Low-Level Radio Frequency (LLRF) Workshop 2025

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Book of Abstracts

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JLAB talk

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The presentation will highlight key LLRF developments at Jefferson Lab, including the Electron-Ion Collider (EIC) and the Proton Improvement Plan II (PIP-II).

Abstract Category:

Lab Talk

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Noise feedback system for Crab Cavities in Large Hadron Collider

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Superconducting RF crab cavities will be implemented in the upcoming High-Luminosity LHC upgrade to compensate the luminosity loss due to a large crossing angle at the interactions points. In order to be beneficial for luminosity, the crab cavity system must have extremely good RF noise performance, else the emittance blow-up from its own noise may further degrade the luminosity.
Required noise performance of the Low-level RF and High-power RF systems is beyond the limit of what is possible with current technology.
An active "noise feedback" in the LLRF system was therefore proposed to help mitigate the emittance growth from the crab cavity system. We present the challenges of very demanding noise feedback LLRF system design, proposed processing algorithms and preliminary results from the proof of concept testing phase.
The challenge is not only the ultra low noise digitizer with large bandwidth and low ENOB converters, but also implementing a high performance, strictly beam synchronous bunch by bunch measurement into an asynchronous, fixed clock LLRF system.

Abstract Category:

Measurement and Control

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LLRF Progress at FRIB: from Commissioning to Operation and Future Directions

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The Facility for Rare Isotope Beams (FRIB) was fully commissioned in 2021 and began user operations in May 2022. This talk provides an update on Low-Level Radio Frequency (LLRF) system activities at FRIB during the transition from commissioning to routine operation. Key efforts have focused on spare parts management and the development of advanced troubleshooting tools to support reliable system performance. We present operational insights from the early stages, including achieved performance metrics, system uptime, lessons learned, automation of cavity turn-on/off, conditioning, auto-restart process and beam based feedback for LLRF energy and phase regulation. Additionally, we briefly introduce ongoing developments of a new LLRF hardware platform designed to support future FRIB upgrade cavities.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633.

Abstract Category:

Lab Talk

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 10

Resonant filling for long pulse operation of EuXFEL using iterative learning based feed forward

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A future operation scenario of the European XFEL (EuXFEL) is long pulse (LP) mode, where the 800 superconducting radio frequency (SRF) cavities of the linac are energized with RF pulse lengths of up to 500ms, in contrast to the current short pulse (SP) mode with only 1.4ms. To improve energy efficiency of LP operation, cavities must be operated at bandwidths in the range of tens of Hertz, narrower by a factor of 10 than in SP. Due to peak power limitation of the proposed high power amplifiers, the fill time will extend to several milliseconds, surpassing the period of mechanical resonances of TESLA cavities. To ensure RF filling on resonance, Lorenz force detuning induced cavity phase shifts are tracked by employing iterative learning control (ILC) on the incident RF phase in a single cavity regulation setup. In vector-sum RF regulation systems, the incident phase cannot be adjusted to each cavity individually. Hence, the concept is inverted by employing ILC on mechanical cavity tuners to align each individual cavity resonance with the common RF drive. Both approaches are simulated and evaluated experimentally.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

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DESY lab talk

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Overview of the latest LLRF developments at DESY. This includes a short report on XFEL and FLASH operation and upgrades. Some R&D highlights related to the preparation work towards continuous wave operation of the European XFEL and DESY's involvement with the iSAS European project (Innovate for Sustainable Accelerator Systems) will also be presented.

Abstract Category:

Lab Talk

Poster Session 1 (System and Ops, Hardware) / 13

Reliable operation of PAL-XFEL LLRF

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The PAL-XFEL LLRF and SSA systems have contributed to the stable operation of PAL-XFEL for nearly a decade with their reliability and robustness. Key achievements of these systems include the development of pulse-by-pulse real-time RF switching function for simultaneous operation of the HX and SX beamlines, development of a converter-type X-band LLRF, and development of a function to improve RF amplitude drift. The systems have faced various challenges during their operation, such as the arrival of key component life cycles, the discontinuation of key components, and the need for upgrades to keep pace with technological advances. Therefore, the following activities are being pursued. The PAL-XFEL LLRF and SSA systems have been field-proven, so upgrades are being carried out based on the existing systems. The discontinued processing PCs have been upgraded to higher-performance industrial boards, the RF modules are being redeveloped, and the A/D and FPGA boards are planned to be upgraded with new FPGAs and PCIe. In addition, an updated SSA prototype has been developed.

Abstract Category:

Hardware

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Development and Testing of a Low-Noise X-Band LLRF Prototype System

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Low-Level RF (LLRF) systems are fundamental to the precise control of accelerating fields in modern particle accelerators, ensuring the required stability in amplitude and phase to achieve consistent beam quality. As accelerator technologies evolve toward higher frequencies and more compact designs, the X-band regime is increasingly adopted due to its support for high-gradient structures and ultra-short RF pulses. However, the shift to X-band introduces greater sensitivity to phase noise, timing jitter, and thermal fluctuations, requiring a new generation of LLRF controllers with faster signal processing and tighter control loops. In this context, a dedicated X-band LLRF prototype has been developed to meet the demanding requirements of the future EuPRAXIA@SPARC_LAB LINAC, as part of the EuPRAXIA Doctoral Network. The prototype integrates a high-speed front-end and back-end system optimized for fast pulse processing and enhanced signal fidelity. It is now prepared for full evaluation on a real accelerator test bench at the TEX facility, INFN-LNF. This paper presents the concept, implementation, and readiness of the prototype system.

Abstract Category:

Hardware

Poster Session 1 (System and Ops, Hardware) / 15

Design, characterization and commissioning of X-band LLRF systems for the TEX RF upgrade at LNF-INFN

Author: Luca Piersanti[1]

Co-authors: Alessandro Gallo [2]; Beatrice Serenellini [3]; Fabio Cardelli [1]; Giorgio Scarselletta [1]; Giuila Latini [1]; Marco Bellaveglia [2]; Michele Scampati [1]; Riccardo Magnanimi [1]; Sergio Quaglia [1]; Simone Tocci [1]; Stefano Pioli [1]; Xianghe Fang [2]

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The TEX (Test-stand for X-band) facility at LNF-INFN was established in 2021 and commissioned in 2022. It serves as an R&D center for X-band technology, supporting activities from waveguide component design and high-power testing to low-level RF (LLRF) system development. TEX is equipped with a 50 MW X-band klystron (CPI, USA) powered by a K400 solid-state modulator (ScandiNova, Sweden), operating at a 50 Hz repetition rate. It was recently upgraded with two additional RF high-power sources: a 25 MW, 400 Hz X-band unit and a 20 MW, 400 Hz C-band unit, both manufactured by Canon. This upgrade required a complete redesign of the X-band LLRF system, now featuring: (i) three C-band Libera LLRF systems (Instrumentation Technologies, Slovenia); (ii) an up/down converter, for frequency translation to the European X-band (11.994 GHz); (iii) a reference distribution system, for coherent frequency reference delivery across all the facility sub-systems. The whole LLRF system has been successfully designed, tested and installed at TEX in spring 2025. We report here the first experimental results from low power commissioning started in June 2025.

Abstract Category:

Hardware

16

New RF control system developments at LNF-INFN

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SPARC_LAB is a high-brightness e-beam for SASE-FEL (self-amplified spontaneous emission-FEL) experiments. It consists of a brazeless 1.6-cell S-band RF gun, two travelling wave S-band accelerating structures each 3 meters long, and a 1.4-meter C-band structure that acts as an energy booster. As part of the SABINA project, co-funded by the Lazio Regional Government for consolidation of SPARC_LAB, a significant upgrade of the RF control systems was completed last year. The activity involved the development of software for remote control of LLRF systems, C-band modulator, as well as custom hardware made by the RF service for fast feedbacks and RF synchronization. Algorithms were also developed for statistical and diagnostic analysis of RF signals, with real-time amplitude and phase jitter monitoring capabilities. Development of a custom EPICS application aimed at optimizing system resources is currently underway. Finally, to support conditioning operations, dedicated software has been implemented for automatic RF plant management, which dynamically adjusts RF power and manages interlocks under critical conditions.

Abstract Category:

System and Operation

17

Achieving Ultra-Stable RF Control for Plasma Acceleration at LNF-INFN

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The SPARC_LAB facility at LNF includes a high-brightness electron linac dedicated to plasma acceleration studies and R&D. Given the stringent stability requirements on electromagnetic fields, especially for particle-driven plasma acceleration, several upgrades have been implemented over the past two years to enhance RF stability and measurement accuracy. In 2024, the low-level RF system was completely refurbished, replacing the original analog systems with digital ones featuring temperature-stabilized front ends and arbitrary pulse shaping capabilities. Additionally, the intra-pulse phase feedback, originally commissioned in 2008 for the S-band klystrons, was upgraded. A new RF design, along with improved error amplifiers and signal acquisition electronics, was deployed and first tested on the machine in Fall 2024. Comprehensive short- and long-term measurements performed at SPARC_LAB confirm the system's ability to reliably and reproducibly reduce S-band klystron phase jitter down to 15 fs rms. The obtained results are now very close to the 10 fs limit demanded by plasma acceleration and represent a promising step toward meeting the requirements of future accelerator facilities.

Abstract Category:

System and Operation

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LLRF System Analysis for the Fermilab PIP-II Superconducting LINAC

Author: Philip Varghese[1]

Co-authors: Lennon Reyes [1]; Matei Guran ; Shrividhyaa Sankar Raman [1]

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PIP-II is a superconducting linac that is in the initial acceleration chain for the Fermilab accelerator complex. The RF system consists of a warm front-end with an RFQ and buncher cavities along with 25 superconducting cryo-modules comprised of cavities with five different acceleration β. The LLRF system for the linac has to provide field and resonance control for a total of 125 RF cavities. Various components of the LLRF system have been tested with and without beam at the PIP-II test stands. The LLRF system design is derived from the LCLS-II project with its self-excited loop architecture used in the majority of the cryo-modules. The PIP-II beam loading at 2 mA is much higher than LCLS-II linac. The control system architecture is analyzed and evaluated for the operational limits of feedback gains and their ability to meet the project regulation requirements for cavity field amplitude and phase regulation.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

Poster Session 1 (System and Ops, Hardware) / 19

Testing the DAE LLRF system with a PIP-II SSR2 Cavity

Author: Radhika Nasery[1]

Co-authors: Philip Varghese [2]; Shrividhyaa Sankar Raman [2]; Matei Guran ; Lennon Reyes [2]; Alok Agashe [1]

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The PIP-II linac is an international collaboration project with in kind contributions of key subsystems from multiple countires including India(DAE). In the research and development phase of the project, the LLRF and resonance control systems were jointly developed by BARC and Fermilab and were delivered to Fermilab for testing and validation. Initial testing of the LLRF system was carried out using Fermilab's analog cavity emulator. Following successful emulator testing, the LLRF system was deployed at STC on a PIP-II 325 MHz SSR2 cavity. The cavity was operated in both SEL and GDR modes at a gradient of 5 MV/m. The results of the testing are presented here.

Abstract Category:

System and Operation

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Compensating for Amplifier Non-Linearity in a SEL Controller

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Co-authors: Philip Varghese [1]; Matei Guran ; Lennon Reyes [1]

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The SEL architecture used commonly in CW superconducting linacs is a positive feedback system that requires determining the correct limits for the operating conditions to ensure stable operation. These limits are determined from the results of the amplifier calibration which characterizes the dac drive(forward power) against the cavity field. When the amplifier non-linearity precludes a simple linear fit for this characteristic, its modification to account for the amplifiers non-linearity is essential to operate the system in the SEL architecture. This process is described with test data from a 32kW SSA for the PIP-II linac.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 21

Update on PIP-II beam pattern generator upgrade

Author: Philip Varghese[1]

Co-authors: John Dusatko [2]; Daron Chabot [2]; Shrividhyaa Sankar Raman [1]; Lennon Reyes [1]; Matei Guran

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The beam pattern generator enables the transfer of beam pulses from the PIP-II linac to the Booster ring, the two RF systems being non-harmonically related. It is synchronized to the timing system to provide beam arrival information to the downstream accelerator subsystems. The design is being upgraded with COTS components and is being developed with a collaboration with SLAC.The pattern generation, digital signal processing and the user interface to an external EPICS server are integrated onto the ARM processor of the SOCFPGA. The progress of the system development is described.

Abstract Category:

Timing and Synchronization

Poster Session 1 (System and Ops, Hardware) / 22

Update on the Fermilab Mu2e LLRF System

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The LLRF system for the Mu2e project shares the same primary LLRF hardware as the Muon g-2 experiment which concluded its run last year. Commissioning of the subsystems for the Mu2e experiment is starting this year.The RF components for this system are located at large distances from the LLRF controller. 2.5 MHz beam bunches from the Recycler are transferred to the delivery ring into 2.36 MHz buckets for resonant extraction to the Mu2e beamline. The LLRF hardware is being upgraded to a larger FPGA board and additional functions such as the drivers for the AC dipole extinction magnets are being added to the system. A local FPGA controller chassis is being used to digitize the cavity signals and to co-ordinate the beam transfer manipulations. The system architecture is described and the results of the initial
testing presented.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 23

Warm Front End upgrade for the PIP-II Linac

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The warm front end for the PIP-II linac consists of an Ion-source an RFQ and four buncher cavities. The LLRF systems for these were the first ones developed more than a decade ago for use at the test stands. Some were VXI crate based and others used early generation FPGA boards that are light in resources. These LLRF systems and the one for the first superconducting cryomodule, the HWR will be upraded with the ARRIA10 SOCFPGA chassis with EPICS interfaces like the rest of the PIP-II Linac. The RFQ and the HWR have unique resonance control systems which are integrated into the LLRF controller hardware. The results of the initial testing with a cavity emulator will be presented.

Abstract Category:

Hardware

24

Lab Talk - Fermilab

Author: Philip Varghese[1]

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An update on the various projects at Fermilab including PIP-II, Mu2e , LBNF and the various test stands

Abstract Category:

Lab Talk

25

Master Oscillator and Phase Reference Line Design for the PIP-II Linac

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The phase averaging reference line system provides the RF phase reference , LO and clock signals to the LLRF and other accelerator subsystems. The PIP-II linac has RF systems at three frequencies –162.5 MHz, 325 MHz and 650 MHz. A temperature-stabilized, low-phase-noise oscillator is used as the master oscillator. Phase reference signals at 162.5 MHz, 325 MHz, and 650 MHz, along with LO signals at 182.5 MHz, 345 MHz, 670 MHz and LLRF clocks at 1320 MHz and 1300 MHz, are generated in temperature-controlled RF modules at each frequency section. A phase reference from each module travels to the next section, where it is doubled to produce required frequencies. The reference also travels alongside the accelerating cavities in the tunnel, allowing cavity probe and reference cables to temperature track and reduce measurement errors from temperature changes or phase drift. The design of the the reference line is described here.

Abstract Category:

Timing and Synchronization

26

Upgrade of BEPC-II LLRF and synchronization system for the new PWFA research

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BEPC-II(Beijing Electron Positron Collider) has been upgraded in past three years both on LLRF system and synchronization system. A new PWFA(Plasma Wake-Field Acceleration) test facility is built to verify electron and position collider based on PWFA principle including the world-first positron acceleration and world-first cascaded-stage acceleration. So this PWFA beam should be synchronized with beam from BEPC-II, new lasers, new phase reference line and LLRF has been built or upgraded. The status of PWFA experiment related with LLRF will be talked.

Abstract Category:

Timing and Synchronization

28

A high-speed MTCA.4-based digitizer for the LLRF control system of the J-PARC MR

Author: Yasuyuki Sugiyama[1]

Co-authors: Fumihiko Tamura [2]; Kiyomi Seiya [1]; Masahito Yoshii [1]

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The J-PARC Main Ring (MR) is a high-intensity proton synchrotron that accelerates protons from 3 GeV to 30 GeV.
Its output beam power for fast extraction reached 830 kW, corresponding to 2.37×10^{14} protons per pulse in March 2025.
Coupled bunch oscillation is well suppressed with the newly installed LLRF control system for the MR.
Instead of the coupled bunch instability, longitudinal microwave instability is observed in the later part of the acceleration.
A new high-speed digitizer is introduced into the LLRF system to monitor the microwave instability.
In this presentation, we present the configuration of the digitizer and its preliminary status.

Abstract Category:

Hardware

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 30

Transitioning to EPICS at EIC: PSCDrv

Author: Kyle Fahey[1]

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Brookhaven National Lab's Electron-Ion Collider (EIC) plans to migrate from the Accelerator Device Object (ADO) framework developed for Relativistic Heavy Ion Collider (RHIC) applications to the Experimental Physics and Industrial Control System (EPICS) framework. EIC is based on a Common Platform architecture with custom-built hardware for controls and communication between a variety of accelerator component sub-systems: RF, Beam Instrumentation, Power Supplies, Timing, etc. The Common Platform design facilitates communication between carriers, specialized daughter cards, and the EIC global control system. To develop and validate this communication plan, LLRF group is using a specialized packet protocol to send and receive data between a Common Platform carrier and a dedicated EPICS Input-Output Controller (IOC) server.

Abstract Category:

Software

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 31

Obvious and non-obvious aspects of digital Self-Excited-Loops for SRF cavity control

Author: Larry Doolittle[1]

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In 1978, Delayen showed how Self-Excited Loops (SEL) can be used to great advantage for controlling narrow-band SRF cavities. Its key capability is establishing closed-loop amplitude control early in the setup process, stabilizing Lorentz forces to allow cavity tuning and phase loop setup in a stable environment.
As people around the world implement this basic idea with modern FPGA DSP technology, multiple variations and operational scenarios creep in that have both obvious and non-obvious ramifications for latency, feedback stability, and resiliency.
This paper will review the key properties of a Delayen-style SEL when set up for open-loop, amplitude stabilized, and phase-stabilized modes. Then the original analog circuit will be compared and contrasted with the known variations of digital CORDIC-based implementations.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

Poster Session 1 (System and Ops, Hardware) / 32

Modernizing SLAC's NC LINAC LLRF System with the LEMP Platform

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The Linac Electronics Modernization Plan (LEMP) replaces the aging CAMAC-based low-level RF (LLRF) controls in SLAC's normal-conducting LINAC. The new system is based on the open-source Marble FPGA carrier and Zest+ digitizer, with a custom RF front end. A prototype has been deployed and tested at station 26-3, demonstrating key functionality including RF control, interlocks, and waveform capture. Development continues on hardware integration, firmware, and CI/CD workflows. This is a preliminary submission describing current status and upgrade plans.

Abstract Category:

Hardware

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RFSoC-Base LLRF Development for CSNS-II LINAC

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RFSOC (Radio Frequency System-on-Chip) integrates FPGA, ARM processors, RF analog-to-digital converters (ADCs), and RF digital-to-analog converters (DACs) onto a single chip, representing a third-generation leap in hardware technology following the shift from analog to digital circuits. Applying RFSOC to accelerator systems significantly enhances operational efficiency while substantially reducing development complexity, hardware maintenance burden, and overall cost. This report will survey recent progress in utilizing RFSOC for accelerator applications, analyze relevant performance metrics, and present research and implementation work concerning RFSOC in the Low-Level RF (LFB) system of the China Spallation Neutron Source (CSNS) linear accelerator.

Abstract Category:

Hardware

Poster Session 1 (System and Ops, Hardware) / 34

Initial commissioning of the new beam control system of the Proton Synchrotron at CERN

Author: Diego Barrientos[1]

Co-authors: Ylenia Brischetto [1]; Heiko Damerau [1]; Francisco Javier Diaz Ferreira [1]; Alan Findlay [1]; Toma Gavric [1]; Korbinian Geis [1]; Alexandre Lasheen [1]; Benjamin Woolley [1]

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The Proton Synchrotron (PS), CERN's first synchrotron, delivers proton and ion beams with intensities covering almost four orders of magnitude using 25 RF cavities with frequencies ranging from

0.4 to 200 MHz. The LLRF system includes multi-harmonic feedback loops to control the field in the cavities and beam-based loops to perform complex beam manipulations. The current beam control system is implemented using a mix of analog and digital hardware, suffering from obsolescence and reproducibility issues. The new fully digital system, implemented in VMEbus Switched Serial (VXS) and MicroTCA platforms, is currently in its initial commissioning phase. This work presents a complete description of the new beam control system as well as the first results of the initial commissioning phase in the machine.

Abstract Category:

System and Operation

35

A Universal Cavity Controller for testing SRF cavities at CERN

Author: Diego Barrientos[1]

Co-authors: Leonardo Balocchi [1]; Kristof Brunner [1]; Korbinian Geis [1]; Alick Macpherson [1]; Lee Millar [1]; Niall Stapley [1]; Tomasz Wlostowski [1]

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As the use of SRF cavities continuously increases at CERN, testing facilities are also being upgraded. Due to the variety of operating frequencies, ranging from 400 MHz to 1.3 GHz, a generic cavity controller has been designed implementing Generator Driven (GD) and Self-Excited Loop (SEL) modes. A modern approach for separating gateware, embedded firmware (micro-controller unit) and low-level software, as well as Continuous Integration (CI) for automatic bitstream generation and simulation have been used in the Universal Cavity Controller (UCC). Additionally, the UCC development is planned to be applied in MicroTCA architecture in the framework of a project for axion detection using a SRF cavity.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

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Multiharmonic enthusiast – Applications of multiharmonic feedback in synchrotrons

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Magnetic alloy (MA) cavities have wideband frequency responses, which allow multiharmonic rf voltage excitation in a single cavity. In the low level rf (LLRF) control system for the Japan Proton Accelerator Research Complex (J-PARC) Rapid Cycling Synchrotron (RCS) the multiharmonic vector rf voltage control feedback is implemented to realize the dual harmonic rf operation for bunch shaping and to compensate of the multiharmonic beam loading. The multiharmonic feedback consists of several classical IQ feedback blocks, and the RCS system has eight feedback blocks. Similar feedback systems are employed for the other proton synchrotrons, such as CERN PSB and CSNS. The possible application of multiharmonic feedback is not limited to bunch shaping using dual harmonic. Using triple harmonic operation, we can generate more flat rf buckets for realization of flatter bunches. Ultimately, barrier buckets can be generated using many harmonics. Other interesting application is generating a non-integer harmonic rf with several harmonics, which can be used for butch compression. In the presentation, we will explore these possible applications. We will also discuss important considerations when using multiharmonic feedback. One must be careful about the frequency response of the cavity voltage monitor to adjust the precise harmonic voltages. Another point is that unwanted cavity voltage jump may happen after fast extraction of a high intensity beam.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 37

Few-Femtosecond Synchronization of Independent Beamlines in High-Power Laser Facilities via a Fully-Automated Fiber-Optic Timing System

Authors: Max Rückmann[1]; Kemal Shafak[1]; Anan Dai[1]; Yousef El Sharkawy[1]; Wahab Khan[1]; Franz X. Kärtner[2]

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We present a fully automated fiber-optic timing distribution and synchronization system developed for high-power laser facilities that require few-femtosecond synchronization between multiple beamlines, each equipped with an independent seed oscillator.
Building on our previous work in pulsed-optical timing distribution using femtosecond lasers and ultra-low-noise stabilized fiber links*, the system achieves an out-of-loop timing drift of just 5.2 fs RMS over 10 hours between a Ti:Sa laser at 780 nm and a Yb laser at 1030 nm, synchronized remotely via fiber-optic links.
The system includes out-of-loop optical delay lines, integrated into the master platform and a coaxial RF distribution subsystem operating in parallel to the fiber-optic links. This allows high-precision, full pulse-period delay tuning of 13 ns, enabling deterministic phase bucket selection across all synchronized beamlines.
An automatic re-locking mechanism restores pulse alignment across all beamlines after oscillator restart without user intervention. The system integrates natively with EPICS control environments and supports robust 24/7 operation, enabling reproducible, high-precision pump–probe experiments.

Abstract Category:

Timing and Synchronization

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 38

Status of DLLRF System Development for Soleil-II Project

Author: Rajesh SREEDHARAN[1]

Co-authors: Edouard CHAZEL [2]; Fernand RIBEIRO [3]; Jocelyn Labelle [3]; Lu ZHAO [3]; Luc MAURICE [2]; Massamba DIOP [3]; Michel LUONG [2]; Olivier PIQUET [2]; Patrick MARCHAND [3]; Robert Lopes [3]

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A compact digital Low Level Radio Frequency (LLRF) system, based on the MicroTCA plateform, is being developed for the SOLEIL upgrade project towards SOLEIL II. This system will provide better flexibility and easier maintenance than the present analog one. Working with a 10 MHz intermediate frequency (IF) and a UltraScale+ Zynq board makes it easily adaptable to any other RF system.

Abstract Category:

Measurement and Control

39

The progress of LLRF control system for SC linac in IMP

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The large scientific and technology facility of CiADS and HiAF, which powered by superconducting linac is under construction, and faces many technological challenges. The low level RF control system has been developed for these science and technology infrastructures for several years, and some new technology has been adopted to enhance the performance and flexibility of hardware, software and system integration. As a fully tested system, the LLRF control system has begun large-scale use online, the progress of development and research results will be reported in this presentation.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 40

Phase drift Performance of Coaxial Cables for Phase Reference Distribution Systems

Author: Andžej Šerlat[1]

Co-authors: Krzysztof Czuba [1]; Bartosz Gąsowski [1]; Maciej Grzegrzółka [1]; Paweł Jatczak [1]; Radosław Papis [1]; Igor Rutkowski [1]; Dominik Sikora [1]; Maciej Urbański [1]

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Phase reference distribution systems (PRDS) provide highly stable, in terms of amplitude and phase stability, reference signals for every part of particle accelerator control systems, and therefore, are crucial for meeting the beam parameters requirements. Among many PRDS requirements, short and long-term phase stability is paramount. In a brief description, the sources of phase instabilities in PRDS are of short-term character, mainly the phase noise of the RF reference signal source, and long-term character, coming from the phase drift introduced by the long coaxial cables, exposed to environmental factors, like temperature, humidity, and air pressure changes. The contribution presents the recent results of long-term phase drift introduced by some coaxial cables selected for potential use in various parts of LLRF and PRDS systems. The goal is to choose RF cables that, in terms of electrical delay, remain as stable as possible in changing environmental conditions. The results present trade-offs between cable diameter, mechanical flexibility, and phase stability versus temperature change vulnerability.

Abstract Category:

Timing and Synchronization

Poster Session 1 (System and Ops, Hardware) / 41

Minimum-Latency Optical Data Acquisition Link (Modal)

Author: Maciej Grzegrzółka[1]

Co-authors: Kaj Rosengren [2]; Krzysztof Czuba [3]; Paweł Jatczak [3]

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The European Spallation Source (ESS) beam instrumentation generates over 100 gigabytes of data per second from over 100 subsystems along the whole ESS linac. Currently, the data is only processed locally. The development of machine learning techniques and hardware created an opportunity to allow complex analysis of the data coming from the whole accelerator. Such analysis can bring benefits to the accelerator operation and improve its reliability.
The main aim of the Modal project is to collect the data from all beam instrumentation subsystems and send it to the central processing unit. This challenging task will be solved using dedicated hardware and firmware components.
This contribution presents the Modal concept and planned architecture with performance measurements, status and plans for the near future.

Abstract Category:

System and Operation

42

RF Phase Drift Measurements Using Two-tone Scheme

Authors: Andžej Šerlat[1]; Krzysztof Czuba[1]; Maciej Grzegrzółka[2]

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Modern linear accelerators require more precise phase drift stability of RF reference signals. Various stabilization schemes were developed to ensure proper phase stability. This contribution presents the preliminary results of a novel two-tone-based RF signal phase drift measurement system intended to be used in the PIP-II Beam Instrumentation Phase Reference Line (BIRL). The presented test system achieved an excellent temperature coefficient of just 0.67 fs/℃.
The system operating principle will be explained. This will be followed by a description of the assembled test system and its performance measurement. The final part presents the plans for further and preliminary BIRL system architecture.

Abstract Category:

Measurement and Control

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 43

LLRF Upgrades for Studying Transient Beam-Loading in RHIC 28 MHz Accelerator Cavity for the Electron-Ion Collider

Author: Arshdeep Singh[1]

Co-authors: Freddy Severino [2]; Geetha Narayan [2]; Kevin Mernick [2]; Kyle Fahey [3]; Michael McCooey [2]; Samson Mai [1]

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The 28 MHz cavities, currently used in the Relativistic Heavy Ion Collider (RHIC), will be modified into 24.6 MHz cavities to be used in the Hadron Storage Ring (HSR) for the future Electron-Ion Collider (EIC). One major difference between the EIC and the current RHIC system is that the EIC HSR will host proton beams with 10 times shorter bunch length, 3 to 10 shorter bunch spacing, and up to 3 times higher beam current than those in RHIC. While this will allow for greater luminosity, it will also introduce challenges for the LLRF system in the form of stronger transient beam-loading. To counteract these effects, digital implementations of a feedfoward (FFWD) and One-Turn Delay Feedback (OTFB) have been developed for an FPGA. Furthermore, using a newly developed digital network analyzer, software has been created that allows for a straightforward method of tuning the LLRF systems for maximum cavity impedance reduction. These developments will be evaluated with beam in the 28 MHz cavities during the 2025 RHIC Run.

Abstract Category:

Measurement and Control

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 44

Development of an FPGA-based Cavity Simulator for Testing RF Controls

Author: Arshdeep Singh[1]

Co-authors: Freddy Severino [2]; Geetha Narayan [2]; Kevin Mernick [2]; Kyle Fahey [3]; Michael McCooey [2]; Samson Mai [1]

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LLRF is used to precisely control the amplitude and phase of the RF field in cavities. Often times, access to test the control algorithms with RF equipment, especially in the presence of beam, is limited or beyond reach. In such cases, testing must be done through computer modeling or simulations. Computer modeling is often too slow and difficult to interface with the LLRF hardware. Analog or digital cavity simulators are preferred as they allow for interaction with the LLRF controls platform in real-time, and compared to their analog counterparts, FPGA-based digital cavity simulators allow for a more adjustable and sophisticated implementation. The newly developed FPGA-based cavity simulator includes the cavity electrical model, the cavity mechanical model including Lorentz Force Detuning and microphonics, an amplifier model which can simulate real amplifier nonlinearities, and a beam model. The simulator will be validated using measurements from BNL's CeC 500 MHz NCRF cavity and the CeC 704 MHz 5-cell SRF cryomodule.

Abstract Category:

Measurement and Control

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 45

Baseband Digital Network Analyzer Upgrade for LLRF Controllers

Author: Samson Mai[1]

Co-authors: Arshdeep Singh [1]; Freddy Severino [2]; Geetha Narayan [2]; Kevin Mernick [2]; Kyle Fahey [3]; Michael McCooey [2]

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Digital Network Analyzers (DNA) have been implemented in many LLRF systems to help characterize and tune digital feedback loops. A modular DNA has been developed on FPGA and integrated into the current RHIC LLRF infrastructure. The DNA characterizes a system by injecting a complex baseband chirp to calculate the system's magnitude and phase response. The DNA is also able to measure the open loop gain, gain and phase margins, and loop delay to help fine tune feedback loop parameters. The DNA has been verified with an implementation of one-turn delay feedback (OTFB) on the bench to maximize gain and stability. The DNA and OTFB are planned to be evaluated with dedicated beam time during a RHIC Accelerator Physics Experiment (APEX) study of transient beam loading. Once verified, the DNA will be integrated into the Common Hardware Platform for the future Electron-Ion Collider (EIC).

Abstract Category:

Measurement and Control

47

Development of new DLLRF for ALBA and ALBAII, for the main and for the 3rd harmonic RF systems

Author: Pol Solans[1]

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ALBA Low-Level RF (LLRF) system has provided over a decade reliable operation and has been adopted by other synchrotron facilities. To meet the evolving requirements of ALBA and ALBA-II, a new LLRF system has been developed for the current fundamental RF system and the future active normal conducting harmonic RF system. This new LLRF features FPGA and ADC/DAC µTCA boards designed by Safran, enabling direct 500 MHz signal sampling without down/up-conversion for the main RF system, while it requires an intermediate frequency in the case of the harmonic system performed in the RTM board itself. These enhancements reduce system complexity, minimize noise, and simplify maintenance. Safran also supplies peripheral modules and the Tango device server generator, while ALBA implemented it and developed a new GUI. Upgraded Digital and RF signal front-ends complement the new hardware. The legacy VHDL code has been updated to improve readability and functionality, incorporating advanced features such as octant selection and a harmonic direct feedback selection method. The latter, based on IIR filtering, isolates positive and negative revolution harmonics in the I/Q domain, feeding them back to amplifiers to effectively mitigate transient beam loading caused by the storage ring bunch train gaps. This upgraded LLRF system delivers enhanced performance and greater flexibility to address the future needs of ALBA and ALBA-II.

Abstract Category:

System and Operation

48

Upgrade of the Barrier Bucket LLRF system for High-Intensity, Low-Loss Multi-Turn Extraction at the CERN PS

Author: Toma Gavric[1]

Co-authors: Benjamin Woolley [1]; Heiko Damerau [1]; Mihaly Vadai [2]; Ylenia Brischetto [1]

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The CERN Proton Synchrotron (PS) LLRF system is one of the oldest in operation at CERN. To meet the growing demands of high-intensity fixed-target experiments at CERN, a sophisticated beam manipulation technique combining barrier-bucket radiofrequency gymnastics with Multi-Turn Extraction (MTE) has been developed and successfully implemented in the PS.
The newly developed system enables cycle to cycle updates off the turn-synchronous voltage waveform applied to the wide-band Finemet cavity. It allows both intra-cycle manipulations and synchronization with respect to the Super Proton Synchrotron (SPS) extraction reference. These features have been fully tested with both the MTE and ion beams, successfully demonstrating synchronous barrier bucket extraction and non-integer harmonic batch compression.
This contribution summarizes the upgrades to the Finemet cavity controller, showing the new system architecture and demonstrating its operation with beams in the machine.

Abstract Category:

Measurement and Control

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 49

RF Data Acquisition System for the APS Upgrade

Author: Timothy Madden[1]

Co-authors: Elaine Chandler [1]; John Breeding [2]; Klemen Vodopivec [3]; Sinisa Veseli [1]; Timothy Berenc [1]; Yawei Yang [1]

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An FPGA- and software - based system has been developed for real-time data acquisition (DAQ) on numerous RF and other technical subsystems of the Advanced Photon Source (APS) accelerator. The software, called DAQ, is based upon the EPICS control system and is tightly integrated to FPGA hardware running on a Micro Telecommunications Architecture (TCA) platform. The FPGA hardware continuously streams data from RF systems over a Peripheral Component Interconnect Express (PCIe) bus as Direct Memory Access (DMA) transfers to a Micro-TCA- based Linux blade. DMA data transfers trigger the EPICS DAQ software running on the Linux blade to continuously stream data to the APS network using the EPICS 7 PVAccess protocol. The RF DAQ software is integrated with many distributed software services on the APS network including data storage, data visualization, and RF system monitor and control. Development of this system required the integration of FPGA firmware, electronics hardware, and software developed by multiple groups at multiple institutions.

Abstract Category:

Software

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 50

The RF Test of the FPGA Based Digital Low-Level RF Control System for the LANSCE Proton Storage Ring

Author: Sungil Kwon[1]

Co-authors: Lawrence Castellano [1]; Michael Brown [1]; Paula Van Rooy [1]; Phillip Torrez [1]; Rupak Dahal [1]

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As part of the modernization of the Los Alamos Neutron Science Center (LANSCE), a digital low level RF (LLRF) control system for the LANSCE proton storage ring (PSR) is designed. The LLRF control system is implemented in a Field Programmable Gate Array (FPGA). The high resolution tunable 2.8MHz reference RF is generated by a direct digital synthesizer at the LANSCE front end and is transmitted to the PSR control system located half mile away. Since the digital LLRF control system is synthesized in the In-phase/Quadrature coordinate, the I/Q reference RF signals are generated by the FIR filter based Hilbert Transformer (HT). For the stabilization of the cavity field, a Proportional-Integral (PI) feedback controller is implemented. In addition, for the future application, a Proportional-Derivative (PD) type beam feedforward controller is provided. The performance of the designed LLRF control system was tested on the LANSCE PSR at full RF power without beam operation

Abstract Category:

Measurement and Control

52

TBD

Abstract Category:

Measurement and Control

Poster Session 1 (System and Ops, Hardware) / 53

Design of the Electron-Ion Collider Common Platform and Applications for RF Controls

Author: Kevin Mernick[1]

Co-authors: Freddy Severino [1]; Geetha Narayan [1]; Samson Mai [1]

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The EIC Common Platform is a modular system architecture which will serve as the basis for EIC Accelerator Controls. It consists of an SoC-based carrier board with up to two independent pluggable FPGA-based Daughtercards. Different types of Daughtercards have custom electronics catering to the specific needs of an application. Daughtercards will have FPGA logic to support a common protocol for communication with the carrier board as well as a basic set of features for programming and telemetry. RF Controls applications will use two versions of an RF Digitizer Daughtercard designed by the LLRF team as well as several of the general purpose Daughtercards designed in collaboration by the LLRF, Accelerator Controls, and Instrumentation groups. The system architectures for various LLRF applications using the Common Platform components will be presented.

Abstract Category:

Hardware

54

Overview of Electron Ion Collider RF Systems

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Co-authors: Freddy Severino [1]; Kevin Mernick [1]; Silvia Verdu Andres [1]; Zack Conway [2]

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Brookhaven National Laboratory (BNL) is the future home of Electron-Ion Collider (EIC) project that will be constructed in partnership with Thomas Jefferson National Accelerator Facility (Jefferson Lab, JLAB). The EIC proposal provides a design that utilizes the existing RHIC facility to produce hadron beams, including high-intensity polarized proton beams, to fully meet the requirements for a lasting research program with high potential for new discoveries. It is also planned as a cost-effective new facility with approximately 30 SRF cryomodules and 55 NCRF cavities that includes reuse of RHIC 28 MHz and 197 MHz cavities. Many systems are still developing but plenty of progress has been made on EIC RF Systems since it was last presented at LLRF Workshop 2022. The scope of the RF systems as currently defined at pre-construction design phase of the EIC project will be presented.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 55

Status of LCLS-II-HE LLRF Project

Authors: Andre McCollough[1]; Andy Benwell[1]; Daron Chabot[1]; Darren Orrell[1]; JING CHEN[1]; Jorge Diaz[1]; Keith Penney[2]; Larry Doolittle[2]; Lucas Russo[2]; Qiang Du[3]; Shreeharshini Murthy[3]; Sonya Hoobler[1]; Vardani Karthik[1]; Zack Taylor[1]

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The LCLS-II-HE project is a high-energy upgrade to the existing LCLS-II superconducting linac at SLAC, designed to increase the beam energy from 4 GeV to 8 GeV. This upgrade includes the addition of 184 high-energy (HE) SRF cavities operating at an average gradient of 22 MV/m, supplementing the 280 existing LCLS-II SRF cavities. To support these new cavities, the HE LLRF project will deploy 46 LLRF rack systems to provide precise RF field regulation—meeting amplitude and phase stability requirements of 0.01% and 0.01° RMS, and resonance control to maintain average cavity detuning below 1 Hz. This paper presents an overview of the HE LLRF project status, reviews system updates, and discusses readiness for the upcoming LLRF installation and checkout, along with key lessons learned throughout the project lifecycle.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 56

Future Upgrades to the LANSCE Accelerator

Author: Paula Van Rooy[1]

Co-authors: Lawrence Castellano [2]; Michael Brown [2]; Phillip Torrez [2]; Rupak Dahal [2]; Sungil Kwon [1]

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The Los Alamos Neutron Science Center (LANSCE) Accelerator is in the initial planning stages to upgrade the front-end of LANSCE, a project known as the Los Alamos Modernization Project (LAMP). As a part of this upgrade the Low-Level Radio Frequency (LLRF) team will be replacing most of their equipment. This involves removing and installing new equipment related to the sources, injectors, low energy beam transport (LEBT), radio-frequency quadrupole (RFQ), medium energy beam transport (MEBT) and the drift-tube linac (DTL). Additionally, a test accelerator will be built to demonstrate the proof of concept for the new systems before removing the front-end of LANSCE. This poster will present the current status of the initial planning of the LAMP project, LLRF's approach to LAMP, the proposed timeline and goals of the LAMP project.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 57

Comparative Evaluation of Xilinx RFSoC Platform for Low-Level RF Systems

Author: Shreeharshini Dharanesh Murthy[1]

Co-authors: Victoria Moore ; Qiang Du ; Angel Jurado Lopez ; Keith Penney ; David Nett ; Benjamin Flugstad

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The rapid advancement of Radio Frequency System-on-Chip (RFSoC) technology from Xilinx (AMD) has enabled the integration of high-speed data converters and programmable logic within a single package. RFSoC platforms are already widely adopted in telecommunications, radar, and satellite communications, where they promise reductions in system footprint and power consumption. However, their suitability for Low-Level RF (LLRF) control systems in accelerator environments—where stability requirements are critical—has not been quantitatively evaluated. This paper presents a comparative measurement-based assessment of RFSoC-based and conventional LLRF designs, focusing on signal fidelity, phase noise, latency, system complexity, and integration challenges. The advantages and challenges of adopting RFSoC-based direct conversion architectures are discussed, providing guidance for future LLRF system implementations.

Abstract Category:

Hardware

58

Low-Level RF System Development for EIC Crab Cavities

Author: Freddy Severino[1]

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The Electron-Ion Collider (EIC) will operate with a 25 mrad crossing angle at the interaction points to enable rapid beam separation, reduce detrimental beam-beam effects, and provide space for forward detectors. This crossing geometry, however, significantly reduces the overlap region of the colliding bunches, resulting in nearly an order of magnitude luminosity loss. To restore effective head-on collisions and achieve maximum luminosity, crab cavities will apply transverse kicks to each bunch, rotating them in the crossing plane. The success of this scheme depends critically on the performance of the Low-Level RF (LLRF) system, which must deliver high-gain, low-noise field control to suppress transverse emittance growth and maintain beam stability. This presentation will describe the LLRF system architecture and control strategy for the EIC crab cavities, including RF noise mitigation, impedance control, crabbing phase closure, and integration planning. The current hardware development status and the roadmap toward full system implementation will also be presented.

Abstract Category:

Other

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 59

Analysis of Required Anode Current in High-Intensity Proton Operations Using LLRF signals and Phasor diagram

Authors: Kiyomi Seiya[1]; Yasuyuki Sugiyama[1]; Fumihiko Tamura[2]; Masahito Yoshii[1]

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The J-PARC Main Ring (MR) is progressing toward the delivery of a 1.3 MW proton beam to the Hyper-Kamiokande neutrino experiment by 2028. To achieve this, the number of protons per pulse (ppp) will increase from 2.3E14 to3.1E14 ppp along with a reduction in the repetition cycle from 1.32 s to 1.16 s.

To accommodate the resulting increase in beam loading, the required anode current—supplying power to two 600 kW tetrode vacuum tubes—will approach the maximum rated capacity of 127 A, based on the current cavity configuration and voltage pattern. The generator current from the RF amplifier sustains the cavity gap voltage, which corresponds to the vector sum of the beam-induced current and the generator current.

The digital Low-Level RF (LLRF) control system, implemented in 2019, ensures stability of both the cavity voltage and phase via active feedback control. Key signals such as the LLRF driving RF signal, the gap voltage signal, and the beam signal provide insights into the dynamic behavior of the system.

In this presentation, we will present measurements of these three RF signals and illustrate their interrelationship using a phasor diagram. We will also discuss potential modifications to the LLRF control system to enable integrated real-time analysis based on this measurement approach.

Abstract Category:

Measurement and Control

60

LBNL Lab Talk

Author: Alessandro Ratti[None]

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This presentation will highlight LLRF activities at LBNL, covering both our accelerators, the collaborations with other laboratories and some applications beyond accelerator controls.

Abstract Category:

Lab Talk

62

Piezo compensation algorithm for SC cavities at ESS

Author: Anders Svensson[1]

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The 3 ms long RF pulse at ESS will make Lorentz force detuning (LFD) significant for the superconductive cavities and at 14 Hz repetition rate some ringing might still be present at the start of the next pulse. An iterative compensation algorithm have been developed to reduce the required overhead to maintain a constant cavity field. It is based on detuning calculation of each pulse and provides a voltage to the Piezo stack to counteract LFD. Design details and initial results will be presented.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 63

A Phase-Stable, Low-Loss, High-Directivity 162.5 MHz Coupler for Use in a Phase Reference Distribution Line

Author: Bartosz Gąsowski[1]

Co-authors: Radosław Papis [1]; Krzysztof Czuba [1]; Maciej Grzegrzółka [2]

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We present a custom-designed directional coupler intended for use in phase reference distribution systems for linear particle accelerators. Such systems require low phase drift, handle relatively high-power signals, and often are subjected to ionising radiation. The coupler is designed for an operating frequency of 162.5 MHz, 25 dB coupling, and input power in the range of 40-50 dBm. The prototype achieves mainline insertion loss below 0.03 dB and directivity above 35 dB. Its physical length of 21

cm (approx. 8¼") is well below quarter-wavelength, making it relatively compact. To allow use of the coupler near the beam-line, radiation-sensitive materials such as PTFE are avoided in the construction. The internal structure is realized on a printed circuit board (PCB), which allows for ease and high repeatability of manufacturing. Importantly, the PCB dielectric serves mainly as a mechanical support for the copper pattern and its influence on the electromagnetic field is minimized. This helps reduce phase drifts due to the sensitivity of dielectric permitivity to temperature changes.

Abstract Category:

Timing and Synchronization

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 65

LCLS-II-HE PHASE REFERENCE LINE

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The Phase Reference Line (PRL) for LCLS-II-HE is an extension of the PRL used for LCLS-II. The system provides a reference signal of 1300 MHz, a 185.7 MHz reference signal for the timing system, and a 1320 MHz LO for the LLRF system. The 1300 MHz signal is sent along a rigid coaxial cable down in the linac tunnel for minimal changes in length due to thermal expansion and contraction. To cancel out the effect of thermal drift on the phase of the signal, phase averaging is used. For the HE installation, the rigid coaxial line in the linac tunnel will be extended from sector 7 to sector 10. In the klystron gallery, the 185.7 MHz timing reference signal and the 1320 MHz LO signal will be extended down to sector 10 and distributed to the LLRF racks. There is also consideration for moving the MO from sector 2 to the Injector CID for increased beam stability or moving the MO to sector 10 and replacing the RF over fiber system with a coaxial line to the experiment hall for increased stability on that end.
This poster will discuss the overall system design, the performance, the extension of the system for the HE installation and the potential changes made to the existing system.

Abstract Category:

Timing and Synchronization

66

RFSoC based LLRF system design at ALS

Authors: Qiang Du[1]; Shreeharshini Murthy[1]; Victoria Moore[None]; Angel Jurado Lopez[None]; Keith Penney[2]; Michael Chin[1]; David Nett[None]; Benjamin Flugstad[None]

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The Advanced Light Source (ALS) at LBNL is upgrading several LLRF systems for its Linac and Sub-Harmonic Bunchers, where it is desired to have a unified LLRF system design to support various RF frequencies (at 125MHz, 500MHz and 3GHz) and configurations. This paper demonstrates an open-source, direct sampling RFSoC based LLRF system design, featuring: sample-to-sample Multi-Tile

Synchronization, deterministic latency, digital up/down conversion, arbitrary waveform generation and acquisition, in-pulse closed loop control, timing and EPICS integration, modular RF frontend and hardware designs. Measured RF characteristics show that the RFSoC LLRF system is able to meet the system requirement.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 67

Identifying the source of beam loss events with Fast Data Acquisition (DAQ) Chassis

Author: Jayendrika Tiskumara[1]

Co-authors: Adam Carpenter [1]; Brian Bevins [2]; Clyde Mounts [3]; Curt Hovater [4]; Dennis Turner [1]; James Latshaw [5]; Rama Bachimanchi [1]; Tom Powers [4]; Tomasz Plawski [1]

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Determining whether an RF cavity with an undetected gradient or phase transient is the culprit behind a beam loss event has been found to be a valuable tool for CEBAF operations. Analysis of beam position with the existing switched electrode electronics BPM hardware at the dispersive area and energy variation before a beam loss event was suggested as a method to determine if the beam loss event was correlated with an energy transient. With this purpose in mind, a prototype off-line system was developed in the fall of 2022. It implemented using National Instruments hardware and LabVIEW software and relied on a software trigger and was not integrated into the EPICS control system. Beam trips with energy transients are compared to the reason for the trips found in the CEBAF down time monitoring system. The initial results indicated that 20% of the faults had energy transients that were not coincident with any cavity faults. As a result cavity interlocks were adjusted so that the cavities tripped on such events. As a solution an existing data acquisition system that was developed for monitoring legacy RF systems in CEBAF system was deployed. It was used to capture BPM wire signals at a sample rate of 20 ksps; was triggered by a fiber signal that is part of the fast shutdown system; and was integrated into the EPICS control system. In addition to being able to analyze the energy transients live in the control room as well as after the fact, these systems allowed us to understand the energy jitter properties just prior to the fault. This paper will present recent results and describe a path forward using commercial off the shelf hardware installed in multiple locations which can be easily be integrated into EPICS.

Abstract Category:

Other

68

Reverse phase operation for CERN's FCC-ee 400 MHz RF system: Increasing flexibility brings challenges for cavity control

Author: Ivan Karpov[1]

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CERN's planned Future Circular electron-positron collider (FCC-ee) must accommodate very different RF system requirements at different energy points, driven by a fixed synchrotron radiation power budget of 100 MW. Recently, a unified RF cavity design with constant loaded quality factor suitable for three beam energies (45.6, 80, and 120 GeV) was adopted as the baseline. The new RF system implementation requires the inclusion of the reverse phase operation (RPO) scheme for the Z operating point (45.6 GeV). In this contribution, the main principles of the RPO scheme are first explained. The need to mitigate the enhancement of transient beam loading due to the RPO scheme is described, along with the corresponding LLRF and HLRF requirements to achieve precise control of the cavity field. Finally, the dynamics of the beam and RF system in the event of RF system failures are analyzed, including a detailed implementation of LLRF loops and interlocks.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 69

Integrated Automation in SHINE LLRF Control System: Design, Implementation and Performance

Author: kai xu[1]

Co-authors: hailong wu [1]; hong wu [1]; hongru jiang [1]; wenfeng yang [1]; xiang zheng [1]; xuefang huang [1]; yubin zhao [1]; yuechao yu [1]; zhigang zhang [1]

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This paper presents the design, implementation, and operational performance of the Low-Level Radio Frequency (LLRF) control system for SHINE. The system adopts a two-layer software architecture to achieve integrated automation in RF field stabilization, fault handling, and multi-cavity coordination. The lower layer utilizes EPICS IOCs implemented on Zynq SoC platforms to provide real-time cavity control. This layer supports multiple operational modes including normal beam operation, maintenance procedures, and automatic fault recovery.The upper management layer coordinates all cavities through distributed EPICS PV monitoring and implements system-wide fault tolerance logic. Key features include real-time status monitoring, automated fault analysis, and coordinated recovery. Notable innovations include the EPICS-Zynq integration for low-latency control, dynamic reconfiguration capability for different operation modes, and data-driven fault diagnosis.This control architecture represents a significant advancement in accelerator automation, combining real-time hardware control with intelligent system management. The implementation provides a robust solution for SHINE's demanding performance requirements while offering tools for efficient operation and maintenance.

Abstract Category:

Software

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 70

LLRF Control System for S-Band Deflecting Cavity at SHINE

Author: xuefang huang[None]

Co-authors: xiang zheng [1]; yubin zhao [1]; kai xu [1]; zhigang zhang [1]; hong wu [1]; wenfeng yang [1]; yuechao yu [1]; hailong wu [1]; hongru jiang [1]

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A traveling-wave transverse RF deflecting structure enables bunch length measurements at the Shanghai High Repetition Rate XFEL and Extreme Light Facility (SHINE). To enhance amplitude and phase stability in this S-band cavity, an efficient LLRF control system implements pulse-to-pulse techniques: feedforward control dynamically adjusts intra-pulse modulator HV amplitude to regulate klystron output power (accelerating voltage), while feedback control stabilizes phase by adapting the low-level RF drive. This paper presents the system's detailed design and implementation.

Abstract Category:

Measurement and Control

Poster Session 1 (System and Ops, Hardware) / 71

LLRF for the L-Band Buncher in SHINE

Author: Zhigang Zhang[None]

Co-authors: Hailong Wu ; Hongru Jiang ; Wenfeng Yang ; Xiang Zheng ; Xu Kai ; Xuefang Huang ; Yuechao Yu ; Yubin Zhao

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In the Hard X-ray Free Electron Laser (SHINE), the normal-conducting L-band buncher is critical for compressing electron bunches, significantly improving beam quality to meet stringent low-emittance and low-energy-spread injection requirements. Due to its 2-cell structure, a digital LLRF control system which based on an FPGA and RF front-end architecture using I/Q demodulation was designed. This system implements amplitude/phase feedback, frequency tuning, and multi-motor coordination for field flatness control. During 10kW continuous-wave (CW) operation the amplitude stability (peak-to-peak) improved from ±0.17% in open-loop to within ±0.03% under closed-loop, while the phase stability (peak-to-peak) was controlled within ±0.05°,and field flatness was maintained within ±2%, fully meeting design specifications. This achievement is critical for ensuring high-stability accelerator operation.

Abstract Category:

Hardware

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 72

Fault Prediction and Diagnosis for SRF Systems–Focus on RF Power Source Failures

Authors: Jiayi Peng[1]; Lijuan Yang[1]

Co-author: Feng Qiu [1]

[1] *Institute of Modern Physics*

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This research aims to develop an efficient and reliable fault detection method for radio frequency (RF) superconducting cavity system power sources. Superconducting cavities are core components of large-scale scientific facilities such as particle accelerators and synchrotron radiation light sources, and their stable operation is crucial for successful experiments. However, as a key component driving superconducting cavities, potential faults in RF power sources can lead to system performance degradation or even interruption. Traditional fault detection methods often rely on manual experience or simple threshold judgments, which suffer from low detection accuracy, poor real-time performance, and difficulty in handling complex fault modes.

This abstract proposes an intelligent fault detection framework based on machine learning, designed to overcome the limitations of traditional methods. The method first involves real-time data acquisition of critical operating parameters of the RF power source, such as output power and LLRF output. Subsequently, through feature engineering on these multi-dimensional data, effective features that can characterize the system's health status are extracted. During the fault detection model training phase, a combined strategy of supervised learning and unsupervised learning will be employed. For known fault types, classification models such as support vector machines will be constructed for precise identification; for unknown or novel faults, anomaly detection algorithms such as local outlier factor will be utilized for real-time early warning.

Experimental validation on CAFe2 demonstrates that this method can detect power source faults 15 days in advance. The research provides effective technical support for the predictive maintenance of SRF systems, enhancing the operational reliability and efficiency of large-scale scientific facilities.Compared to traditional methods, this intelligent fault detection system exhibits stronger adaptability and robustness, effectively reducing system downtime and ensuring the stable operation of large-scale scientific facilities. This research provides new insights for the predictive maintenance and intelligent management of RF superconducting cavity system power sources.

Abstract Category:

Software

73

LLRF activities at CERN

Author: Ben Woolley[1]

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This talk will present an overview of the ongoing and future Low-Level RF (LLRF) activities at CERN, addressing the growing challenges of hardware obsolescence, support for legacy systems, and the need for long-term consolidation across the accelerator infrastructure. Major ongoing projects, such as the development of the Crab Cavity controller with beam noise feedback for the High Luminosity LHC, the LLRF system for AWAKE Run 2c, and ongoing efforts in supporting superconducting RF cavity testing through dedicated controls infrastructure will be covered.

Going forward, LLRF studies for the Future Circular Collider (FCC) are underway, with possible co-development activities foreseen with the LHC and electron injectors. In parallel, machine learning and AI techniques are being actively investigated for applications in diagnostics, anomaly detection, and real-time control optimization.

Abstract Category:

Lab Talk

Poster Session 1 (System and Ops, Hardware) / 74

EIC Resonance and Interlocks Control

Author: James Latshaw[1]

[1] *JSA*

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The Electron Ion Collider project is a large and exciting effort within the accelerator community. There will be 8 different styles of Cryomodule and as many varied styles of normal conducting cavities. All of these modules require interlock protection and most require some form of resonance control. This abstract presents the ongoing efforts at Jefferson Lab to develop a modular system which can scale in accordance to a cavities resonance and interlock control needs; thereby reducing the number of different styles of resonance and interlocks control chassis required and consolidates the interface controls to one common system. The immediate benefit is reduced cost in manufacturing and the long term benefit will be in simplified support for common shared spares.

Abstract Category:

Hardware

Poster Session 1 (System and Ops, Hardware) / 75

Fast DAQ for Machine Learning

Authors: Curt Hovater[1]; Dennis Turner[2]; James Latshaw[3]; Jayendrika Tiskumara[2]; Rama Bachimanchi[2]; Tomasz Plawski[2]

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At the LLRF 2023 conference, Jefferson Lab's Fast DAQ for Machine Learning was shared. This system equips the legacy CAMAC zones with a digital fast data acquisition system which samples and reports at a rate of 5 kHz to allow for detection of transients that operators would be otherwise blind to. This equips the legacy zones with both real time waveforms of key cavity control signals as well as the ability to trigger when beam is lost in the machine. This poster will help track ongoing efforts related to these fast DAQs as well as some problems that were encountered along the way.

Abstract Category:

Hardware

76

Advanced LLRF Automation and Diagnostic Strategies for Horizontal Testing of HIAF SRF Cavities

Author: FENG QIU[1]

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The High Intensity heavy-ion Accelerator Facility (HIAF), currently under construction, will employ a series of superconducting RF (SRF) cavities in its injector linac (iLinac) to accelerate heavy-ion beams. Comprehensive performance validation of each SRF cavity in a horizontal test stand prior to its installation in the accelerator tunnel is a critical prerequisite for the successful commissioning of the iLinac. To this end, we have developed an advanced Low-Level RF (LLRF) automation and diagnostic system for the horizontal test stand of HIAF's low-beta SRF cavities. This system integrates several key functions: high-precision measurement of cavity parameters, automated conditioning at both room and cryogenic temperatures, reliable quench detection, and stable closed-loop operation. The successful application of these advanced strategies not only validates that the cavity performance meets design specifications but also significantly enhances the efficiency and consistency of the testing process, laying a solid foundation for the subsequent installation and commissioning of the HIAF iLinac.

Abstract Category:

Measurement and Control

77

Status of the ISIS Digital LLRF Systems

Author: Andrew Seville[1]

Co-authors: David Allen [1]; Neil Farthing [1]; Ian Gardner [1]; David Gibbs [1]; Alan Letchford [1]; Robert Mathieson [1]

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A digital LLRF system [1] has been successfully developed and deployed for control of the accelerating Voltages on the Ferrite loaded RF cavities on the ISIS Synchrotron over the last decade. The final stage of the digital control system has recently been completed which now includes digital control of the cavity tuning.
Similar National Instruments FPGA modules to those used in the Synchrotron LLRF system have been used to develop a LLRF control system for the RAL Front End Test Stand (FETS) [2] and the ISIS Pre-Injector Test Stand (PITS) [3]. These systems are based on the digital LLRF system developed at the University of the Basque Country [4].
The RF system on FETS comprises of a Radiofrequency Quadrupole (RFQ) and 3 re-bunching cavities operating at 324MHz. That for PITS consists of an RFQ and 4 quarter wave resonator cavities all operating at 202.5MHz and is intended as a pre-cursor to the upgrade of the ISIS Pre-Injector planned for 2027, when the same LLRF control system will also be deployed on the 4 LINAC tanks and de-bunching cavity. Initial tests of the LLRF system have been made on one of the QWR cavities and both RFQs and will be continued as more cavities become available.

1. "Status of the ISIS Synchrotron Digital LLRF System"Seville et al, LLRF 2022.
2. "Status of the RAL Front End Test Stand"Letchford et al, IPAC 2015.

3. "The Pre-Injector Upgrade for the ISIS H– LINAC"Lawrie et al, LINAC 2022.
4. "New PXIe-Based LLRF Architecture and Test Bench for Heavy Ion Linear Acceleration"Badillo et al, IEEE-NPSS Real Time Conference 2014

Abstract Category:

Measurement and Control

Poster Session 1 (System and Ops, Hardware) / 78

Local Oscillator Conditioner for the Electron Ion Collider

Author: Joshua Settle[1]

Co-author: Kevin Mernick [2]

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[2] *BNL*

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The Electron Ion Collider is an exciting collaborative effort to advance and invest in the future of nuclear physics and accelerator science. Part of this great effort includes designing a diverse set of RF cavities and control systems, in which heterodyning still plays a fundamental role. There are multiple frequencies in the VHF and UHF bands which require up and/or down conversion, and designing one circuit board that can accommodate local oscillator signals for multiple mixing schemes was a valuable and interesting task. A combinatorics problem emerged out of this component's constraints that required organizing a large number of cases and integrating commercial data to reveal the best design choices. Pictures of the prototypes and their performance are displayed to demonstrate its success. This poster showcases only part of the vast and impressive collaboration between Brookhaven National Laboratory and the Thomas Jefferson National Accelerator Facility.

Abstract Category:

Hardware

Poster Session 1 (System and Ops, Hardware) / 79

LLRF COMMISSIONING OF THE CEBAF C75 UPGRADES SAM 2024/2025

Authors: Clyde Mounts[1]; James Latshaw[2]; Jayendrika Tiskumara[3]; Joshua Settle[3]; Michael Geesaman[None]; Rama Bachimanchi[3]; Tomasz Plawski[3]

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One easily overlooked component of Low-Level Radio Frequency (LLRF) design is the commissioning of new system installations. During Jefferson Lab's (JLab) 2024 Scheduled Accelerator Maintenance (SAM), two CEBAF zones were upgraded with C75 Cryomodules and JLab's LLRF 3.0 system.

JLab's team has invested heavily in the automation and standardization of their commissioning process. Several key components of this process include verification of the interlocks, klystron characterization and cavity characterization. This poster will present a summary of LLRF commissioning at JLab.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 80

RF modeling of EM cavity resonator in Simulink

Author: Temo Vekua[None]

The presentation showcases RF modeling techniques for designing a digital twin of electromagnetic cavity resonators in Simulink. A comprehensive workflow includes:
• RF data analysis
• system design
• budget analysis
• simulation of RF-controlled components at the system level
Simulink offers a unified environment for seamlessly integrating RF chains with digital signal processing algorithms and control logic in feedback and feedforward configurations.
Through simulation-driven insights, the session highlights how engineers can model, analyze, and refine resonant cavity performance using digital twin strategies, accelerating development and boosting system reliability in RF applications.

Abstract Category:

Software

82

Anomaly Detection in the CERN Proton Synchrotron RF Systems Using Machine Learning

Author: Joel Axel Wulff[1]

Co-author: Alexandre Lasheen [1]

[1] *CERN*

Corresponding Author: joel.wulff@cern.ch

The CERN Proton Synchrotron (PS) is equipped with several RF systems covering a wide range of revolution frequency harmonics. While the beam synchronous RF signal generation and cavity controllers are mostly digital, the global low-level RF beam loops still rely on analogue hardware. Upgrades to a fully digital system are underway.

Digitizing additional key signals from the present beam control recently enabled the exploration of automated monitoring methods. Subtle RF issues such as parameter drifts and intermittent anomalies often go undetected, delaying diagnosis until beam quality degrades or operation is disrupted. To address this, we investigate machine learning-based anomaly detection models that aggregate information from low-level RF signals, beam diagnostics, and contextual data (e.g. magnetic field). These models seek to automatically detect abnormal behaviour and connect beam effects with underlying causes linked to the RF systems, supporting both real-time alerts and root-cause analysis.

This proactive, data-driven approach aims to shorten the response time to performance degradation, improve reliability, and support preventative maintenance of the PS RF systems.

Abstract Category:

System and Operation

Poster Session 2 (Software, SRF Ctrl, Timing, Meas & Ctrl, Other) / 84

LEMP LLRF Firmware and Software

Author: Jorge Diaz Cruz[1]

Co-authors: Andy Benwell [1]; Larry Doolittle [2]; Nashat Sawai [3]; Qiang Du [4]; Shreeharshini Murthy [4]; Sonya Hoobler [1]

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[2] *LBNL*

[3] *Stanford Linear Accelerator Center (SLAC)*

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The LCLS began operations in 2009, utilizing SLAC's normal-conducting LINAC, which features control equipment dating back to the 1960s and 1980s. The Linac Electronics Modernization Plan (LEMP) aims to replace the legacy control equipment with a system based on the open-source Marble carrier board and a modified version of the Zest digitizer board, both of which are used in the LCLS-II HE LLRF system. Adaptation of the LLRF system from the CW SRF LCLS-II to the short RF pulse NC LCLS includes leveraging the knowledge and experience gained from recent LLRF projects at SLAC and efficiently reusing the core functionality of the code base developed at LBNL. Here, we describe the firmware and software infrastructure, highlight key features, and present initial test results.

Abstract Category:

Other

85

APS-Upgrade Digital LLRF Systems Summary*

Author: Tim Berenc[1]

Co-authors: John Breeding [2]; Timothy Madden [1]; Yawei Yang [1]

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[2] *Cutting Edge Communications*

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Various digital low-level radiofrequency (LLRF) systems are now operating for the Advanced Photon Source Upgrade (APS-U). This includes a passive superconducting bunch-lengthening cavity LLRF system primarily used for quench detection and signal monitoring of both the cavity and beam. The original analog-based LLRF systems for the klystron-driven main accelerating cavities were kept intact. However, a digital 60-Hz-harmonic-related rf noise suppression (RFNS) system was added to suppress noise from the megawatt-class klystrons which leads to beam motion. Additionally, within the injectors, the Particle Accumulator Ring was upgraded to digital LLRF for improved control. This report summarizes the systems and shares operational experience with beam.

- Work supported by U. S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 86

RF commissioning at SHINE injector

Author: Yubin zhao[1]

Co-authors: Hailong Wu [1]; Hongru Jiang [1]; Kai Xu [1]; Qiang Chang [1]; Wenfeng Yang [1]; Xiang zheng [1]; Xuefang Huang [1]; Yuechao Yu [1]; Zhigang Zhang [1]

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The SHINE injector consists of an electron gun, a bunching cavity, a single-cavity cryo-module, and an 8-9 cell cryo-module. It has now completed commissioning, with an output energy of 100 MeV and an energy jitter of 0.003% (RMS). The amplitude and phase control accuracy of all RF acceleration structures have met the design specifications.

Abstract Category:

System and Operation

87

Seven Years of RF Fault Identification at JLAB

Author: Tom Powers[1]

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The digital low level RF systems that are used to operate 17 of the 53 cryomodules that are installed in CEBAF have the capability to log 17 waveforms either on demand or when one of the cavities in the cryomodules trips off. In 2018, the software and hardware in the digital low-level RF systems was configured such that a fault would trigger an acquisition process to record 17 RF waveform signals for each of the 8 cavities within the cryomodule for subsequent analysis. To date approximately 15,000 faults have been analyzed. This contribution will describe the types of faults encountered during operation and their signatures in the time domain data, as well as how it is being used to modify the setup of the machine and implement improvements to the cryomodules.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 88

The Development of an Ultra-Low Phase Noise Source for Electron-Ion Collider Crab Cavities

Author: Michael McCooey[1]

Co-authors: Arshdeep Singh [1]; Freddy Severino [2]; Geetha Narayan [3]; Kevin Mernick [4]; Kyle Fahey [3]; Samson Mai [1]

[1] *Brookhaven National Laboratory*

[2] *Brookhaven National Labs*

[3] *Brookhaven National Lab*

[4] *BNL*

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The Electron-Ion Collider (EIC) is a long-term project to design and construct a facility to collide high energy polarized electron beams with polarized proton and heavy ion beams at center of mass energies from 20 to 140 GeV with luminosity up to 1034 cm-2s-1. This facility will be built on top of the Relativistic Heavy Ion Collider (RHIC), Brookhaven National Laboratory's current operational high energy collider. In order to achieve the high luminosity outlined in the EIC's design, Crab Cavities will be used around Interaction Points to correct for geometric effects due to crossing angles. These cavities have extremely strict phase noise requirements that are challenging to achieve (< -151 dBc/Hz at a 10 kHz offset from a 197 MHz Carrier). In order to meet these requirements, a low noise 2 GHz clock was designed using a 100 MHz OCXO. The 100 MHz OCXO was then locked to a separate low noise 100 MHz clock using an analog PLL to further reduce close in phase noise. This clock was then used with a low noise DAC (AD9164) to generate an RF drive signal at various frequencies of interest.

Abstract Category:

Hardware

89

Status of LLRF activities at SLAC

Author: Andy Benwell[1]

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A status of LLRF activities at SLAC will be presented including operational accelerators and ongoing projects.

Abstract Category:

Lab Talk

Poster Session 1 (System and Ops, Hardware) / 90

LLRF system upgrade of Argonne Wakefield Accelerator Facility

Authors: Alexander Ody[1]; Charles Whiteford[1]; Eric Wisniewski[1]; Gongxiaohui Chen[1]; John Power[1]; Josh Hlavenka[1]; Keith Penney[2]; Larry Doolittle[2]; Lucas Russo[2]; Qiang Du[3]; Qing Ji[3]; Scott Doran[1]; Shreeharshini Murthy[3]; Wanming Liu[1]

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In collaboration with the Berkeley Accelerator Controls and Instrumentation Program, the Argonne Wakefield Accelerator Facility successfully completed an upgrade of its Low-Level Radio Frequency (LLRF) system using the LCLS-II LLRF platform. This poster will present the details of the upgrade.

Abstract Category:

System and Operation

91

Analysis of Deployment Challenges for Machine Learning Signal Processing Algorithms

Author: Jonathan Edelen[1]

Co-authors: Christopher Hall [1]; Vikshar Rajesh [1]

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A challenge that industrial particle accelerators face is the high amounts of noise in sensor readings. This noise obscures essential beam diagnostic and operation data, limiting the amount of information that is relayed to machine operators and beam instrumentation engineers. Machine learning-based techniques have shown great promise in isolating noise patterns while preserving high-fidelity signals, enabling more accurate diagnostics and performance tuning. Our work focuses on investigating the challenges associated with the implementation of a noise reduction autoencoder that operates in real time on a Field Programmable Gate Array, which we do by creating firmware to run on a Xilinx ZCU104 evaluation kit with the intention of being deployed on industrial particle accelerators in the near future.

Abstract Category:

Measurement and Control

93

High-Precision LLRF System for the upgrade of SXFEL

Authors: CHENGCHENG XIAO[1]; Wencheng Fang[None]; YIMING XU[2]

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A high-performance low-level radio frequency (LLRF) control system based on ZYNQ MPsoc has been developed to enable the digital and intelligent upgrade of Shanghai Soft X-ray Free-Electron Laser (SXFEL). It includes 8 channels of 310 MSPS 16-bit ADCs and 2 channels of 500 MSPS 16-bit DACs, capable of outputting continuous wave and pulse wave signals, respectively. The LLRF control system is equipped with an FMC(LPC) interface to communicate with the White Rabbit(WR) device in the control system, providing feedback on the SXFEL' s orbit, focusing, and beam energy states. In experimental measurements on SXFEL, the LLRF system achieves a amplitude stability of 0.016% (RMS) and a phase stability of 0.015o at pulse compressor output.

Abstract Category:

System and Operation

94

Crab Cavity Low-Level RF in hadron machines

Author: Themis Mastoridis[1]

[1] *California Polytechnic State University, San Luis Obispo*

Corresponding Author: tmastori@calpoly.edu

The Crab Cavity Low-Level RF systems in hadron machines will have to reduce the Crab Cavity impedance to prevent transverse instabilities, while regulating the crabbing voltage and minimizing the Radio Frequency noise levels injected to the beam. These are challenging and partly conflicting requirements. In this talk, I will summarize the studies that set the Crab Cavity LLRF specifications and guide the design. I will also present possible trade-offs in the architecture and identify the major challenges as these systems are designed, built, and commissioned.

Abstract Category:

Other

95

Electromagnetic compatibility. Does it matter when everything is digital anyway?

Author: Daniel Valuch[1]

[1] *CERN*

Corresponding Author: daniel.valuch@cern.ch

With evolution of technology, accelerator RF systems are becoming more and more complex and dense. At the same time, requirements for performance, precision or noise floor are getting increasingly tighter. Electromagnetic compatibility and signal integrity must be part of the design right from the beginning regardless if is it a 1 MW RF amplifier or an FPGA sitting on a 10 layer printed board.

In this tutorial, we will recap basic principles of EMC and signal integrity and discuss some of the most popular problems on signal routing, printed boards, decoupling, cables, connectors, grounding, filtering or shielding.

Abstract Category:

Other

96

System identifications of superconducting cavity parameters with recursive least squares algorithms

Author: Volker Ziemann[1]

[1] *Thomas Jefferson National Accelerator Facility*

Corresponding Author: ziemann@jlab.org

Based on analyzing the forward and transmitted signals we describe algorithms to continuously improve estimates of cavity parameters, such as bandwidth and detuning. We also discuss the trade-off between ultimately achievable precision and the ability to follow time-varying parameters. The method can be adapted to additionally measure the unloaded and the external quality factor.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

98

BNL Lab Talk

Author: Kevin Mernick[1]

Co-authors: Arshdeep Singh [1]; Freddy Severino [2]; Geetha Narayan [3]; Kyle Fahey [3]; Michael McCooey [1]; Samson Mai [1]

[1] *Brookhaven National Laboratory*

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This talk will review the LLRF activities at BNL for the Collider-Accelerator complex and the Electron-Ion Collider (EIC). Topics include analysis, specification and development of systems for the EIC as

well as operational highlights for the Relativistic Heavy Ion Collider (RHIC) and its injector complex.

Abstract Category:

Lab Talk

99

Registration Open and Exhibitor Load In

100

China Lab Talk

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Abstract Category:

101

SRF Controls Talk - To Be Determined

Abstract Category:

102

Software Talk - To Be Determined

103

Progress in Advanced Ferroelectric Technologies for Fast SRF Cavity Tuning

Author: Alexei Kanareykin[1]

[1] *Euclid Techlabs LLC*

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With the talk, we present recent developments of the high-power microwave components with their applications for SRF accelerators. The first example is the Ferroelectric Fast Reactive Tuner (FE-FRT) developed by Euclid in collaboration with FNAL and BNL, and successfully tested at CERN. This technique has now become practically feasible due to the recent development of a new extremely low loss and fast (10 ns-100 ns time range) ferroelectric material, which has been tested, and fast frequency tuning has been demonstrated. The Horizon Europe iSAS project focuses on improving accelerator efficiency and includes the integration of a ferroelectric fast reactive tuner (FE-FRT) to

enhance energy conservation. Applications under this initiative include transient beam loading and microphonic compensation. In the U.S., FE-FRT technology is under active development for microphonics compensation in CEBAF by the DOE SBIR 2025 project. In the initial part of the project, an RF model of a 3-stub tuner with the ferroelectric section are being fabricated to be tested at Jlab. Control System and LLRF model of integration of the ferroelectric based three-stub tuner into the CEBAF cryomodule is under development.

Abstract Category:

SRF Control (RF for Superconducting Resonators)

104

Measurement and Controls Talk - TBD

Poster Session 1 (System and Ops, Hardware) / 105

Progress review of the cavity characterization and LLRF operation support tools for ESS by TUL-DMCS

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Covering topics such as temperature-dependent capacitance of piezo actuators, fast tuner range and polarity determination, Lorentz force detuning coefficient, cavity mechanical response and π-mode detection, through to real-time firmware-based cavity parameter identification, fast and slow quench detection, and more, LUT-DMCS has developed and validated a comprehensive set of firmware and software tools dedicated to the characterization and operational support of ESS superconducting structures.

This contribution summarizes the development, deployment, and verification of these tools in the ESS Test Stand 2 environment. Selected results from cryomodule testing and parallel LLRF system studies are also discussed.

Abstract Category:

System and Operation

107

Amplifier Additive Phase Modulation Noise Characterization and Testing and Theoretical Discussion of White and Flicker Noise Processes in both Small and Large Signal Regions of Operation

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Amplifier Additive Phase Modulation (APM) noise performance is a critical and often overlooked parameter which may significantly impact the signal integrity of Communication, RADAR, EW, Synthesizer, Frequency Converter, and related equipment.

This tutorial will address APM noise test equipment capabilities and limitations and will provide a detailed description of Mini-Circuits'Device Under Test (DUT) characterization procedures and methodologies.

A theoretical discussion of white and flicker noise processes in amplifiers and their impact on APM noise performance in both small and larger signal regions of operation will be presented.

The tutorial will further demonstrate that AM-to-PM distortion, another often unspecified amplifier parameter, may significantly degrade APM noise performance in both the White and Flicker noise regions when operating near or above the amplifiers 1 dB compression point.

Active device technologies and different amplifier topologies are discussed and measured data supporting the results are presented.

Abstract Category:

Hardware

108

Radio Frequency Astronomy

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The talk will begin with an overview of the National Radio Astronomy Observatory (NRAO), a facility of the National Science Foundation (NSF) tasked with building and operating radio telescopes and instrumentation for the global astrophysics community. I will briefly describe the four world-class instruments we currently operate, along with forthcoming key instrumentation upgrades and the Next Generation Very Large Array (ngVLA) currently under development. This will be followed by an introduction to the principles of astronomical interferometry and a discussion of the key electronic components and enabling technologies that go into a modern radio telescope. I will conclude with a technical focus on a key component of my own research—the reflectionless filter—which was developed initially to meet the needs of radio astronomy but which has proven beneficial in wide variety of applications including wireless communications, test and measurement instrumentation, defense, and most recently in quantum computing.

Abstract Category:

Other

109

Hardware Talk

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Exception handling in SELAP (Self Excited Loop Amplitude and Phase) at JLAB

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SELAP (Self Excited Loop Amplitude and Phase) algorithm has been operational at Jefferson Lab for controlling high Q cavities since 2021. Core algorithm of controlling the amplitude and the phase works reliably independent of the environment. When combined with the operational aspects such as high microphonics, mechanical coupling between the cavities, heavy beam loading etc., lot of exception handling had to be added in the gateware and software for making the operation easier and reliable. This poster describes some of the operational aspects noticed and the methodology used for detection and the mitigation.

Abstract Category:

System and Operation

Poster Session 1 (System and Ops, Hardware) / 111

The status of the RFPI systems development and preparation for the PIP-II project

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Ranging from detecting a slow temperature rise to responding rapidly to excessive current flow in the coupler bias high-voltage circuit, and up to detecting stray RF signals, the Radio Frequency Protection Interlock (RFPI) system is designed to monitor numerous cavity-related signals and react within 100 µs - 1ms time to any observed violation of safety margins. This contribution summarizes the current status of the design and evaluation of a novel RFPI system developed for the Proton Improvement Plan II (PIP-II) project at Fermilab. It presents an overview of the system's evolution—from the initial proof-of-concept (PoC) prototype to the final design version prepared for the last stage of evaluation before the mass-production campaign. The status of the dedicated test-stand environment used for system verification is also discussed

Abstract Category:

Hardware

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TBD

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TBD