Coherent pulse stacking (CPS) is a new time-domain coherent addition technique that stacks several optical pulses into a single output pulse. This technique enables high average power, which will have a significant impact on laser-driven particle accelerators. We develop a robust and scalable digital control system with firmware and software integration for algorithms, to support the coherent pulse stacking application. We model coherent pulse stacking as a digital filter in the Z-domain and implement a pulse-pattern-based cavity phase detection algorithm on an FPGA. A 2-stage (2+1 cavities) 15-pulse stacking system achieves a 11.0 peak-power enhancement factor. Each optical cavity is fed back at 1.5 kHz, and stabilized on an individually-prescribed round-trip phase with 0.7° and 2.1° RMS phase errors for Stage 1 and Stage 2 respectively. Optical cavity phase control with nm accuracy ensures 1.2% intensity stability of the stacked pulse over 12 hours.

### Z-domain modeling

Model the coherent pulse stacking in Z-domain.

#### System architecture

Hardware:
- M605 + FMC110 - XMI15
- 2 CH 12-bit A/D & 2 CH 16-bit D/A & 400 Msps
- 1 kHz Feedback Control Repetition Rate

Firmware:
- Bottom Layer: Hardware-Dependent Drivers
- Intermediate Layer: Data Communication (UDP)
- Top Layer: Project Specific DSP and control modules

#### Algorithm of cavity phase stabilization

Failure to maintain the cavity phase matching translates into a decrease of the peak-power enhancement factor. An enhancement factor of simply and quickly by a dot-product of the N-pulse pattern-based cavity phase detection algorithm.

Cavity phase is stabilized by proper feedback control of a piezo-transducer with pendulum model. The pendulum model contains a phase-unwinding algorithm to calibrate the complex template vector.

### Stabilization results of coherent pulse stacking

Each cavity is stabilized with 0.7° and 2.1° (RMS) phase errors for Stage 1 and Stage 2.

- Intensity stability of the stacked pulse is kept within 1.2% (RMS) over 12 hours.

- Noise spectrum of the cavity phase.

- Noise spectrum of the stacked pulse.