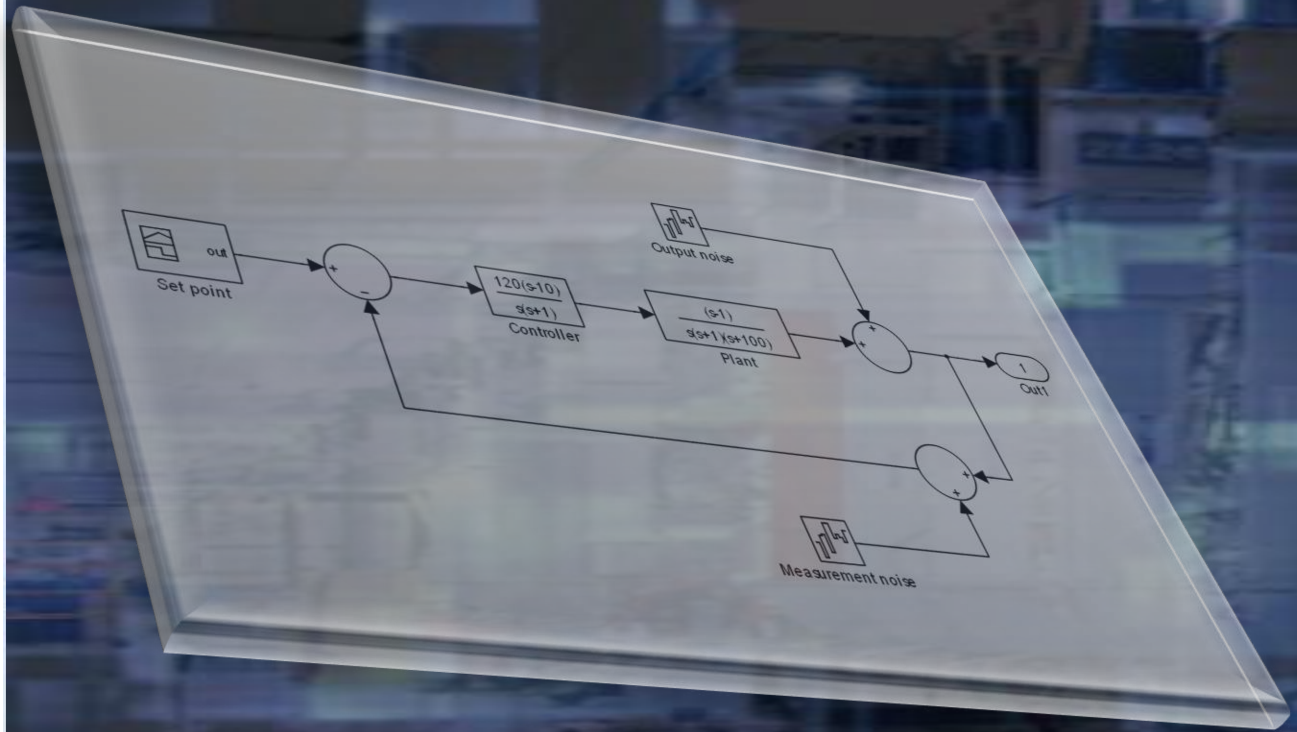


LLRF Activities at Jefferson Lab

Tomasz Plawski

for the JLAB LLRF Team

October 23, 2023

LLRF2023

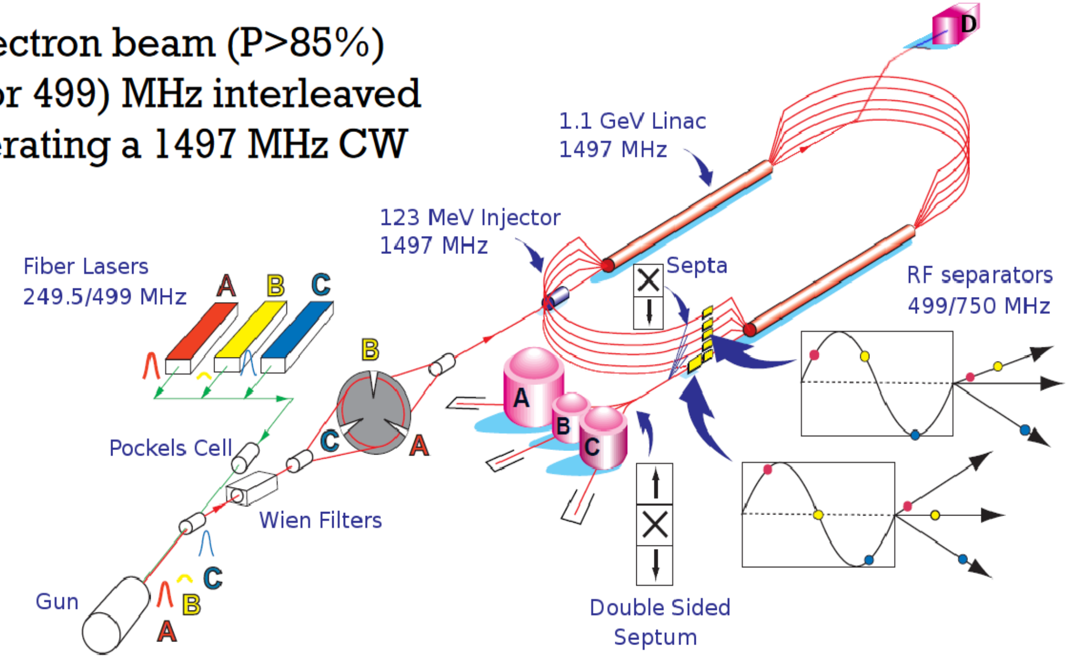
LOW LEVEL RADIO FREQUENCY WORKSHOP 2023

OCTOBER 22-27, 2023

IN GYEONGJU, REPUBLIC OF KOREA

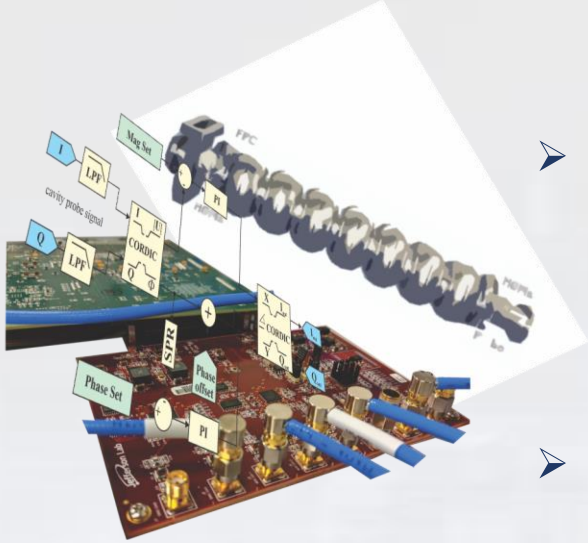
The Continuous Electron Beam Accelerator Facility (CEBAF), at Thomas Jefferson National Accelerator Facility (TJNAF), provides high-quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons. CEBAF operates as a pair of superconducting radio frequency linacs, in a "racetrack" configuration, capable of delivering electron beams simultaneously to four experimental halls.

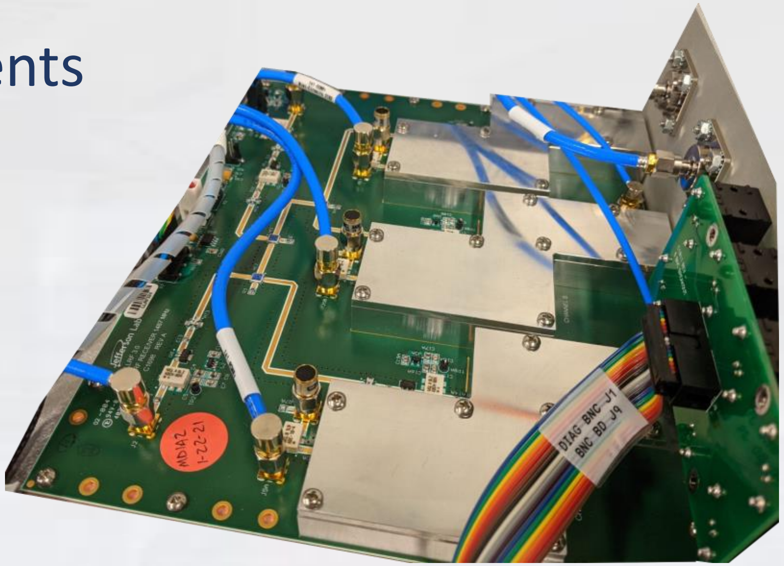
- Polarized electron beam (P>85%)
- Four 249.5 (or 499) MHz interleaved beams, generating a 1497 MHz CW beam



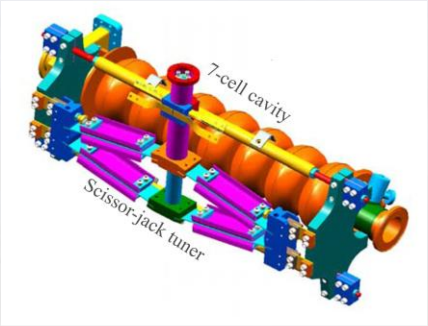
- CW SRF linacs
- Design energy 2.2 GeV/pass:
  - 5 passes, 11 GeV (Halls A,B & C)
  - 5.5 passes, 12 GeV (Hall-D)
- Flexible extraction options for ABC, 1st…5th pass
- Hall A & C 1 MW high power dumps

JLAB LLRF team assignments



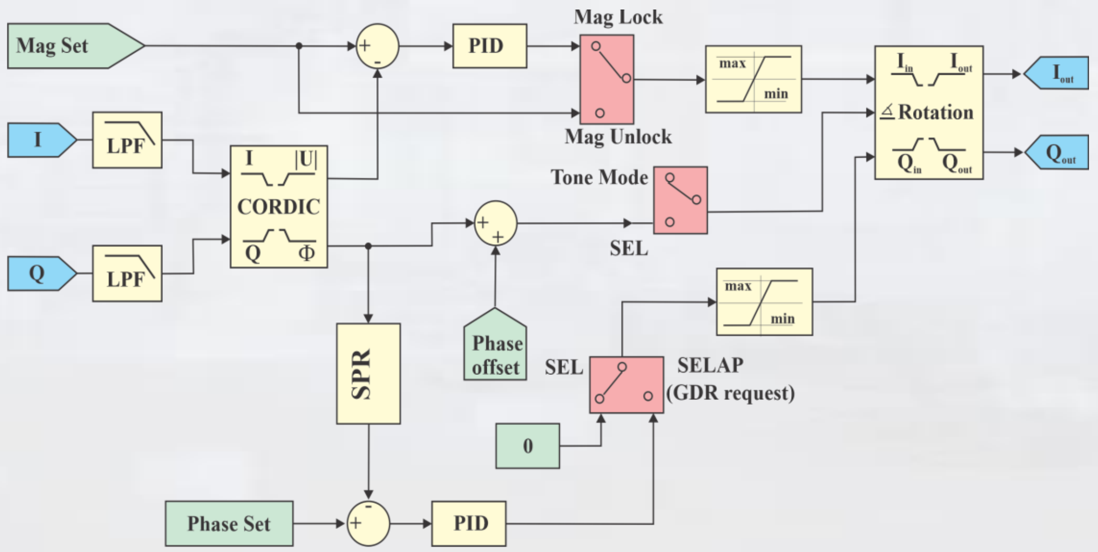


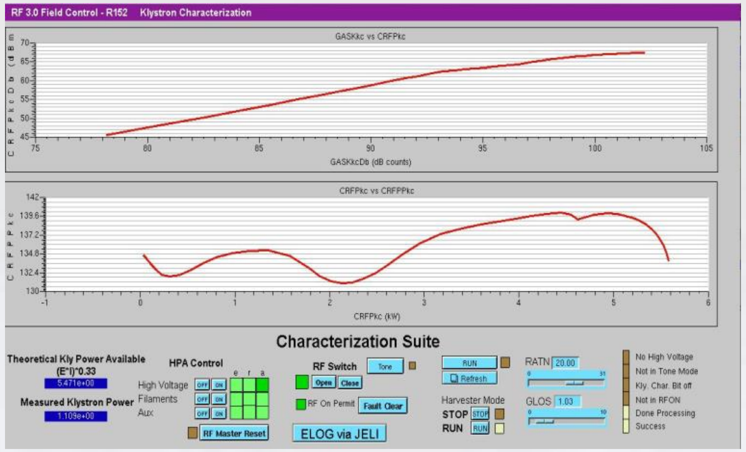
- The CEBAF accelerator support
  - 418 SC cavities – in two linacs
  - 20 NC cavities – Injector, Separator
  - RF Reference System
- New Design Implementation
  - Field Control System 3.0
  - LLRF 3.0 based system for CEBAF DC PhotoGun
  - LLRF Upgrade for Bunch Length System at the CEBAF Injector
  - DAQ system for legacy/analog LLRFs
- Electron-Ion Collider RF Systems (BNL) -a collaborative effort between BNL and JLAB
- LERF – (Low Energy Recirculator Facility): LCLS-II cryomodule testing
- PIP II (Fermilab) – Resonance Control System

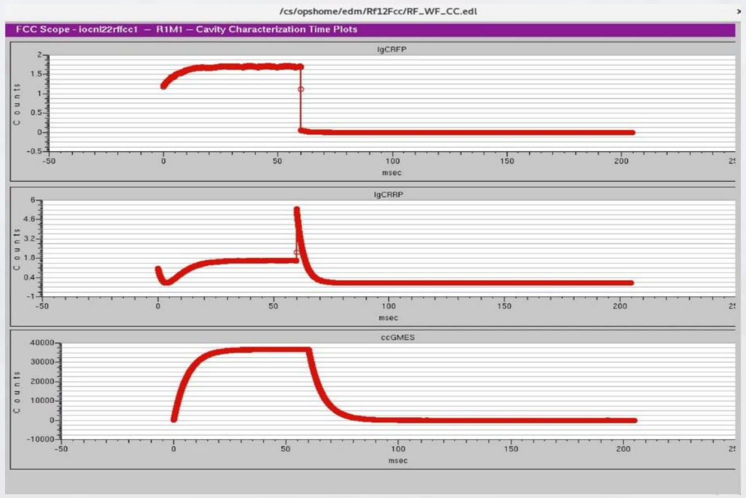


Continuous progress on LLRF 3.0 SELAP firmware development

When the magnitude PI controller output is constant and the phase PI controller equals 0, the system is in free-running SEL mode. Applying magnitude feedback, the amplitude is locked (stabilized), although the system is still in SEL mode. This mode (called SELA) helps with compensating small amplitude modulation caused by SEL mode imperfections. Once the phase loop is closed (SELAP), the system will compensate for any cavity detuning by adding an offset vector (Q in the figure above). In practice, the system remains in full SELAP mode as long as it has enough RF power. If the system clips/saturates the RF power, the phase loop unlocks itself and the system generates a beam shutdown signal for the machine. Once the detuning drops below the power saturation level, the phase loop locks back and beam operation can continue.



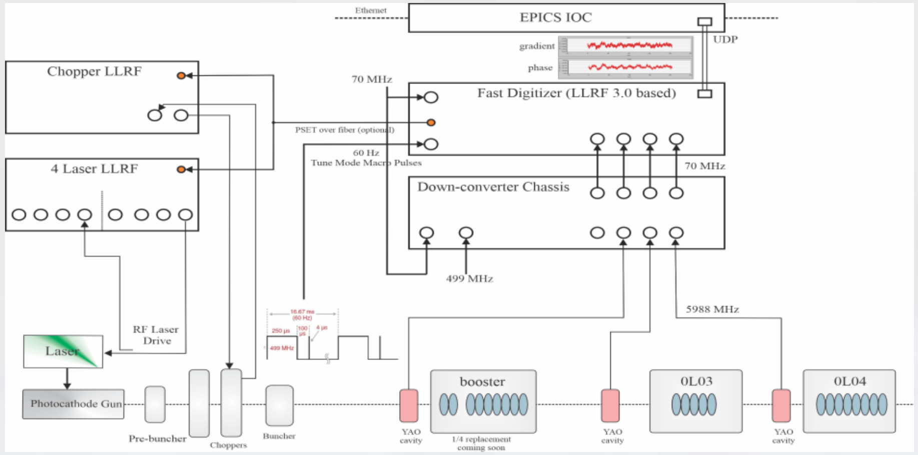


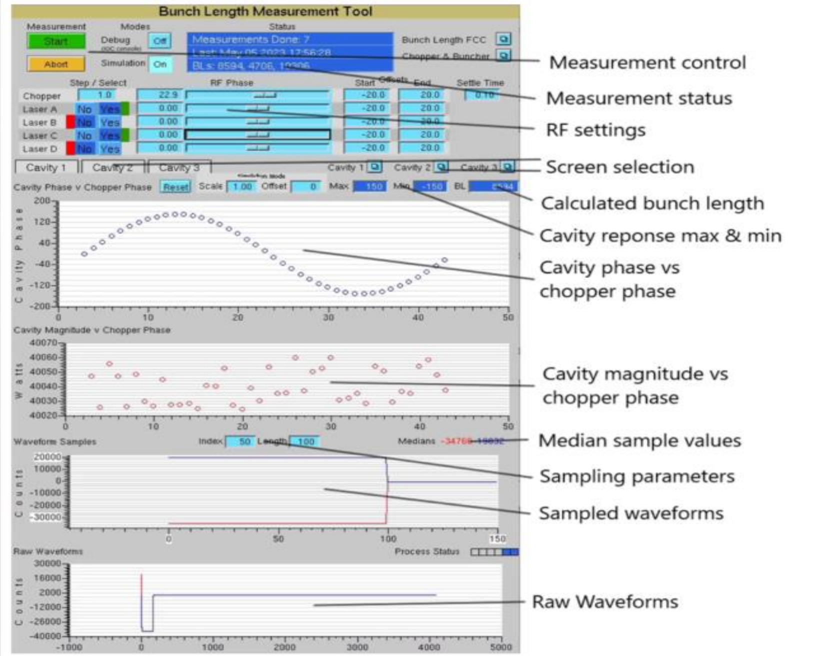


Plawski, T. E., Bachimanchi, R., Higgins, S., Hovater, C., Latshaw, J., and Mounts, C. I.. First SELAP Algorithm Operational Experience of the New LLRF 3.0 RF Control System. United States: N. p., 2022. Web. doi:10.18429/JACoW-LINAC2022-THPOPA24.

https://www.osti.gov/biblio/1903605

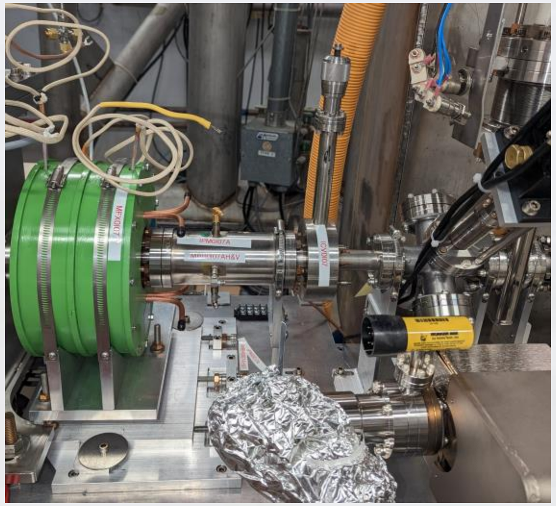
New Bunch Length System at the CEBAF Injector (poster # 63)





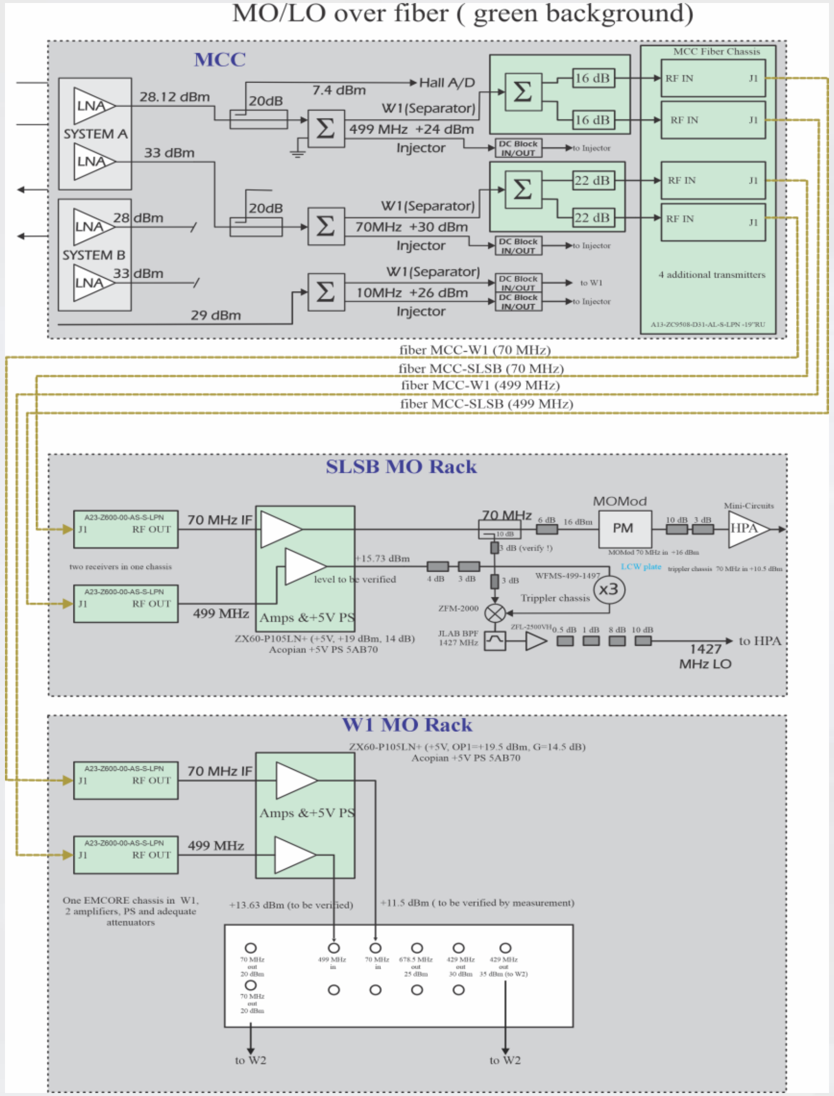
https://doi.org/10.18429/JACoW-NAPAC2022-FRXD6

- Network-attached device architecture
- 4 channel 5988 MHz receiver
- Cyclone 10GX FPGA board and fast digitizer board
- Precise digital demodulation



AD9653 / 16-bit, 4 channel 125MSPS ADC

RF Reference System – RF over Fiber (RFoF) Upgrade

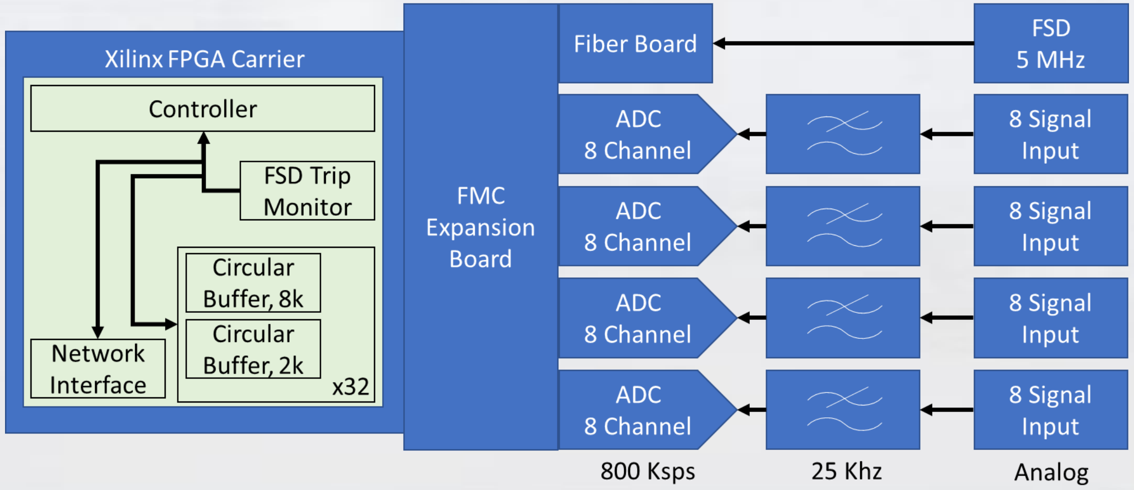


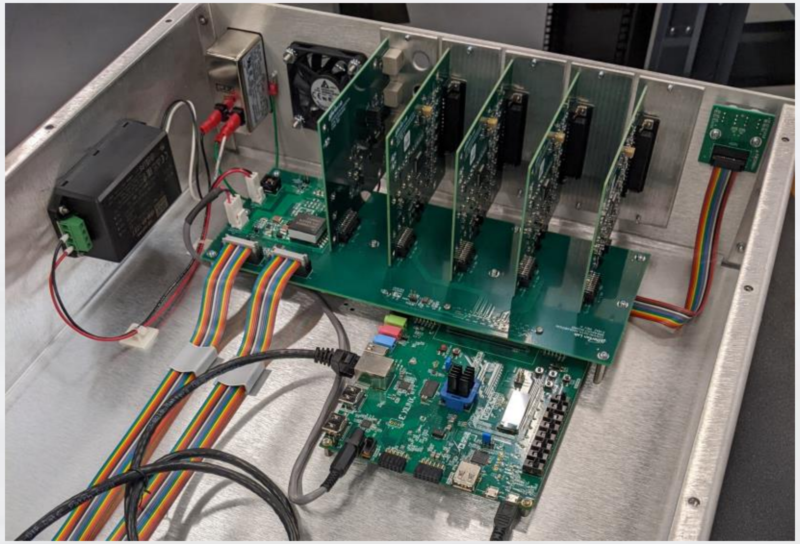
- Replace aging underground coaxial cables
- Provide better isolation from lightning-induced EMI
- Easy installation
- Minimal RF losses on long distances

Fast DAQ for Machine Learning and More (poster # 60)

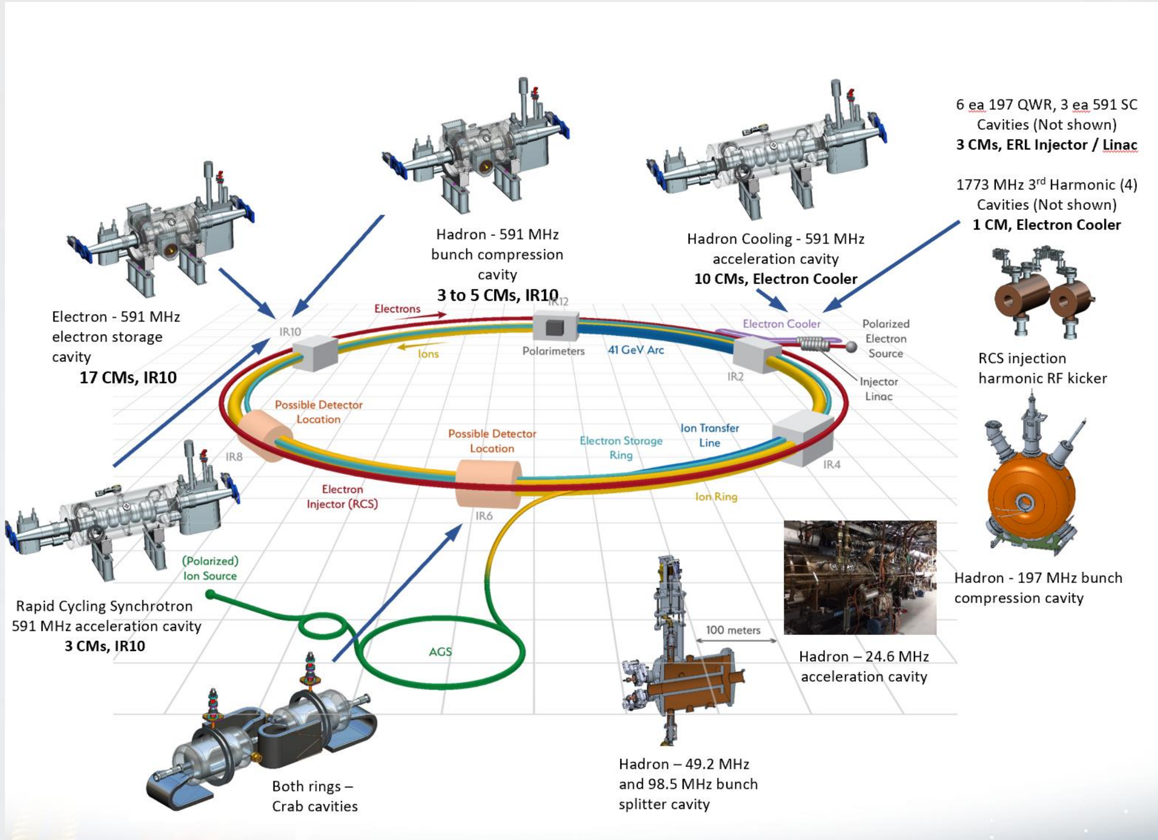
Multichannel ADC chassis to monitor legacy LLRF 1.0 System signals

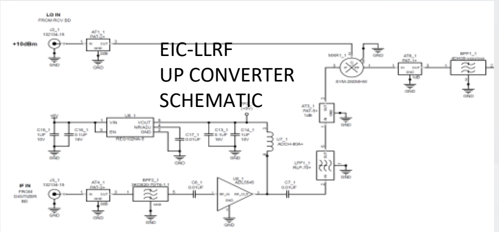
- Support SC cavity operation troubleshooting
- Correlate beam FSD with a specific cavity filed instability (project in progress)
- An auto-encoder-based machine learning model, as well as a PCA-based model, are being developed to identify anomalous SRF cavity behavior and report these to operators.



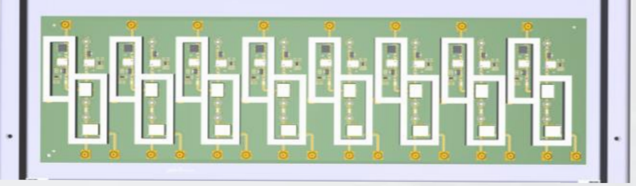


Electron-Ion Collider RF Systems (BNL) -a collaborative effort between BNL and JLAB





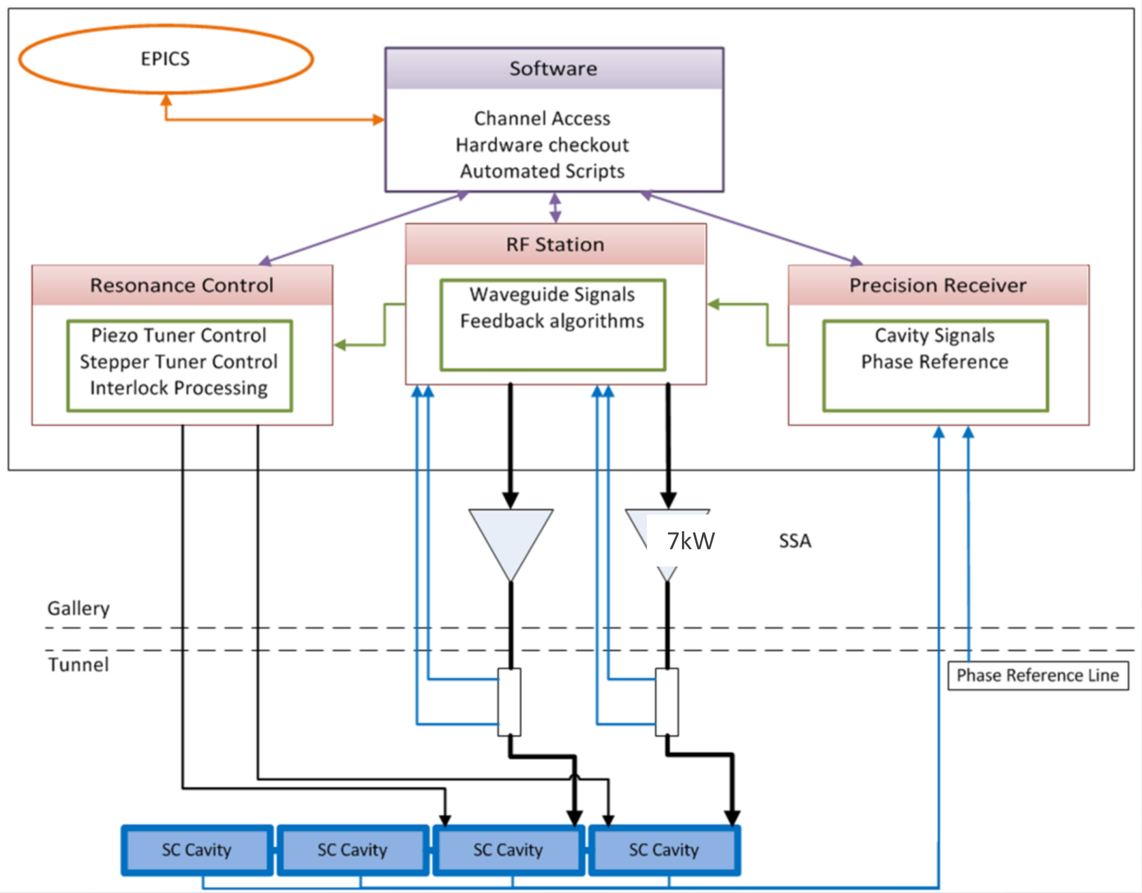
3-D model of 8 channel Down-Converter board



- RF Down-converter/ Up-converter
- LO frequencies generation
- Fast Digitizer
- Resonance Control & Interlock System

RF System	Sub System Functions	Freq [MHz]	Type	Location	# Cavities
Electron Storage Ring	Accel / Store	591	SRF, 1-cell	IR-10	17
Rapid Cycling Synchrotron	Accel / Store	591	SRF, 5-cell	IR-10	3
	Harmonic Kickers	591	NCRF, QWR, 1-mode NCRF, QWR, 2-mode	IR-2 or IR-12	1 1
	Bunch Merge Type 1	295	NCRF, Reentrant	IR-4	2
	Bunch Merge Type 2	148	NCRF, Reentrant	IR-4	1
Hadron Storage Ring	Capture / Accel	24.6	NCRF, QWR	IR-4	4
	Bunch Split 1	49.2	NCRF, QWR	IR-4	2
	Bunch Split 2	98.5	NCRF, QWR	IR-4	2
	Store 1	197	NCRF, Reentrant	IR-4	7
	Store 2	591	SRF, 1- or 2-cell	IR-10	5 or 3
Strong Hadron Cooling / Energy Recovery Linac	ERL Injector	197 591	SRF, QWR SRF, 1-cell	IR-2	2 1
	ERL Low Energy Linac	197 591	SRF, QWR SRF, 1-cell	IR-2	4 2
	ERL Fundamental	591	SRF, 5-cell	IR-2	10
	ERL Third Harmonic	1773	SRF, 5-cell	IR-2	4 (1 CM)
Crab Cavities	Hadron	197	SRF, RFD	IR-6	8 (4 CM)
	Hadron/Electron	394	SRF, RFD	IR-6	6

Commissioning the LCLS-II LLRF System in the LERF* Facility



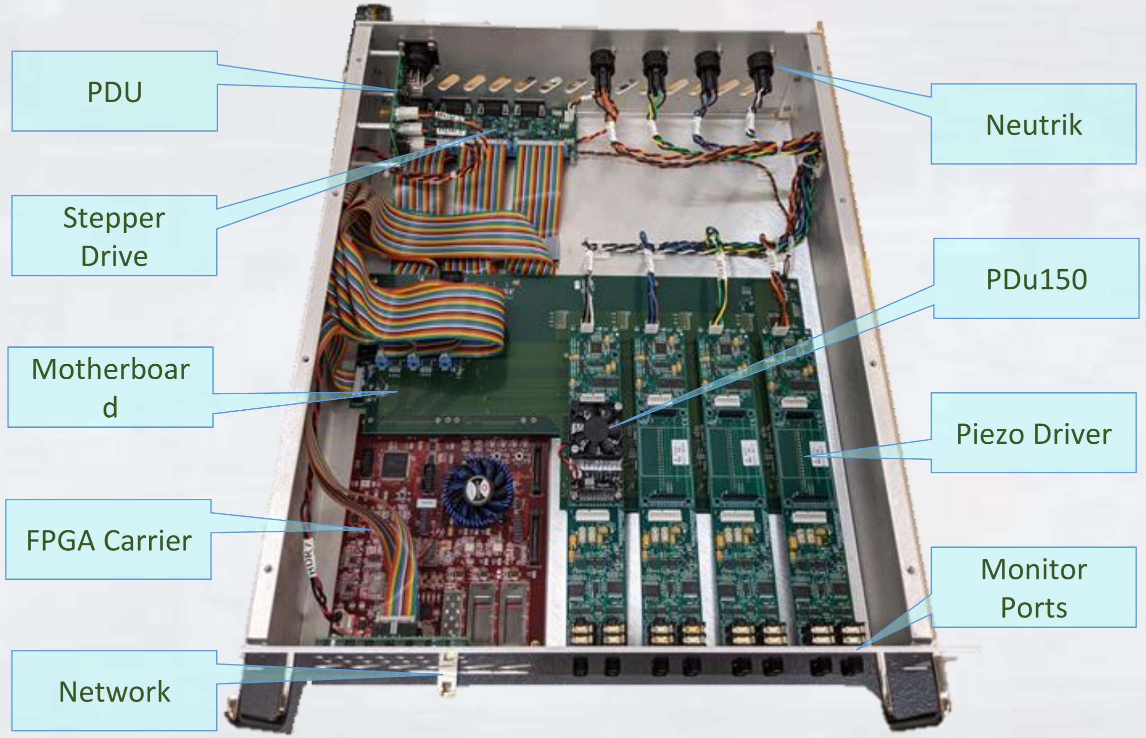
https://doi.org/10.18429/JACoW-SRF2019-THP049

* LERF - Low Energy Recirculator Facility/ Jefferson Lab

PIP-II Resonance Control System

Abstract

The PIP-II Resonance Control System has the goal of providing the electronics to mechanically tune four superconducting cavities as directed by two RF control stations or via LAN manual commands (python LEEP scripts). This solution leverages the LCLS-II Resonance Control chassis design, but with an Intel based FPGA carrier and is largely compatible with LCLS-II screens. This resonance control system will have a 2 Hz/step resolution with up to 256 micro steps per full step. This system also employs piezo driver control with intended resolution better than 1 Hz and a control bandwidth of ~ 500 Hz. The piezo driver boards have ADCs for sampling key piezo signals and the DAC output. Cavity detuning information is received over a QSFP fiber interface from the RF station(s). The waveforms of these sampled signals are displayed on EPICS screens for live troubleshooting and diagnostics.



https://indico.psi.ch/event/12911/contributions/38438/attachments/22894/40447/llrf_workshop_22_FHNW.pdf

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Posters

James Latshaw: Fast DAQ for Machine Learning

Rama Bachimanchi: New Bunch Length System at the CEBAF Injector

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