ideal qubits, however we saw consistently better results with CRAB optimization.

In our first optimization trial, we tested non-linear dependence on control pulses, but realized that the signal obtained was widely varying, and did not have a band-limit that would limit signal fluctuations. This is most likely due to a large standard deviation in the results when the sampled qubits is small, and would average out once performed on a large number of qubits. However, aspects of the initial optimization program, such as the dephasing term representing the dephasing noise between the noise Hamiltonian and the control Hamiltonian, were carried to the next iteration optimization.

In the band-limited pulse optimization, the frequency of alpha is bounded by negative and positive alpha_max, acting as a low pass filter to the signal. In terms of the output of the real time signal, the maximum slew rate constraint caps the fluctuations between adjacent segment values. Alpha 1 and alpha 2 are time varying pulses multiplied by the Pauli matrices, sigma x and sigma z. The model also considers the stochastic dephasing noise process from the beta signal.

Applying a filter to the real time-dependent pulse results in a smoother output signal that is less susceptible to fluctuations in a small sample size of qubits. A sinc function filter in the time domain corresponds to a square wave pulse in the frequency domain from Fourier transformations, which essentially imposes a frequency cutoff value in the frequency domain. Since a convolution of two signals in the frequency domain corresponds to a multiplication of their Fourier Transforms in the time domain, we utilize the qctrl.operations.convolve_pwc function to apply the filter. From the filter output, we then discretize the signal using the qctrl.operations.discretize_stf method.

Due to time constraints, we were not able to optimally calibrate the signals. However, if this process was done on real commercial hardware, we would run several calibration tests, such as the Rabi rates calibration over a DC electric signal at various voltages, and measure the rabi rate frequency to determine the optimal parameters such that the dependence is linear. Several other experiments, such as the evolution of populations of qubits as a function of time for known systems, can be used to determine if the pulses are correctly calibrated and at which limits the control pulses result in a large error. Other considerations, such as the detuning frequency of the population of ground states in a quantum system, should also be observed through a Detuning scan and calibrated such that there are minimal excitations when the detuning frequency increases. Signals that are less susceptible to detuning noise will perform better and be more robust in real world environments and applications.

Chopped Random Basis Optimization (CRAB) is a process in which a randomized Fourier basis is to define microwave pulses. For our second optimization trial, we used the optimized control guide to help reduce our error in NOT and H gates. First, we created the Hamiltonian equation using randomized real and imaginary parts and we plotted it for visual purposes. Before we can move on to CRAB, we had to redefine the standard basis to 2x2 matrices. Like before, we won't be using state $|2\ >$ and therefore, not necessary for us to account for the third dimension. Rest of the CRAB optimization didn't need to be altered and the final output of the function "get_optimized_matrix()" is optimization_resuls. To calculate the error between ideal_NOT and realistic_NOT, we went back to our error calculation in smoothing via linear filter and our latest test run shows that error reduced by magnitude of 10.

While we feel that we were able to obtain satisfactory results with our previously described optimizations, we believe we could improve further given more time. As discussed previously, we would more optimally calibrate the signals. Additionally, we would like to experiment with learning control, or closed-loop automated optimization. Our team had some intuition of the physics that allowed us to achieve reasonable results with robust optimization strategies, however we are curious to see how far we could push our fidelity if we allowed the system to make those choices for us.

In conclusion, we believe that we have learned quite a bit about working with and optimizing pulses for non-ideal qubits. We started this challenge with little knowledge of how this technology works and feel that we have achieved satisfactory results, given the amount of time available.