

Measuring the Pulse Duration of an Ultrashort Femtosecond Laser using Intensity Autocorrelation

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Introduction

The goal of this project is to program a delay stage that will be used to measure the pulse duration of an ultrashort femtosecond laser. However, to measure the duration of an event, it is necessary to use another event of the same/smaller duration. Since there is no other feasible event to use in this timescale (quadrillionths of a second, meaning standard sensors alone are incapable), we must use the laser to measure itself, a method known as autocorrelation.

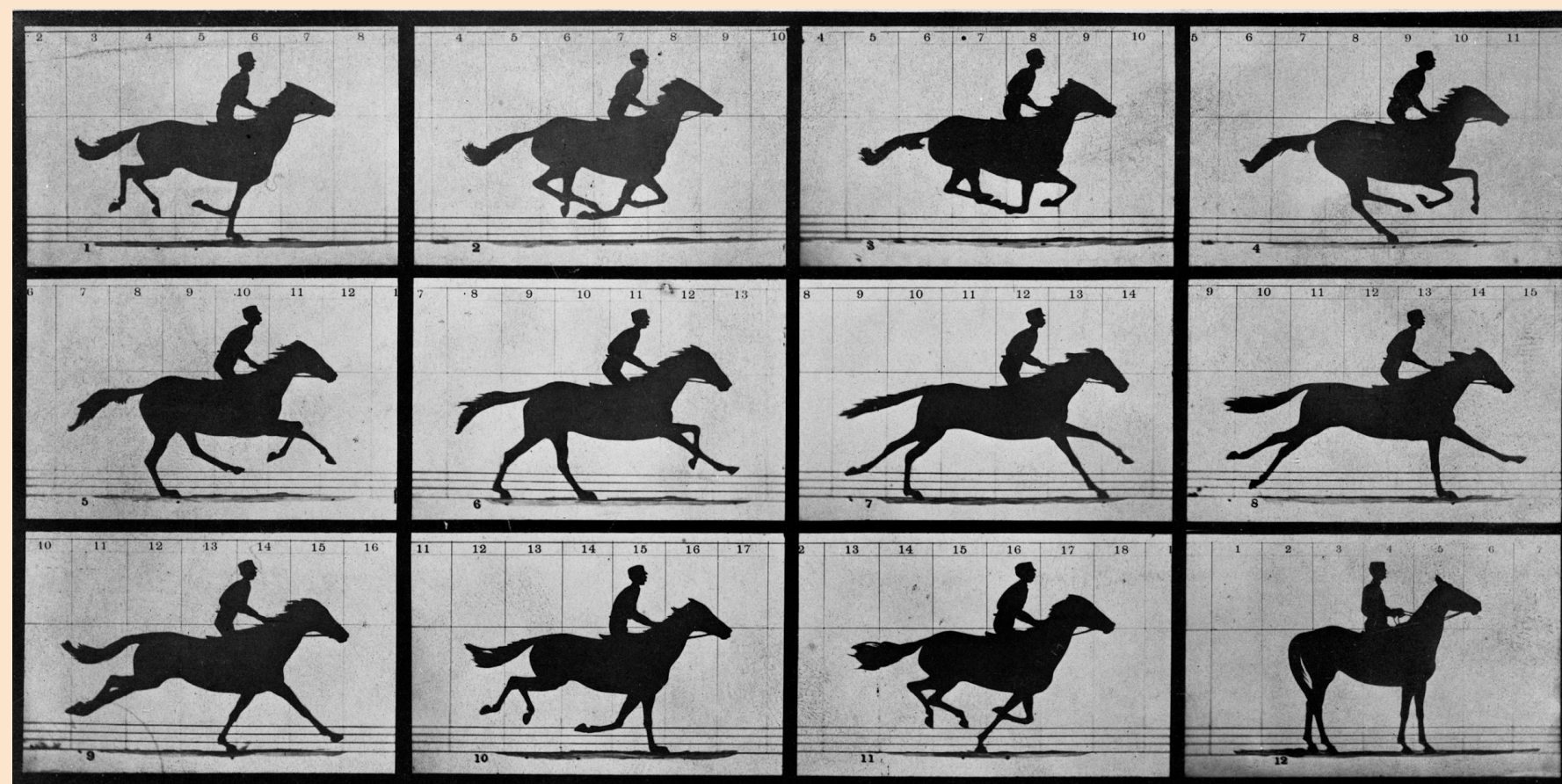


Figure 1: These are the various stages of a horse gait. In this case, the faster event is the flash and shutter speed of the camera recording each frame of the movement.

In particular, we will be working with an intensity autocorrelator. This device measures pulse duration by recording the correlation between time delay and the intensity of the related second-harmonic beam (twice the energy of the original beam). It is important to be able to characterize ultrashort laser pulses, as they are applicable in a wide range of experiments throughout condensed matter physics. For example, they can help determine the atomic properties of materials and discover superconductivity in unconventional media. More importantly, they give researchers the opportunity to investigate ultrafast processes such as electron dynamics, phase changes, chemical reactions, and other short-lived phenomena. Measuring the pulse duration is crucial in making the correct calculations for these processes, confirming the laser's functionality, and opening new avenues for even shorter pulses that can be used to better study events in these timescales.

Background

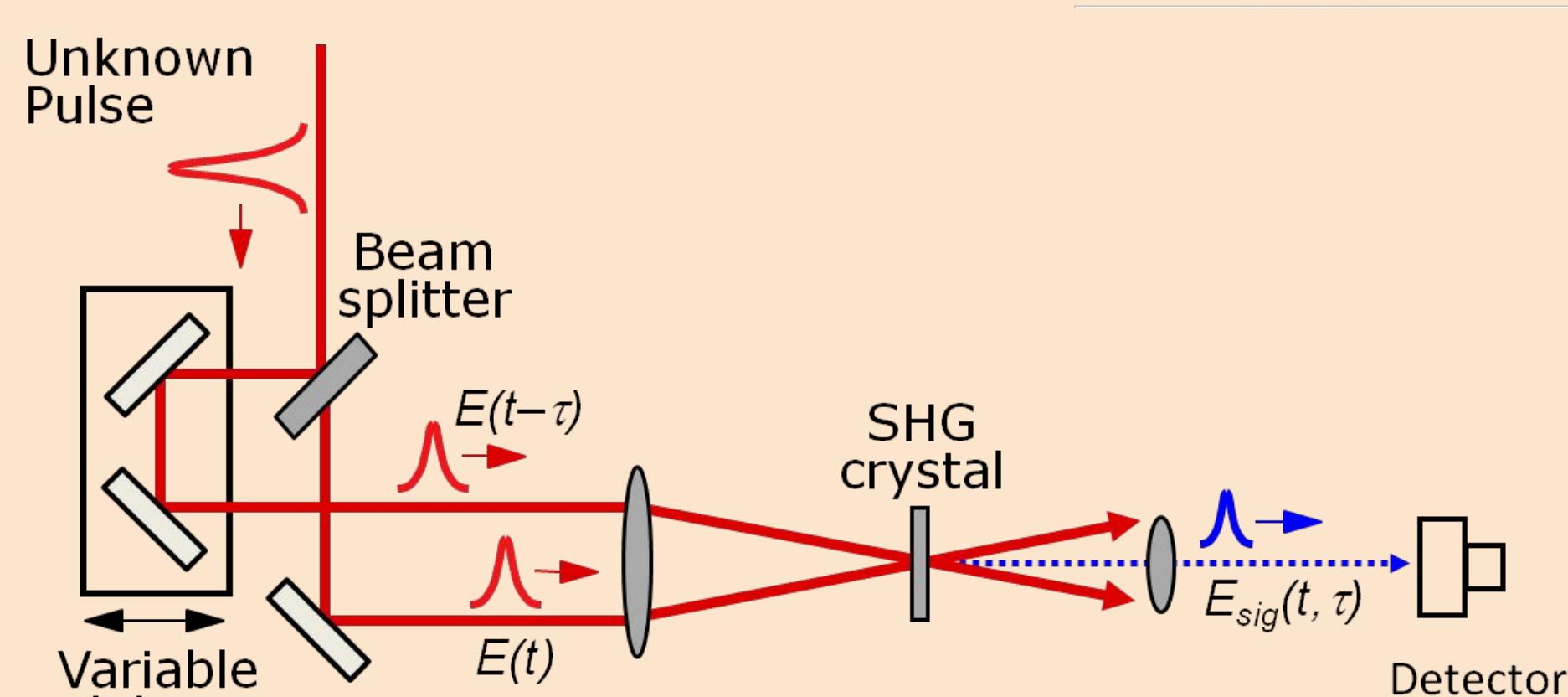


Figure 2: This is an intensity autocorrelator.

In an intensity autocorrelator, the laser first enters a beam splitter, which behaves similarly to a mirror, but instead only reflects half of the light off the diagonal and allows the other half to pass through. The part of the light that is reflected then travels through a delay stage, marked by the black box in the diagram. This can be moved back and forth on the micrometer scale, delaying the beam in time. After both beams pass through a converging lens, they intersect in a SHG crystal, forming a new second-harmonic beam (marked in blue on the diagram). However, these two beams will intersect at different temporal phases based on how much delay is given to the reflected beam, causing the second-harmonic intensity to vary.

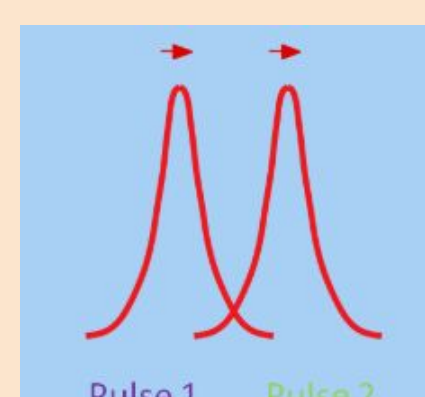


Figure 3a: Pulse 1 arrives after Pulse 2.

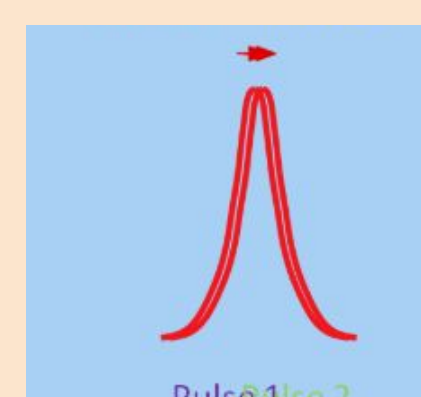


Figure 3b: Pulse 1 and Pulse 2 arrive together.

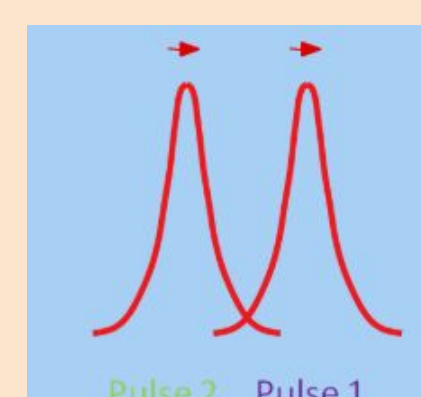


Figure 3c: Pulse 1 arrives before Pulse 2.

In Figure 3a and Figure 3c, the pulses intersect much further out of phase than in Figure 3b. This causes the measured intensity of the second-harmonic beam to diminish. When the beams intersect like in Figure 3b, however, the measured intensity is maximized. By delaying one beam in time and recording the intensity, different data points are collected. When each intensity measurement is plotted against its respective time delay on a graph, the autocorrelation signal can be obtained. The pulse duration is measured by taking the FWHM (full-width at half-maximum) of the resulting graph.

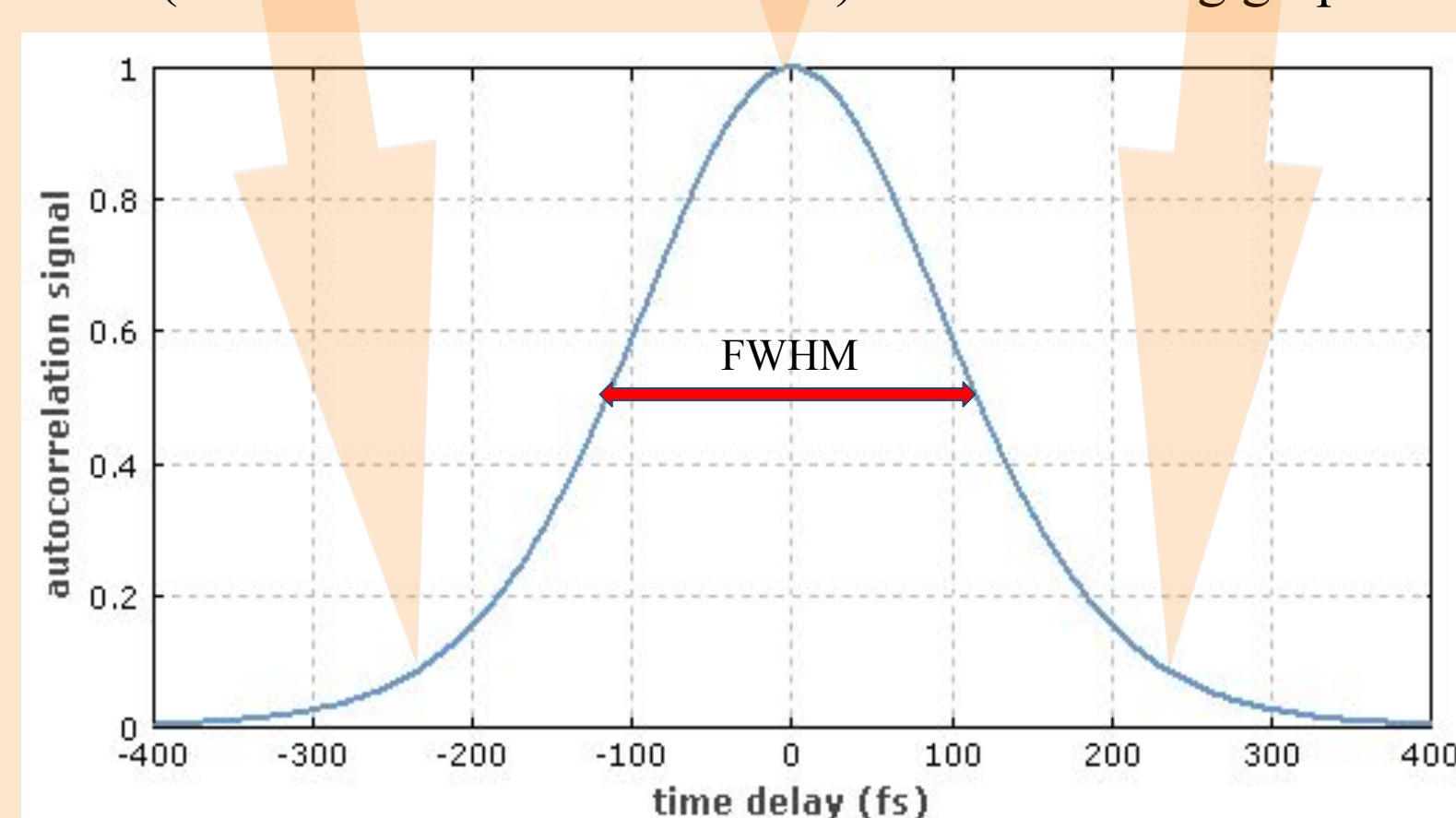


Figure 4: This is an example autocorrelation signal. The FWHM is shown in red.

Methods

Multiple steps and revisions were taken to successfully program the delay stage. In this project, we used LabVIEW 2019, a Newport SMC100CC Motion Controller, and a Newport MFA-CC Motorized Linear Stage. First, we connected the hardware components as shown.

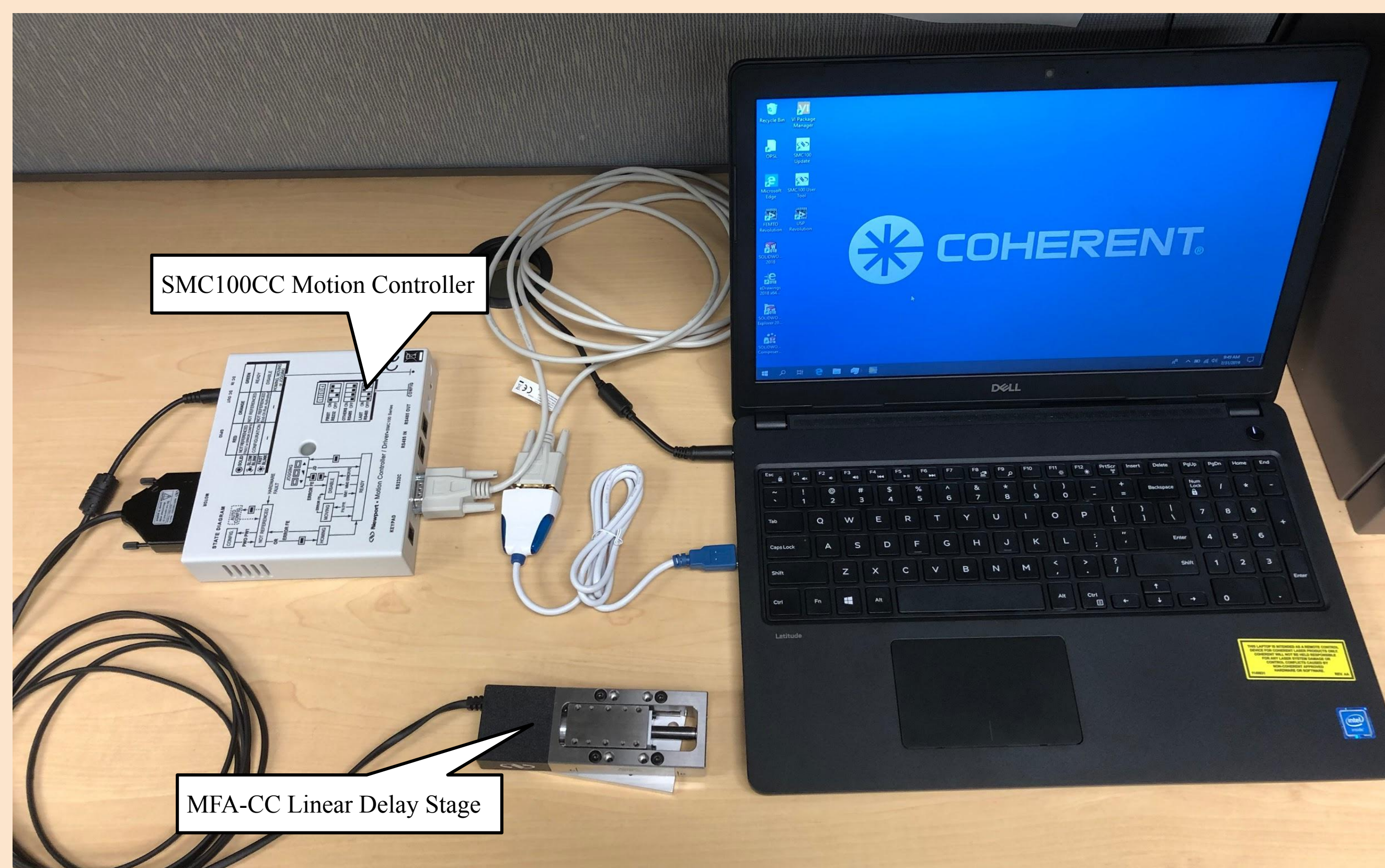


Figure 5: This is the hardware setup. The delay stage moves along the axel inside.

Next, we used Measurement and Automation Explorer (MAX) and the SMC100CC Motion Controller App to ensure the computer recognized the delay stage and that it was able to move.

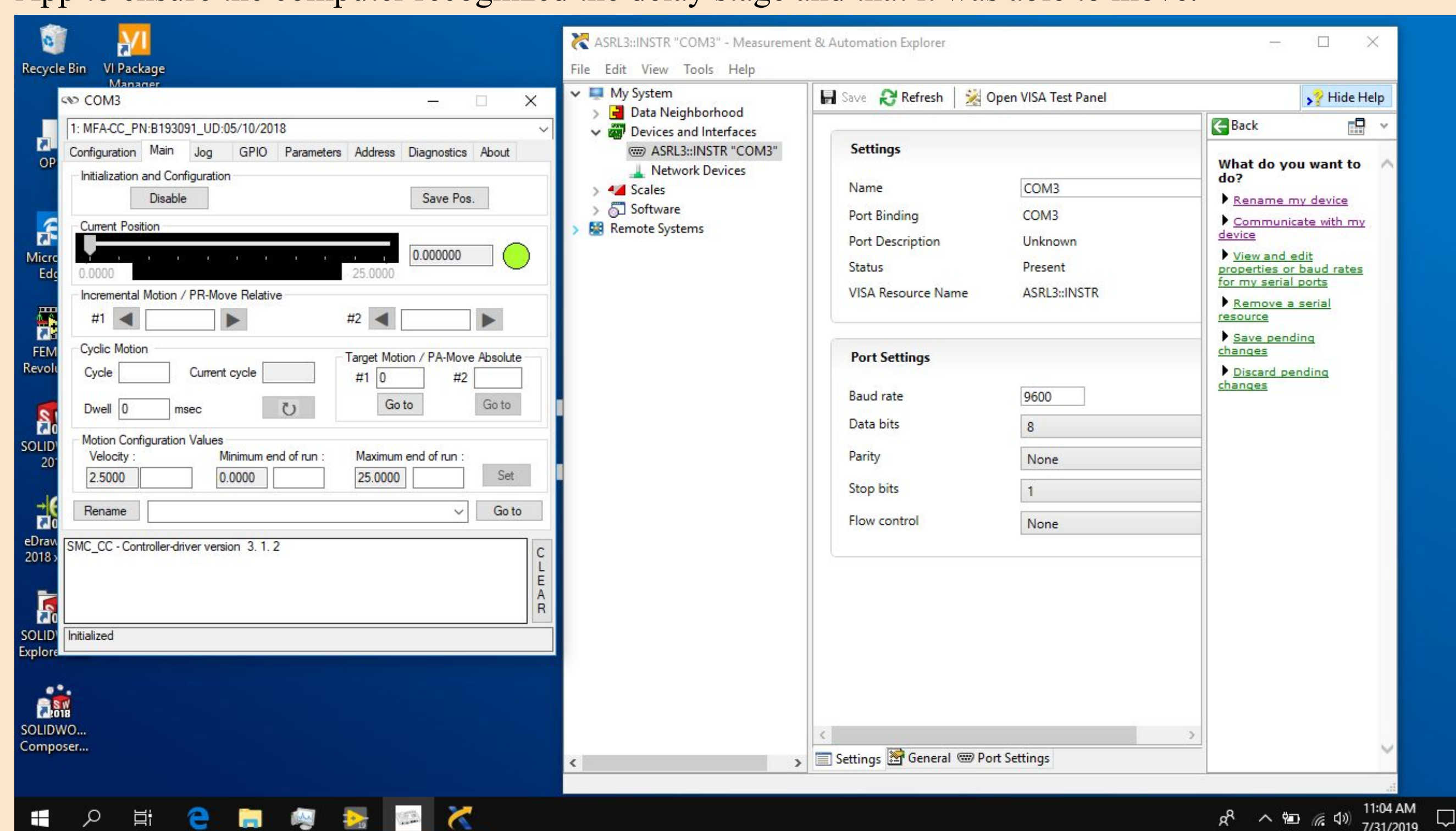


Figure 6: These are the SMC100CC Motion Controller App (left) and MAX (right).

Finally, using the provided SMC100CC drivers, we constructed a basic movement program in LabVIEW (top block diagram). We continued to test and optimize our program to provide the most versatile interface for the user (bottom block diagram). The final version includes many more features and directly connects the program to our goal, which is to measure the pulse duration (see results).

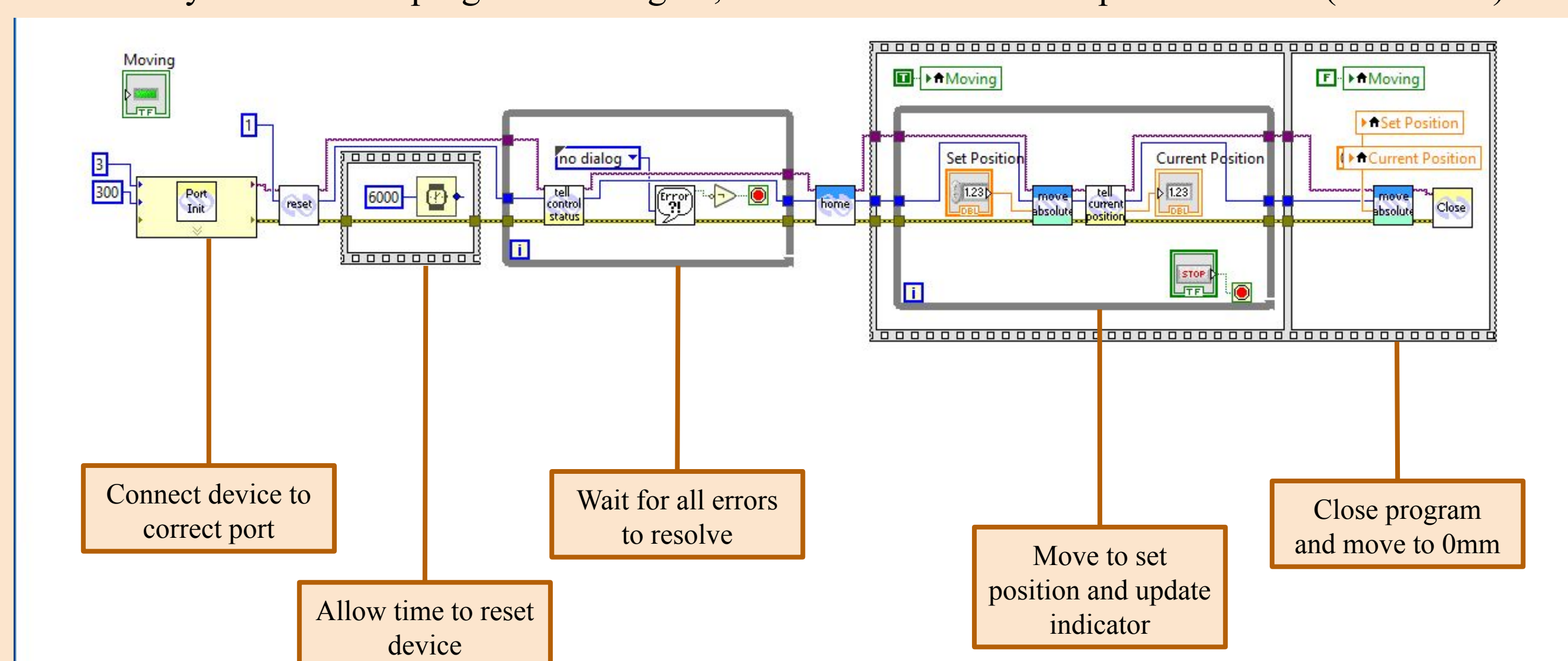


Figure 7a: This is the first version of the block diagram.

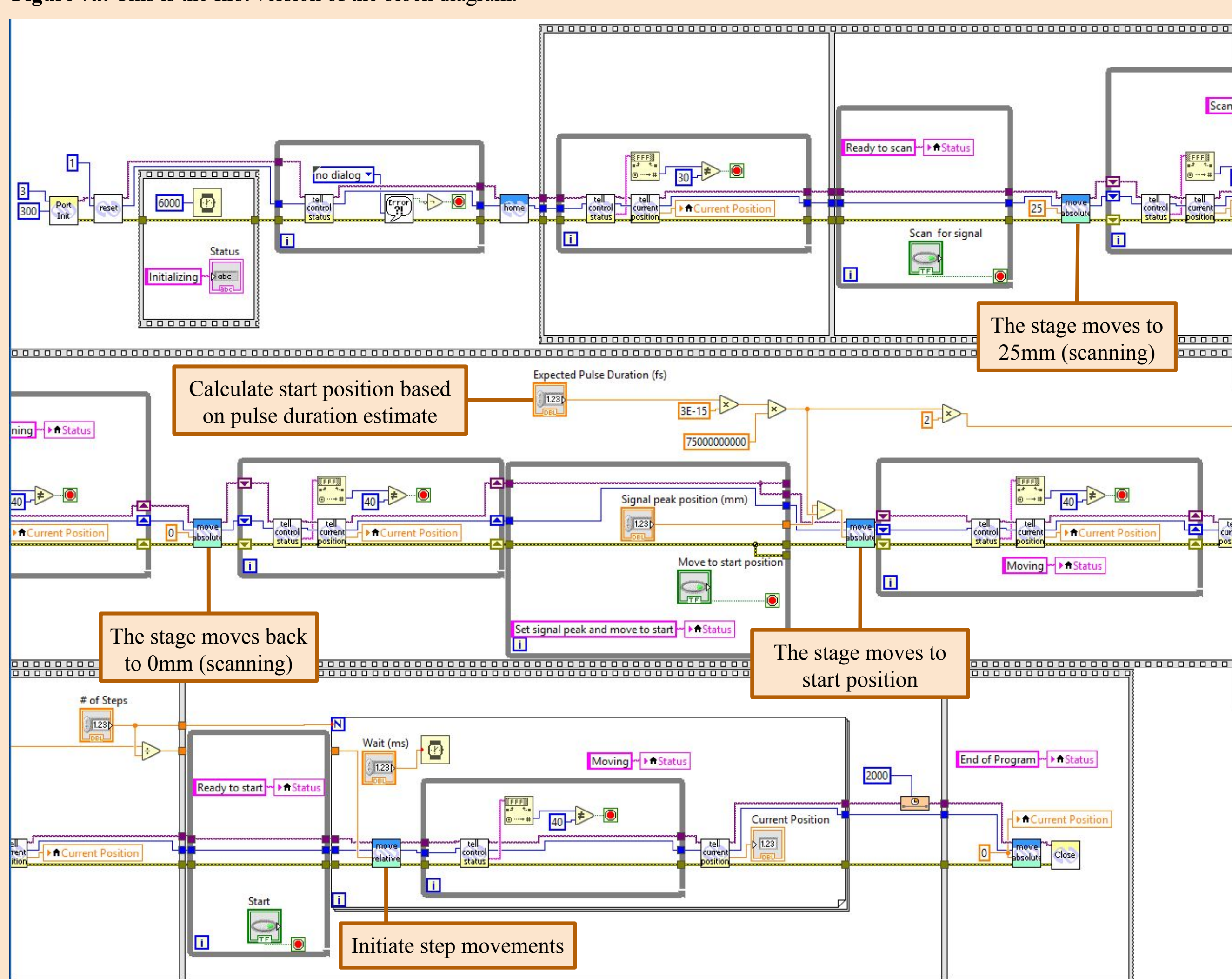


Figure 7b: This is the final version of the block diagram (split in 3 parts to accommodate space).

Results

The block diagram is the backend of the code. When the user runs the program, they will see a much more intuitive front panel that they can interact with.

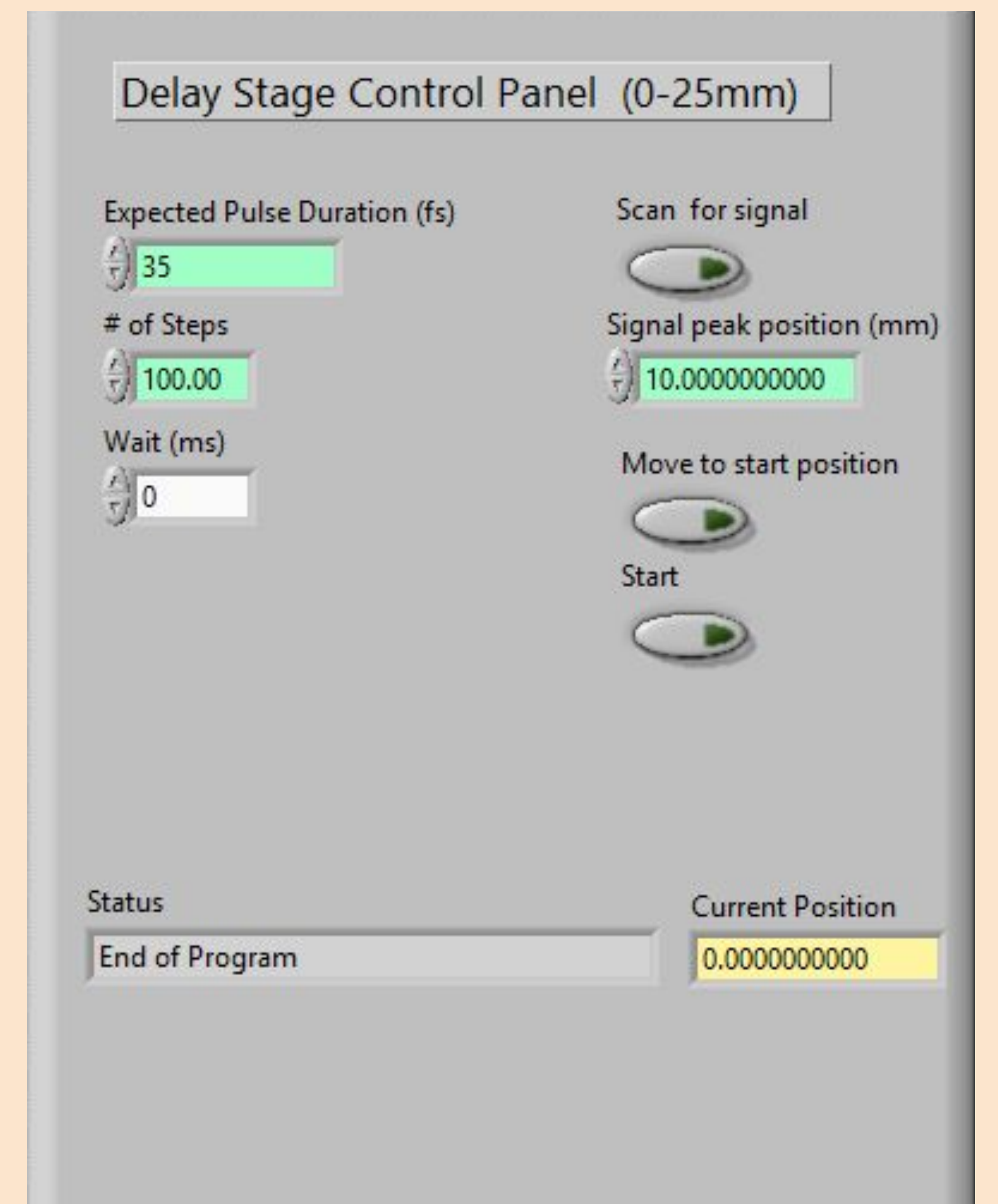


Figure 8: This is the front panel of the program.

Here, the user inputs the expected pulse duration to check if it matches what is actually measured. The number of steps is equivalent to the number of data points that will be used to create the autocorrelation signal. At each step, the stage will pause for its designated wait time which will allow the intensity of the second-harmonic beam to be measured. After the user sets these three values (left side), the "Scan for signal" button will move the stage throughout the 0-25mm range, which allows the user to see at what position the signal spikes. The user then inputs this signal peak position into the box. From there, the "Move to start position" button will relocate the stage to a point slightly before the signal peak position (depending on the estimated pulse duration) to ensure that the device will capture the full signal. Pressing "Start" will initiate the step movements, measuring the second-harmonic intensity at each stop until the stage reaches the same distance past the signal peak position. Finally, the stage returns to 0mm.

$$\tau = \frac{2L}{C}$$

Figure 9: This equation relates the delay in time to a delay in space.

The range that the stage needs to scan over to measure the full signal is determined by the equation above. By substituting 3 times the expected pulse duration for time delay (on the left side of the equation), we cover nearly the entire signal (see Figure 4). The equation is in essence, time = distance/speed. 2L represents the distance in space that the stage needs to move, so by starting the stage L before the signal peak and stopping it L after, the full autocorrelation signal can be graphed.

References

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