Development of a Python Interface for AOM-Based Laser Pulse Shaping

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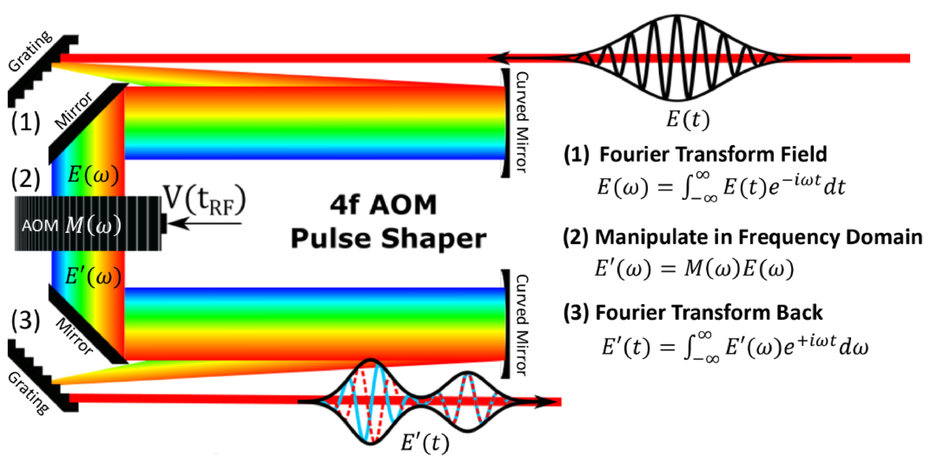
INTRODUCTION

LCLS-II now moves towards a 1 MHz repetition rate [1], thus allowing more exploration in expanded laser parameter spaces. An optical pulse shaper is an ideal tool for controlling a laser pulse and exploiting this new opportunity. The optical pulse shaper is a setup that places a programable element at the Fourier plane of a zero-dispersion stretcher. Here, the programmable element is an acousto-optic modulator (AOM) controlled by an arbitrary waveform generator (AWG). This project aims to deliver the AWG's complementary software program, offer versatility in designing useful waveforms necessary for pulse shaping at LCLS, and thus exploit the new capabilities of LCLS-II.

BACKGROUND

When a pulsed laser enters the AOM pulse shaper setup, the setup:

1) Disperses frequency components onto the Fourier plane via the first grating and curved mirror
2) Uses the AOM to manipulate the spectral components of the pulsed laser by applying phase and amplitude masks
3) Recombines the frequency components via the bottom curved mirror and grating--producing the shaped pulse in the time domain. [2]



It is possible to map optical frequency (in the AOM) to acoustic time (from the AWG) with this equation:

Map Optical Frequency to Acoustic Time

$$\omega(t_{RF}) = c_2 {t_{RF}}^2 + c_1 t_{RF} + c_0$$

With this calibration, a digital mask with the AWG can be faithfully converted into an optical mask by the AOM:

Write Arbitrary RF-Acoustic Wave

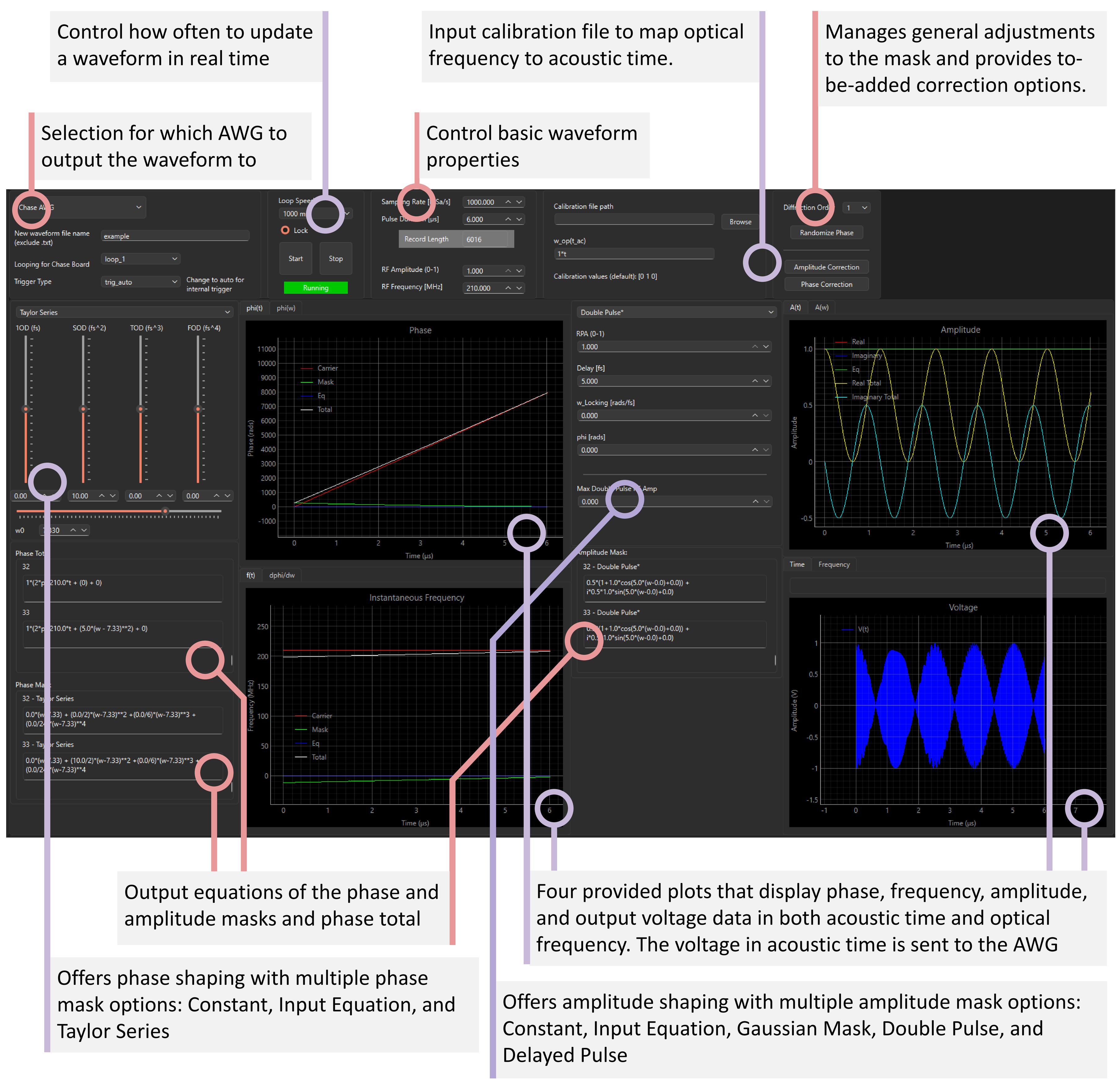
$$V(t_{RF}) = A(t_{RF})\cos\left(2\pi f_{RF} t_{RF} + \phi(t_{RF})\right)$$

$$M(\omega) = A(\omega)e^{i\phi(\omega)}$$

Amplitude: Diffraction Amp
Phase: Periodic Refractive Index

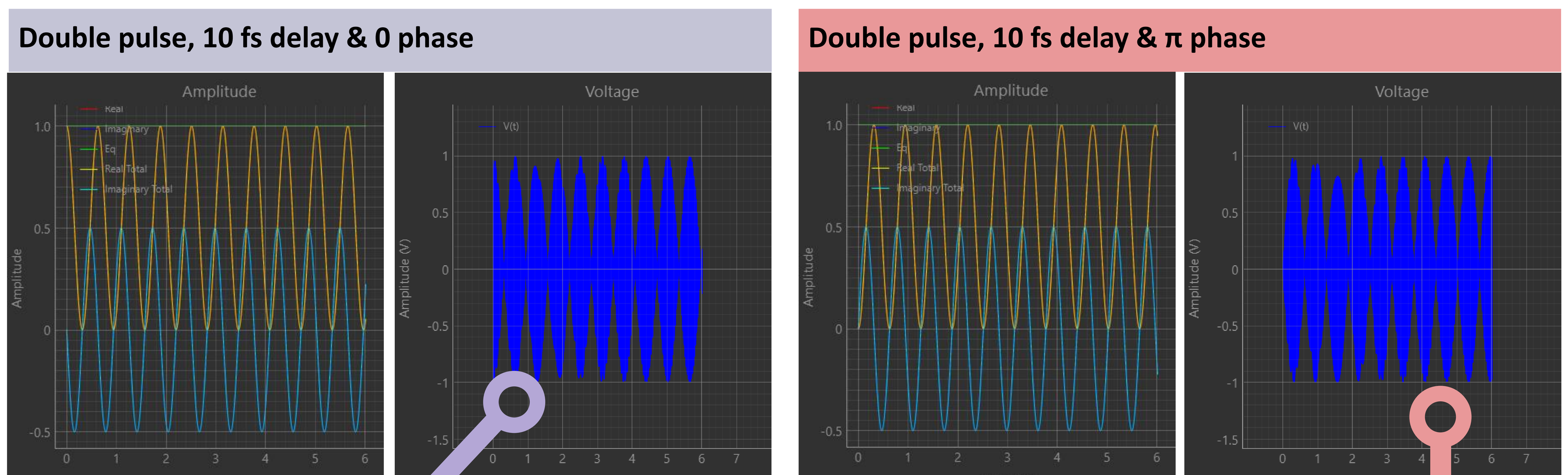
Thus, the digital mask can be generated with this pulse-shaping Python interface, sent to the AWG to output a voltage signal, and applied optically with the AOM.

Application Interface

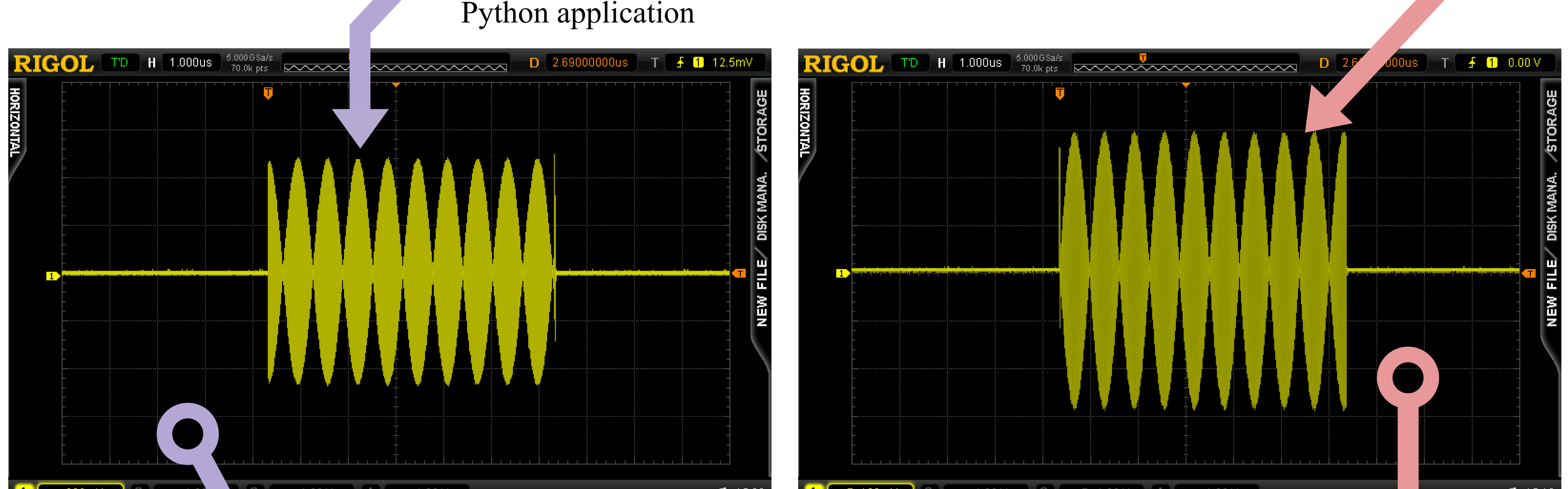


RESULTS

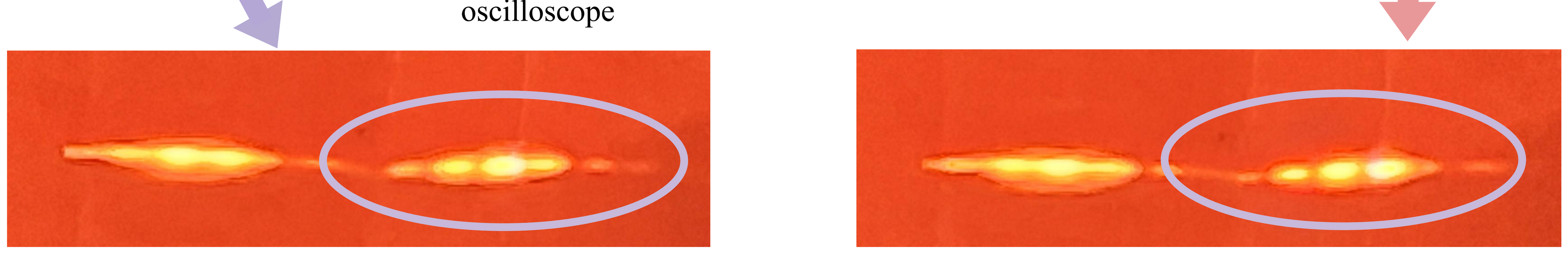
Double pulse, 10 fs delay & 0 phase | **Double pulse, 10 fs delay & π phase**



Amplitude mask and calculated voltage signal in Python application



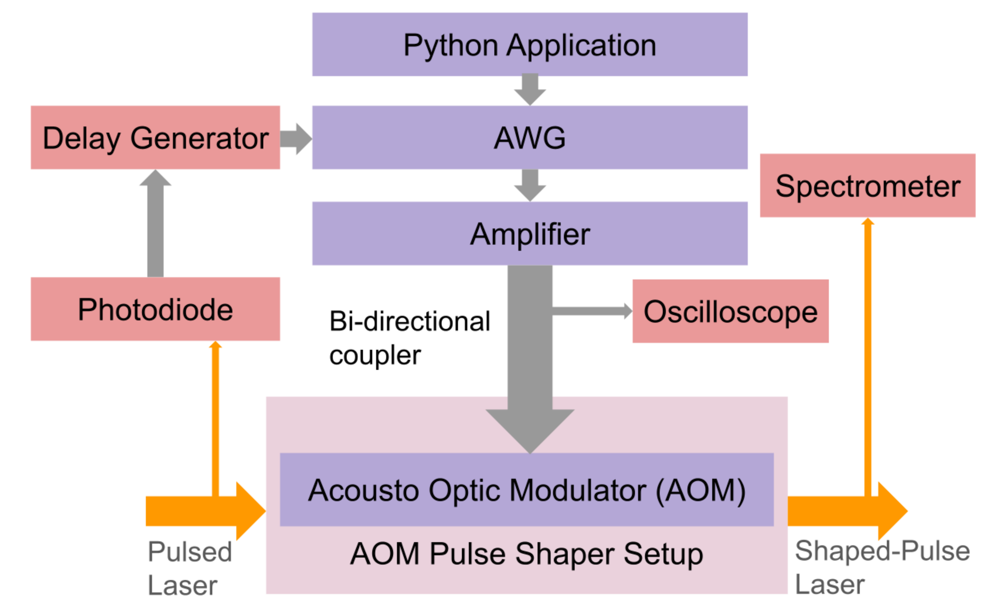
Output voltage signal from AWG measured on oscilloscope



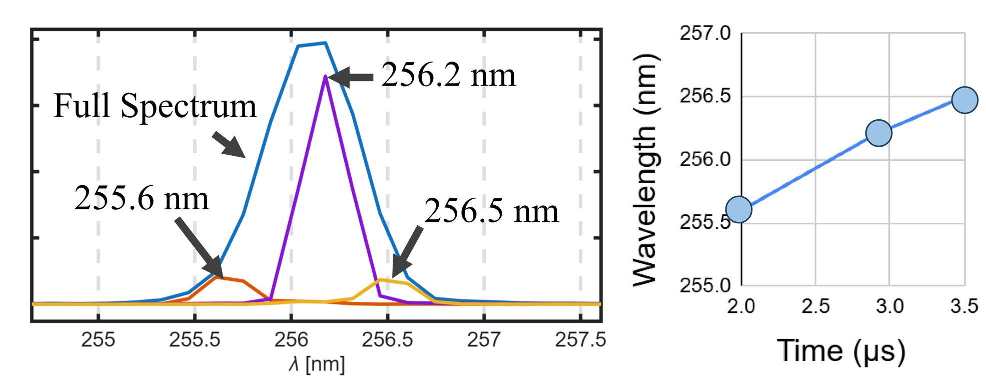
Spectrally dispersed shaped laser pulse viewed on a card just before the 2nd curved mirror in AOM pulse shaper setup

When applying any such mask from the application upon the AOM, the 1st order diffraction of the laser expresses the voltage signal from the application.

PHYSICAL SETUP



CALIBRATING SOFTWARE TO LASER



Without proper calibration, the digitally created mask does not map to its intended optical mask; optical frequency is not directly related to acoustic time. To determine the calibration:

1) Without calibration (t=0), apply narrow gaussian masks (has narrow time feature) with varying frequency delays.
2) Measure wavelength of each narrow spectral feature (red, purple, & orange plot lines above) using spectrometer
3) Correlate time with wavelength, creating λ(t) that corresponds with the calibration equation:

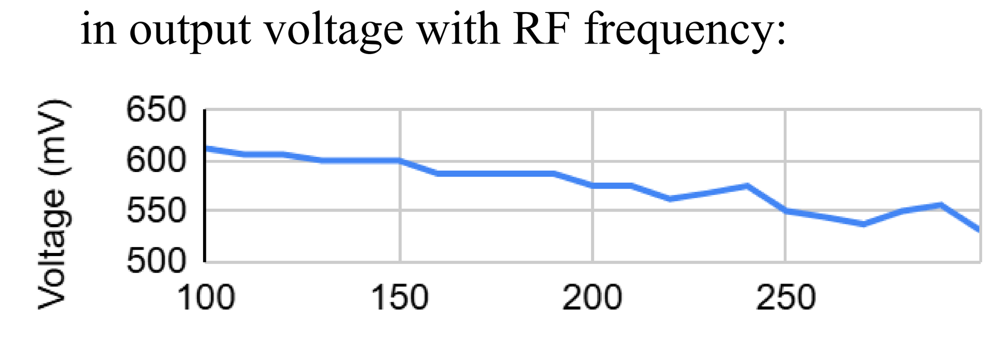
$$\omega(t_{RF}) = \frac{2\pi c}{\lambda(t_{RF})} = c_2(t_{RF})^2 + c_1(t_{RF}) + c_0$$

CONCLUSION

- The software provides various mask options and input parameters for flexibility in shaping laser pulses
- Capable of integrating different AWGs in the setup
- Being written in Python, the software is compatible with LCLS controls for future installation in the instrument hutches.

FUTURE DIRECTIONS

- Python provides easier implementation with machine learning algorithm(s)
- Improve low frame rate performance at high waveform update speeds
- Implement RF bandwidth restrictions to prevent signal back reflections from poor impedance matching with AOM
- Correct RF non-uniformities such as variations in output voltage with RF frequency:



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[1] SLAC National Accelerator Laboratory, "LCLS-II design & performance," *Linac Coherent Light Source*. [Online]. Available: https://lcls.slac.stanford.edu/lcls-ii/ldesign-and-performance. [Accessed: Aug. 7, 2026]
[2] J. Codere, M. Belmonte, B. Kaufman, M. Wahl, E. Jones, M. G. Cohen, T. Weinacht, and R. Forbes, "High repetition-rate pulse shaping of a spectrally broadened Yb femtosecond laser," *Optics Continuum*, vol. 3, no. 5, pp. 785–794, 2024.