# **Longitudinal Feedback** for the LCLS-II Superconducting Linear Accelerator at SLAC

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### **RF ABSTRACTION LAYER**

## LONGITUDINAL FEEDBACK

SLAC has commissioned a new superconducting continuous-wave MHz repetition-rate free electron laser utilizing separate dedicated soft and hard x-ray undulator lines. The total design energy is 4 GeV. The electron beam energy is measured along the linear accelerator in four dispersive regions, using beam position monitors and their accompanying dispersion as shown in Fig. 1:



The RF Abstraction Layer (RFAL) controls all superconducting RF cavities in an orchestrated manner. It calculates and distributes individual cavity phases, at up to ~20 Hz, to achieve a user-specified beam energy and energy spread (aka chirp). The RFAL is a dedicated EPICS soft IOC that uses pyDevSup to integrate Python control code with EPICS. There are also accompanying Python Display Manager (PyDM) user interfaces. The energy and chirp can be set for multiple regions of the accelerator, and *qang phase* offsets can be applied to each region to compensate for global phase or time of flight changes (Fig. 3):

		SCRF Abstr	action Layer - PyDM (on Icls-srv01)		000	RFAL Gang Phases - PyDM (on lcls-srv01)	000
e View	History Tools				1	File View History Tools	
	Energy	Chirp	Headroom	Mode Fault		Gang Phase Control RFA	L Main
.0B	88.01 MV	0.00 MV	Energy Chirp   2.11 MV -11.45 MV Remaining   90.13 MV -11.45 MV Lim	ACTIVE -	more	These PVs change the phases of all the cavities in the CMs listed by the same degrees of 1.3 GHz. Each time you hit return, the value in the PV is sent as a cavity's PTOF PV.	e number of delta to each
172			Energy Chirp			Expected use case: changing the path length of the beam by moving a buncl chicane and you need to adjust the phase of all the cavities downstream, thu name: PTOF = Phase Time of Flight	h compressor Is the PV
.18	153.12 MV 🔘	-115.00 MV 🔕	29.08 MV -48.27 MV Remaining	ACTIVE -	more	The LLRF system uses this offset: PACT=PRAW+PTOF+PREF+	

The longitudinal feedback is fully Python–based and self-contained with minimal, widely-available dependencies. It runs as a standalone process on a central server, independent of any user interface, and utilizes EPICS Process Variables (PVs) that wholly control the feedback. The feedback code in its entirety is just over 700 lines and is easily maintained or ported to other machines/applications with minimal configuration file changes.

There is an accompanying PyDM user interface (with expert panel) that allows the end user to easily control the feedback. Options are provided for on the fly adjustment:

- PID Gains and overall gains
- Feedback actuation rate

Figure 1: Energy Measurement using Beam Position Monitors The bunch length is also measured in the two bunch compressor chicanes BC1B and BC2B. Together with the energy at four locations, this makes a total of six parameters to be controlled using feedback (Fig. 2):



18	153.08 MV -115.00 MV	182.15 MV -103.27 MV -103.27 MV	Each time you hit return, the value is sent as a delta to each cavity!
HL	-52.00 MV O -51.95 MV -6.89 MV Re-Init	Energy Chirp   -6.53 MV -20.84 MV Remaining   -58.53 MV -27.74 MV Lim	LOB -2.00 Deg Only CM01
L2B	1127.57 MV -670.75 MV Re-Init   1127.39 MV -670.72 MV Re-Init	Energy Chirp   196.79 MV -294.85 MV Remaining   1324.23 MV -965.59 MV Lim ACTIVE *	L1B 13.00 Deg Obgrees of 1.3 GHz to change phase by CM02, CM03, H1 and H2
L3B	2262.08 MV O 2262.05 MV -0.01 MV	Energy Chirp   68.54 MV -422.81 MV Remaining   2330.62 MV -422.81 MV Lim ACTIVE more	HL 0.00 Deg Only H1 and H2
SUMS	EDES CDES   3630.61 MV -785.75 MV	Ctri-r to see all values	L2B 22.00 Deg Degrees of 1.3 GHz to change phase by CM04-CM15
	3630.52 MV -785.73 MV EACT CACT	All Al-SELECT Gang Phases	L3B -1.00 Deg O Degrees of 1.3 GHz to change phase by CM16-CM35
		Archives and Strips	Ctri-r to see all values

Figure 3: RFAL Main (Left) and Gang Phase (Right) Displays

The user can also specify in real-time which RF cavities are used for which purpose:

- NOTA: Abstraction Layer does not control
- Chirp Only: Used to impart energy spread
- FB Negative: Used to adjust energy, maintain chirp
- FB Positive: Used to adjust energy, maintain chirp



- Energy verniers (can shift target energy)
- Maximum step sizes
- Ability to save and restore setup



Figure 5: PyDM Main (Left) and Expert (Right) Displays

## CONCLUSION

achieved LCLS-II light first using the superconducting linear accelerator in both the Soft Hard X-ray Undulator lines in August and and September of 2023. The Abstraction Layer and Longitudinal Feedback have been running smoothly for several months in advance of that important milestone and have proven to work reliably while not introducing additional jitter or variability. The bunch length monitors are still being commissioned, but the bunch length feedbacks are expected to work well as they utilize the same root code and have been tested on the original LCLS Copper Linac.

The superconducting continuous-wave RF cavities are relatively slow to change phase and also prefer to have a fixed amplitude due to Lorentz Force Detuning. For these reasons, it was decided to make a simple and relatively slow feedback to control the energy and bunch length in various regions using only cavity phases. But first, there needed to be a way to collectively control the phases of 296 individual cavities!

Figure 4: Cavity Modes Illustration (Left) and Real-Time Display (Right) for a region

The abstraction layer lets a human easily set up the desired energy and chirp and provides the perfect actuator interface for a longitudinal feedback!

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