Low Level RF Workshop 2022

9-13 Oct 2022, Brugg-Windisch, Switzerland

PAUL SCHERRER INSTITUT

Book of Abstracts

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
103	Overview of SLAC LLRF activities - Lab Talk	This lab talk will cover the highlights of LLRF activities at SLAC both with the controllers for the new SRF linac as well as other warm structures. Topics include the LCLS-II commissioning underway, the test results of the crymodule production and testing, the operations of the SLAC linac both for FEL (LCLS) and plasma wakefield studies (FACET).	Oral	Lab Talks	Alessandro Ratti, Andrew Benwell (SLAC National Accelerator Laboratory)	
54	CERN Lab Talk	This talk will review the progress of the LLRF systems at CERN, in particular the LHC Injector upgrade projects with the first introduction of MicroTCA technology in the accelerator field at CERN. The last two years saw the gradual commissioning of these new systems that also include new overall RF systems with solid state amplifiers for the PS Booster Synchrotron and the SPS. The new systems allow advanced beam manipulations such as the slip-stacking of ions in the SPS and simultaneous use of cavities in the PSB at multiple harmonics. Challenges of future projects both for upgrades (LHC) and consolidation will be outlined.	Oral	Lab Talks	Wolfgang Hofle (CERN)	
105	KEK Lab Talk	Recent progress of LLRF systems in several accelerator facilities at KEK (SuperKEKB Ring, PF/PF-AR Ring, LINAC, cERL, STF etc.) will be reported.	Oral	Lab Talks	Toshihiro MATSUMOTO (KEK, Accel)	
66	Jefferson Lab "Lab" Talk	Presentation of the work the JLAB LLRF engineering staff since 2019.	Oral	Lab Talks	Curt Hovater (Jefferson Lab), James Latshaw (Jefferson Lab), Ramakrishna Bachimanchi (Jefferson Laboratory), Tomasz Plawski (Jefferson Lab, Virginia, USA)	
104	DESY Lab Talk	DESY LAb activities report.	Oral	Lab Talks	Julien Branlard (DESY)	
83	Lab Report – Update on Fermilab Projects	The current major projects at Fermilab include PIP-II – an 800 MEV superconducting LINAC, LBNF (long baseline neutrino facility), DUNE(deep underground neutrino experiment), the Muon g-2 and the Mu2e experiment and several accelerator upgrade projects preparing for the higher intensity proton beam with the commissioning of the PIP-II Linac. PIP-II has entered the construction phase while the Mu2e experiment is nearing commissioning in 2024. The PIP-II IT test was completed successfully last year and the LLRF systems are in the final design phase. This talk will be a brief summary of all these projects focusing on the RF and LLRF systems and test facilities.	Oral	Lab Talks	P. Varghese (Fermi National Accelerator Laboratory(FNAL))	Brian Chase (Fermilab)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
106	Lab talk - LLRF Activities in Chinese Labs	Many accelerator projects are going on in China, ranging from small-scale cyclotrons for medical treatments, 4th generation synchrotron radiations, to CW X-ray superconducting free-electron lasers. These projects place high demands on low-level RF (LLRF) systems with different requirements on reliability, RF field stability, and multi-mode operability. Super active research and developments on LLRF are being carried on in different labs in China. Since international travel is still restricted in Chinese labs, we propose this talk as a special "lab talk" to summarize the LLRF activities in China since the last LLRF workshop. The major goal is to communicate with the international LLRF community about the LLRF progress in Chinese labs and welcome comments and suggestions from experts worldwide. The list of authors is still to be determined and will be shown in the presentation.	Oral	Lab Talks	Zheqiao Geng (PSI - Paul Scherrer Institut)	
95	ORNL Lab Talk	This presentation will highlight the LLRF developments at the Spallation Neutron Source at Oak Ridge National Laboratory.	Oral	Lab Talks	Mark Crofford (Oak Ridge National Laboratory)	Mark Musrock (ORNL), Jeff Ball (ORNL), Stacey Whaley (ORNL), Marnelli Martinez (ORNL), Chip Piller (ORNL), Josh Graham (ORNL)
4	PSI Lab Talk	This is the lab talk, which covers all LLRF topics in a summary of all facilities operated at PSI (SwissFEL, SLS, HIPA, Proscan).	Oral	Lab Talks	Roger Kalt (PSI - Paul Scherrer Institut)	
81	LBNL Lab talk	The presentation will provide highlights from LBNL of the most relevant developments in LLRF at this lab.	Oral	Lab Talks	Carlos Serrano (LBNL), Christos Bakalis (Lawrence Berkeley National Laboratory), Daniele Filippetto (Lawrence Berkeley National Laboratory), Gang Huang (LBNL), Larry Doolittle (LBNL), Qiang Du (LBNL), Shree Murthy (LBNL)	
93	MACHINE LEARNING BASED SRF CAVITY ACTIVE RESONANCE CONTROL	Motion control for acceleration system is usually very complex, as beam and electromagnetic field may couple with mechanical energy. For example, in SRF cavity, electromagnetic modes are strongly coupled with its mechanical modes via Lorentz-force detuning or external microphonics. Since the coupling is very nonlinear, motion control is usually very challenging, such as resonance control of SRF cavity. We propose to develop a high precision active motion controller based on machine learning (ML) technology and electric piezo actuator. We'll first develop a data-driven model for system motion dynamics, and then develop a model predictive controller (MPC). Finally, the performance of the controller will be verified on a real machine. For the technology demonstration, we'll apply the technology for SRF cavity resonance control on LCLS-II SRF linac, as it is a great test bed for challenging motion control problem.	Oral	Machine Learning	Faya Wang	
23	Machine Learning assisted Cavity Quench Identification at the European XFEL	A server-based quench detection system is used since the beginning of operation at the European XFEL (2017) to stop driving superconducting cavities if they experience a quench. While this approach effectively detects quenches, it also generates false positives, tripping the accelerating stations when failures other than quenches occur. Using the post-mortem data snapshots generated for every trip, an additional signal (referred to as residual) is systematically computed based on the standard cavity model. Following an initial training on a subset of such residuals previously tagged as "quench" / "non-quench", two independent machine learning engines analyze routinely the trip snapshots and their residuals to identify if a trip was indeed triggered by a quench or has another root cause. The outcome of the analysis is automatically appended to the data snapshots and distributed to a team of experts. This constitutes a fully deployed example of machine-learning-assisted failure classification to identify quenches, supporting experts in their daily routine of monitoring and documenting the accelerator uptime and availability.	Oral	Machine Learning	Annika Eichler (DESY), Julien Branlard (DESY), Jan Timm (DESY)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
5	FPGA-based hardware acceleration of machine learning algorithms for particle accelerators	Diagnosis and supervision of particle accelerators is mostly a manual task, requiring deep insight by human operators. The usage of machine learning and data analysis has the potential to enhance the controllability and the diagnosis capability. However, applications like longitudinal phase-space estimation, automatic control optimization, or anomaly detection can be used only when the hardware acceleration enables them to cope with the huge amount of data and stringent latency in response times required. This work discusses how to trade off latency and throughput in FPGA-based hardware acceleration for machine learning algorithms. Specifically, current off-the-shelf tools focus on throughput, while latency is the main optimization goal in our setting.	Oral	Machine Learning	Gianluca Martino (TUHH, DESY), Ahmad Al Zoubi (TUHH), Julien Branlard (DESY), Holger Schlarb (DESY), Goerschwin Fey (TUHH)	
63	Applications of Machine Learning for RF Systems	The application of machine learning to accelerators has been a dinner table discussion amongst members of the community with an ever increasing list of application spaces. ML has successfully been applied to the improvement of diagnostics, on-line modeling, anomaly detection, and postmortem data analysis. When it comes to accelerator RF systems, machine learning has been of most interest for improving superconducting systems and quench detection / protection systems. Given modern hardware infrastructure, these only scratch the surface of potential applications. This talk will provide an overview of recent applications of machine learning technologies for both slow-controls and real-time systems and highlight some opportunities for the integration of machine learning techniques for the improvement of control systems for RF structures.	Oral	Machine Learning	Jonathan Edelen (RadiaSoft), Joshua Einstein-Curtis (RadiaSoft)	Nathan Cook (RadiaSoft LLC), Matthew Kilpatrick (RadiaSoft LLC)
108	Electron-Ion Collider RF Systems	The Electron-Ion Collider (EIC), to be constructed at Brookhaven National Laboratory (BNL), is a roughly 10 year project to design and construct a facility to collide polarized high energy electron beams with polarized proton and heavy ion beams at center of mass energies from 20 GeV to 140 GeV and luminosity up to 10^34 cm^(-2s-1). The project is a partnership between BNL and the Thomas Jefferson National Accelerator Facility (Jefferson Lab, JLAB). The facility requires generation and storage of Ampere-class beams of hadrons and electrons in the collider rings, cold high-current electron beam in the strong hadron cooler (SHC), and precise high-gradient crabbing of electrons and hadrons in the interaction region. To achieve this, a diverse and challenging set of RF systems is needed comprising approximately 50 SRF and 20 NCRF cavities. Challenges include heavy beam loading, very high RF power, ultra-low-noise operation of the crab cavities, extremely low noise operation of a 100mA, 150 MeV SHC ERL, bunch merging and splitting gymnastics, and operation over a wide range of energies. This talk will provide an overview of the machine parameters and RF systems.	Oral	Systems and Operations	Kevin Mernick (Brookhaven National Laboratory)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
58	LLRF and timing control system based on MicroTCA.4 at SPring-8	A new injector linac was constructed for the New SUBARU, a 1.5 GeV synchrotron radiation facility, at SPring-8. The accelerating frequencies used at the new linac are 238, 476, 2856 and 5712 MHz. The required accuracy is, for example, 8e-4 at 238 MHz for amplitude and 0.2 degree at 476 MHz for phase. Also, the master trigger of the linac must be synchronized with both the aimed bucket timing of the storage-ring (SR) and the linac master clock. To fulfill these requirements, the LLRF and timing control system were developed using the modules of Micro Telecommunication Computing Architecture 4 (MTCA.4) standard. The operation of the NS has been carried out stably since April 2021 without any significant faults. Furthermore the MTCA.4 based 509 MHz LLRF system for SPring-8 SR had been developed and replaced from NIM-based LLRF system. These LLRF and timing systems are also applied to a new 3 GeV light source in Tohoku, named NanoTerasu, which is now under construction. These development and achievement related to LLRF and timing control system will be reported.	Oral	Systems and Operations	Eito Iwai (JASRI/RIKEN)	Takahiro Inagaki (RIKEN SPring-8 center), Takashi Ohshima (JASRI/RIKEN), Naoyasu Hosoda (JASRI/RIKEN), Hirokazu Maesaka (RIKEN SPring-8 Center), Hideki Dewa (JASRI), Shinichi Matsubara (JASRI)
82	Heavy-Ion Synchrotron and Storage Ring LLRF Systems at GSI and FAIR: Status and Machine Development Experiment Results	Besides the realization of the LLRF systems for the new heavy-ion synchrotron SIS100 and the storage rings CR and HESR, the FAIR project at GSI also includes an upgrade of the LLRF systems of the existing accelerator rings such as SIS18 and ESR. Although each accelerator and each type of RF system has its own specific requirements, the basic underlying concept and topology is the same for all machines. A central paradigm is the use of a modular setup with well-defined interfaces between standardized analog and digital hardware modules that can be reconfigured or recombined in order to fulfill the variety of specific requirements. This contribution illustrates the LLRF concept and presents measurement results from machine development experiments in the existing heavy-ion synchrotron SIS18 that demonstrate different features such as multi-harmonic operation and bunch compression. Finally, the status of the LLRF realization for FAIR is summarized and an outlook is given.	Oral	Systems and Operations	Dieter Lens (GSI Helmholtzzentrum fuer Schwerionenforschung)	Kerstin Groß (GSI Helmholtzzentrum für Schwerionenforschung GmbH), Harald Klingbeil (GSI Helmholtzzentrum für Schwerionenforschung GmbH), Ulrich Laier (GSI Helmholtzzentrum für Schwerionenforschung GmbH), Bernhard Zipfel (GSI Helmholtzzentrum für Schwerionenforschung GmbH)
79	FRIB LLRF STATUS UPDATE AND EARLY OPERATION EXPERIENCE	The Facility for Rare Isotope Beams (FRIB) was fully commissioned by the end of 2021 and opened for full user operation in May 2022. In this paper, we give an update of the LLRF activities at FRIB for the past few years, including commissioning of the linac segments 2 and 3, and the performance achieved. As the facility transitioned from commissioning to operation, effort has been devoted to spare parts management and development of troubleshooting tools. The experience from early stage operation will be discussed including automation of cavity turn on/off, conditioning, and auto-restart. Efforts on new LLRF hardware platform development for the FRIB upgrade cavities will be presented briefly as well.	Oral	Systems and Operations	Shen Zhao (FRIB)	Shriraj Kunjir (FRIB), Dan Morris (FRIB)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
90	Low Level RF System of the LIGHT Proton Therapy Linac	The LIGHT (Linac for Image-Guided Hadron Therapy) linac is designed to produce proton beams up to 230 MeV for cancer therapy. The machine consists of three different kinds of accelerators: RFQ (Radio-Frequency Quadrupole), SCDTL (Side Coupled Drift Tube Linac) and CCL (Coupled Cavity Linac). These accelerating structures operate with RF power at 750 MHz (RFQ) and 3 GHz (SCDTL, CCL) which is generated from the Low-Level RF (LLRF) system and is amplified in the high RF power feeding stations. The LLRF system is not only responsible of sourcing RF with high amplitude and phase stability, but also of monitoring the RF signals coming from the RF network and the accelerating structures. In addition, the LIGHT LLRF is commissioned to shape RF pulses, apply feedback corrections to keep amplitude and phase stability, RF breakdown detection and resonance frequency feedback. These functionalities operate on a pulse-to-pulse basis and their control is integrated in a Front-End Controller (FEC) which connects it to the main LIGHT control system. In this contribution we exhibit the main features of the AVO LLRF system, its operation and performance.	Oral	Systems and Operations	Dario Soriano Guillen (AVO-ADAM)	
33	Synchronised PS-SPS transfer with barrier buckets	For the future intensity increase of the fixed-target beams in the CERN accelerator complex, a barrier bucket scheme has been developed to reduce the beam loss during the 5-turn extraction from the PS towards the SPS, the so-called Multi-Turn Extraction. The low-level RF system must synchronize the phase of the barrier with the PS extraction and SPS injection kickers to minimize the number of particles lost during the rise times of their fields. As the RF voltage of the wide-band cavity generating the barrier bucket would be too low for a conventional synchronization, a combination of a feedforward cogging manipulation and the real-time control of the barrier phase has been developed and tested. A deterministic frequency bump has been added to compensate for the imperfect circumference ratio between PS and SPS. This contribution presents the concept and implementation of the synchronized barrier-bucket transfer. Measurements with high-intensity beam demonstrate the feasibility of the proposed transfer scheme.	Oral	Systems and Operations	Mihaly Vadai (CERN)	Massimo Giovannozzi (CERN), Alexandre Lasheen (CERN), Alexander Huschauer (CERN), Heiko Damerau (CERN)
34	Update on the LLRF operations status at the European XFEL	The European XFEL (EuXFEL) is a Free Electron Laser in the X-ray range for users. Its high availability is one of the key aspects of the machine and, in 2022, it entered in the sixth year of operation. The EuXFEL linac is based on the TESLA superconducting RF technology, operating at 1.3 GHz with a repetition rate of 10 Hz. The LLRF system is based on the MicroTCA standard and relies on a high level of automation. In this contribution, we review the LLRF operation at the EuXFEL and the development of new tools to improve the monitoring and extend the usability of the LLRF system.	Oral	Systems and Operations	Marco Diomede (DESY)	Björn Lautenschlager (DESY), Christian Schmidt (DESY), Julien Branlard (DESY), Mariusz Grecki (DESY), Martin Hierholzer (DESY), Matthias Hoffmann (DESY), Nicholas John Walker (DESY), Sven Pfeiffer (DESY), Valeri Ayvazyan (DESY)
67	The CERN SPS LowLevel RF: Architecture & Implementation	The Super Proton Synchrotron (SPS) Low Level RF (LLRF) has been completely upgraded during the CERN long shutdown (LS2, 2019-2020). The novel architecture of the LLRF and the hardware used will be presented. The architecture is based on a White-Rabbit (WR) network and fast GigaBit links, and all the electronics is using fixed sampling and processing clocks. The WR network is used for the clocks and RF synchronization between RF stations. The clocks are reconstructed locally from the WR data stream and a PLL reduces the phase noise. The RF synchronization is done through the RFNCO IP which is implemented in every node of the network. The RFNCO is also a central component for the fixed-Frequency Acceleration scheme and the Ions slip-stacking to merge batches, these two examples show the flexibility of the SPS LLRF architecture. The hardware of the Beam-Control and 200MHz Cavity-controllers have been replaced with digital electronics implemented on the MicroTCA platform. Finally, a brief list of result with beam from April 2021 until now will be presented.	Oral	Systems and Operations	Gregoire Hagmann (CERN)	Arthur Spierer (CERN), Ireneusz Stachon (CERN), Julien Egli (CERN), Philippe Baudrenghien (CERN), Tomasz Wlostowski (CERN)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
51	APS-Upgrade LLRF System Overview and Status	The Advanced Photon Source Upgrade (APS-U) will replace the more than 25 year old storage ring with a multibend achromat lattice. To alleviate beam lifetime and emittance concerns, the new storage ring will include a passive superconducting bunch-lengthening cavity whose voltage will be regulated via slow cavity tuning control. The reduction of the synchrotron tune will make the beam more susceptible to 60Hz line-harmonic related rf amplitude and phase noise in the main rf system, which will be addressed using LLRF adaptive notch filters. In the injectors, up to 10 times more charge must be provided with a Booster circumference that will no longer be rationally related to that of the storage ring. Upgrades to the LLRF in the injector chain include those for the fundamental and harmonic systems in the Particle Accumulator Ring as well as for the Booster, that will be compatible with the new timing scheme for bunch transfers. An overview and status update of the APS-U LLRF systems will be presented. work supported by U. S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357	Oral	Systems and Operations	Tim Berenc (Argonne National Laboratory)	Tim Madden (tmadden@anl.gov), Yawei Yang (Argonne National Laboratory), Uli Wienands (Argonne National Laboratory)
32	Installation, Commissioning and Performance of Phase Reference Line for LCLS-II	Any cavity controller for a distributed system needs a Phase Reference Line (PRL) signal from which to define phases of a cavity field measurement. The LCLS-II PRL system at SLAC provides bidirectional (forward and reverse) phase references at 1300 MHz to each rack of the LLRF system. The PRL controller embedded with the Master Oscillator (MO) locks the average phase of the two directions to the MO itself. Phase-averaging tracking loop is applied in firmware which supports the feature of cancelling the phase drift caused by changes in PRL cable length. FPGA logic moves the phase of digital LO to get zero average phase of the two PRL signals. This same LO is used for processing cavity pickup signals, thus establishing a stable reference phase for critical cavity RF measurements. At low frequencies, open-loop PRL noise relative to the LO distribution includes a strong environment and 1/f components, but the closed-loop noise approaches the noise floor of the DSP. The implication is that the close-in phase noise of the cavities will be dominated by the chassis DAQ noise. The final out-of-loop phase noise relevant to machine operations is that of the cavity field relative to the beam.	Oral	Timing and Phase Reference	Shreeharshini Murthy (Lawrence Berkeley National Laboratory), Larry Doolittle (LBNL), Charlie Xu (SLAC National Accelerator Laboratory), Bo Hong (SLAC National Accelerator Laboratory), Andrew Benwell (SLAC National Accelerator Laboratory), Jing Chen (SLAC National Accelerator Laboratory)	
45	FLASH2020+ RF Reference Generation System Upgrade Status	FLASH was the first FEL in the world to provide ultrashort pulses of radiation in extreme ultraviolet and soft X-ray range, first launched in 2005. The FLASH2020+ plan is to upgrade the existing FEL lines, by implementing tunable undulators and extending the maximum electron beam energy to 1.35 GeV. The upgrade plan was also a perfect opportunity to completely rebuild the RF reference generation system and its infrastructure, which were done within the cooperation of ISE WUT and DESY. FLASH RF reference area was rearranged and a new set of RF cabling was installed and documented. Based on ISE team's experience in designing RF reference and distribution modules for FLASH, European-XFEL, and ESS new, custom-made RF modules were designed, manufactured, tested, and installed in FLASH. Not only do they provide better performance than the previous modules, but also are designed in a far more compact shape that maintains excellent serviceability and robustness. This contribution presents the RF reference generation channels upgrade process, describes the new modules, like the new Master Oscillator, Distribution Module, and Frequency Conversion Modules, and summarizes the status.	Oral	Timing and Phase Reference	Maciej Urbanski (Warsaw University of Technology)	Bartosz Gasowski (Warsaw University of Technology), Serlat Andzej (Warsaw University of Technology), Bartlomiej Kola (Warsaw University of Technology), Pawel Jatczak (Warsaw University of Technology), Tomasz Owczarek (Warsaw University of Technology), Krzysztof Czuba (Warsaw University of Technology), Julien Branlard (Deutsches Elektronen Synchrotron), Heinrich Pryschelski (Deutsches Elektronen Synchrotron), Katharina Schulz (Deutsches Elektronen Synchrotron), Daniel Kuehn (Deutsches Elektronen Synchrotron), Frank Ludwig (Deutsches Elektronen Synchrotron)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
107	White Rabbit-based LLRF upgrade for CERN's SPS	The Super Proton Synchrotron (SPS) Digital LLRF 200 MHz system at CERN was redesigned in 2020, using a fixed-frequency clock provided by the White Rabbit network instead of the usual RF clock. This triggered the development of WR hardware with sufficient performance (approx. 100 fs rms jitter above 100 Hz and 13 ps/1 degree end-to-end phase stability). WR is also used in the SPS to distribute the revolution frequency across large distances in the form of Frequency Tuning Words encapsulated in Ethernet frames, which drive an RF Numerically Controller Oscillator (RFNCO). The reconstructed RF is used for synchronization with other machines and systems. This paper describes the developments that made the WR-based LLRF possible: the MTCA.4 eRTM14/15 Timing Receiver board which generates the clocks and Local Oscillator signals for the Cavity and Beam Controllers and the WR2RF-VME board, which reproduces the RF-synchronous signals and pulse patterns from the data streams received from the WR network. We also describe the phase noise and transceiver stability optimizations used in the components of the WR network, which enabled WR operation with the performance necessary for the SPS LLRF.	Oral	Timing and Phase Reference	Adam Wujek, Gregoire Hagmann (CERN), Tomasz Włostowski (CERN), Arthur Spierer (CERN), Dimitrios Lampridis (CERN), Grzegorz Daniluk (CERN), John Robert Gill (CERN), Juan David Gonzalez Cobas (CERN), Julien Egli (CERN), Karol Adrianek (CERN), Maciej Lipiński (CERN), Maciej Sumiński (CERN), Mattia Rizzi (PSI - Paul Scherrer Institut), Michel Arruat (CERN), Philippe Baudrenghien (CERN), Predrag Kuzmanović, Saul Novel Gonzalez (CERN), Tristan Gingold (CERN)	
74	Status of the Phase Reference Line for the European Spallation Source	The required phase synchronization for the European Spallation Source proton linac LLRF and Beam Diagnostics systems is: 0.1° for short term (during 3.5 ms pulse), 0.1° for long term between adjacent outputs, and 2.0° for long term (hours to days) between any two points at both frequencies of 352 MHz and 704 MHz. The phase reference distribution system consists of a Phase Reference Line (PRL), which is a fully passive system based on a single 1-5/8" coaxial rigid line installed at the tunnel ceiling above the beamline and supporting systems installed in the ESS Klystron Gallery Hall. The PRL was designed to distribute both reference frequencies from a Master Oscillator to 56 tap points in the tunnel. Each tap point has several (3 or 6) signal outputs, giving 294 of the total output number. The length of the PRL is around 580 meters. The entire PRL is temperature stabilized (+/-0.1 deg C) and includes an inner-line gas pressure stabilization to assure synchronization accuracy. This contribution covers the concept of the PRL, technical assumptions, the design, the status of installations, and current performance test results.	Oral	Timing and Phase Reference	Krzysztof Czuba (Warsaw University of Technology)	Dominik Sikora (Warsaw University of Technology), Pawel Jatczak (Warsaw University of Technology), Radosław Papis (Warsaw University of Technology), Rihua Zeng (ESS), Morten Jensen (ESS), Michał Kalisiak (WUT), Anirban Krishna Bhattacharyya (ESS), Wojciech Wierba (WUT), Krzysztof Oliwa (WUT)
117	Reference Distribution Methods and Techniques Summary	Summary and Open Discussion: Reference Distribution Methods and Techniques	Oral	Timing and Phase Reference		

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
97	Diversity in LLRF and STEM: existing initiatives at CERN/PSI/FHNW, current situation and how we can improve it.	Developing Low Level Radio Frequency (LLRF) systems for accelerators requires teams with skills in a variety of areas such as beam dynamics, feedback theory, analogue/digital electronics, firmware/software engineering. This fascinating field suffers from a lack of diversity, mirroring the situation in the various accelerator facilities and research centers. For example, the number of women attending the LLRF workshop is low, possibly because of the team composition in each participating laboratory. Over recent years CERN, PSI and FHNW have started programs to improve diversity in the workplace and in particular in the area of Science, Technology, Engineering and Mathematics (STEM). The session will start showing statistics for past and present attendance to the LLRF workshop. Then the existing Diversity and Inclusion (D&I) programs at CERN, PSI and FHNW will be outlined. A discussion on how to improve the situation in STEM and within our LLRF field will follow. All participants to the LLRF workshop and their accompanying persons are invited to take part in this event.	Oral	Diversity Session	M. E. Angoletta (CERN), L. Carvalho (CERN), M. Coletta, (CERN), N. Lerch-Pieper (PSI), M. Spycher (PSI), A. F. Bauer (FNHW), R. Schmitt (FNHW), L. Doolittle (LBNL)	
41	Next generation RF field detection with the carrier-suppression interferometer (CSI))	With the help of complex control systems, today's FELs (e.g. the EuropeanXFEL at DESY) are able to provide light pulses with a duration of less than 100fs. The demands on the low-level RF (LLRF) control systems of such accelerators are high and the RF field detection in the superconducting cavities is crucial. To overcome the main limitations of today's LLRF receivers, such as the noise of the ADCs or RF mixers, the carrier-suppression interferometer (CSI) presented here is used as a receiver front-end to the conventional LLRF system and enables RF detection of highest precision. By taking advantage of the destructive interference of the carrier signal at 1.3GHz, the detection resolution with the CSI at DESY was enhanced by factor 500 to a timing jitter of 10.8as for the measurement band from 40Hz to 1MHz and a noise floor of -205 dBc/Hz. Latest developments and future steps as, e.g., its application to CW-machines are reported. Thorough investigations on the resolution limits and key components are presented. The CSI can be used in future in combination with conventional RF receivers and enhances the state of the art of phase noise measurements to attosecond resolution and above.	Oral	Hardware	Frank Ludwig (DESY), Louise Springer (DESY), Heinrich Pryschelski (DESY), Holger Schlarb (DESY), Matthias Hoffmann (DESY), Uros Mavric (DESY)	
30	Digital Low-Level RF control system for Accumulator Ring at Advanced Light Source Upgrade Project	Currently ALS is undergoing an upgrade to ALS-U to produce 100 times brighter soft X-ray light. The LLRF system for Accumulator Ring (AR) is composed of two identical LLRF stations, for driving RF amplifiers. The closed loop RF amplitude and phase stability is measured as < 0.1% and < 0.1° respectively, using the non-IQ digital down conversion together with analog up/down conversion, under a system-on-chip architecture. Realtime interlock system is implemented with < 2 us latency, for machine protection against arc flash and unexpected RF power. Control interfaces are developed to enable PLC-FPGA-EPICS communication to support operation, timing, cavity tuning, and interlock systems. The LLRF system handles alignment of buckets to swap beams between AR and Storage Ring by synchronous phase loop ramping between the two cavities. The system also includes an optimization routine to characterize the loop dynamics and determine optimal operating point using a built-in network analyzer feature. A cavity emulator of 31 kHz bandwidth is integrated with the LLRF system to validate the performance of the overall system being developed.	Oral	Hardware	Qiang Du (LBNL), Shreeharshini Murthy (Lawrence Berkeley National Laboratory), Michael Betz (Lawrence Berkeley National Laboratory), Kevin Bender (Lawrence Berkeley National Laboratory), Wayne Lewis (Lawrence Berkeley National Laboratory), Sergio Paiagua (Lawrence Berkeley National Laboratory), Lawrence Doolittle (Lawrence Berkeley National Laboratory), Carlos Serrano (Lawrence Berkeley National Laboratory), Kenneth Baptiste (Lawrence Berkeley National Laboratory)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
13	Status of the uTCA Digital LLRF design for SARAF Phase II	One of the crucial control systems of any particle accelerator is the Low Level Radio Frequency (LLRF). The purpose of a LLRF is to control the amplitude and phase of the field inside the accelerating cavity. The LLRF is a subsystem of the CEA control domain for the SARAF-LINAC instrumentation and Seven Solutions has designed, developed, manufactured and tested the system based on CEA technical specifications. The final version of this digital LLRF has been already installed in the SARAF accelerator in Israel at the end of 2021 and the first results are going to be shown. The architecture, design and development as well as the performance of the LLRF system will be presented during this talk. The benefits of the proposed architecture and the first results obtained under different conditions will be detailed.	Oral	Hardware	Pilar Gil Jaldo (Orolia Spain S.L.U), Juan Fernadez (Orolia Spain S.L.U)	Guillaume Ferrand (CEA-Saclay), Nicolas Pichoff (CEA-Saclay)
28	LANSCE Digital Low Level RF Upgrade Overview	Incremental upgrades of the legacy low level RF (LLRF) equipment—50 years for the Los Alamos Neutron Science Center (LANSCE)—involves challenges and problems not seen with new and total replacement opportunities. The digital LLRF upgrade at LANSCE has deployed 30 of the 53 required systems as of September 2022. This paper describes the performance of the digital upgrade, current status, and future installations along with the technical challenges, including unexpected challenges, associated with deploying new digital systems in conjunction with legacy analog equipment. In addition, this paper discusses the operational details of simultaneous multi-energy beam operations using high energy re-bunching, beam-type specific set points and simultaneous multi-beam operations at LANSCE. The adaptability of the digital LLRF systems is essential as the design is able to accommodate new control and beam parameters associated with future systems without significant hardware modifications such as the expected LANSCE Modernization Program. This adaptability of the digital LLRF technology was recently demonstrated with the Module 1, 201.25-MHz high-power RF upgrade completed in 2021.	Oral	Hardware	Paula Van Rooy (Los Alamos National Labratory)	Mark Prokop (Los Alamos National Laboratory), Sung Il Kwon (Los Alamos National Laboratory), Phillip Torrez (Los Alamos National Laboratory), Lawrence Castellano (Los Alamos National Laboratory), Aaron Archuleta (Los Alamos National Laboratory)
80	Very Low Noise Receiver Technology for Digital Beam Position and Phase Detection	Recent studies showed that the transverse feedback system noise floor in the Large Hadron Collider (LHC) must be reduced by at least factor of two in order to operate the machine with large beam-beam tune shift as foreseen in the High Luminosity (HL) LHC. Also, the future feedback system foreseen to suppress the LHC Crab Cavity noise relies on improved noise performance of the beam position measurement system. An upgrade program was launched to lower the LHC transverse feedback system noise floor mainly focusing on a new generation, very low noise beam position measurement module. Innovative methods in the RF receiver, digital signal processing, thorough optimization of every element in the signal chain from pickup to the kickers allowed to achieve a significant reduction of the system noise floor. This unprecedented noise performance opens also new possibilities for auxiliary instruments, using the position data from the transverse feedback. The contribution presents the new RF receiver architecture, with notable implementation details which allowed to lower the measurement noise floor by more than a factor 6 and obtain the required system noise performance.	Oral	Hardware	Daniel Valuch (CERN)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
68	FPGA implementation of a multi-harmonic cavity controller for the Proton Synchrotron Booster at CERN	The LLRF system of the Proton Synchrotron Booster (PSB) was widely renovated during Long Shutdown 2 (LS2) as part of the LHC Injectors Upgrade (LIU) project. Wide-band Finemet cavities were installed and a new cavity controller implemented in Field Programmable Gate Arrays (FPGA) was put into operation. In the new system, a fixed frequency clock is used with individual demodulation/modulation of 16 revolution frequency harmonics. Feedback loops allow the amplitude and phase of the different harmonics to be controlled as well as enabling precise synchronization between different cavities in the ring. New features such as an embedded network analyzer and a new method for longitudinal blow-up control are also included. The system was commissioned in late 2020, allowing all operational beams to be produced with the required beam characteristics within the LIU project.	Oral	Hardware	Diego Barrientos (CERN), John Molendijk (CERN), Michael Jaussi (CERN), Simon Albright (CERN), Maria Elena Angoletta (CERN), Alan Findlay (CERN)	
60	Status of the LLRF system for ESS related in-kind project by PEG	The single cavity field regulation systems, with active cavity resonance control, systematically complete the ESS project linac infrastructure. This LLRF system has a modular design provided by the MTCA.4 electronic standard choice. Thanks to this feature, the PEG (Polish Electronic Group) consortia members could develop and deliver individual components of the system. The work realized in the frame of the in-kind project includes hardware and low-level software development of the chosen sub-modules and overall LLRF system integration and installation in the dedicated part of the ESS linac. This work summarizes the PEG efforts towards various hardware components development and production (eq. RTM-Carrier, LO-RTM, PiezoDriver RTM, Pin-diode, Electron pick-up, etc). It also summarizes endeavours involving the delivered HW units firmware preparation and work on the systems integration and installation. Finally, it discusses the challenges encountered by PEG during the project realization and implementation.	Oral	Hardware	Wojciech Cichalewski	Konrad Chmielewski (NCBJ), Krzysztof Czuba (Warsaw University of Technology), Maciej Grzegrzółka (Institute of Electronic Systems, Warsaw University of Technology), Tomasz Kowalski (NCBJ), Krzysztof Oliwa (WUT), Dominik Rybka (NCBJ), Maciej Sitek (NCBJ), Jarosław Szewiński (NCBJ), Wojciech Wierba (WUT), Morten Jensen (ESS), Anders Svensson (University of Copenhagen), A Johannson (Lund University)
38	Digital cavity controller for the 20 MHz, 40 MHz and 80 MHz cavities in the CERN PS	The CERN Proton Synchrotron (PS) is equipped with high frequency RF systems at 20 MHz, 40 MHz and 80 MHz. These are used to perform longitudinal beam manipulations in order to provide short bunches with 25 ns spacing to the Super Proton Synchrotron (SPS). As part of the "LHC Injectors Upgrade" (LIU) project, a new digital low level RF (LLRF) firmware has been developed for the high frequency cavities. The firmware combines an automatic voltage control (AVC) loop and a multi-harmonic feedback (MHFB) into an integrated cavity controller. The AVC loop and internal RF source provide pulse voltage regulation and phase control, while the MHFB reduces the cavity impedance throughout the acceleration cycle. The controller is implemented on the pre-existing PS one turn delay feedback board, built around the Altera Stratix II FPGA. Due to the modest size of this FPGA, a multiplexed CORDIC and complex multi-harmonic source are used to optimise the amount of FPGA resources required. Beam tests of the AVC loop and commissioning results of the fully integrated controller are presented.	Oral	Hardware	Azeddine Jibar (CERN), Ben Woolley (CERN), Florian Bertin (CERN), Heiko Damerau (CERN), Nathan Pittet (CERN), Ylenia Brischetto (CERN)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
24	Signal Processing Development Methodologies for FPGA Platforms using Reusable and Generic PSI Library components	Over the past ten years, two digital LLRF systems (SwissFEL, HIPA) with FPGA based digital signal processing (DSP) have been developed at PSI and the third for SLS-2 is underway. Other accelerator systems such as beam diagnostics also use FPGA platforms for their DSP. Even though there are large differences in the applications even between the LLRF systems, many similarities in the under laying DSP algorithms exist. It was observed that not many blocks of the various FPGA signal-processing developments could be reused due to the lack of genericity, so it was decided to create a library with basic DSP blocks and fixed-point arithmetic units. In this contribution, the PSI Open-Source FPGA DSP libraries and development methodologies applied as example in the HIPA and the SLS-2 LLRF systems are introduced. The presented approach demonstrated the productivity increase by the means of non-regression test and reliability because of their use to all range of application in accelerators.	Oral	Open Hw-Fw-Sw	Benoit Stef (PSI - Paul Scherrer Institut)	
114	Open Source Projects at DESY	What is the firmware framework? What it should provide and why you want to have it. Why you want to have an open source framework and open source firmware? What is needed to make collaboration possible? What is our idea for the firmware framework. Licensing.	Oral	Open Hw-Fw-Sw		
115	Open Source Initiatives at CERN - Status	In this short introduction, I will describe our 15-year experience in CERN's control group sharing hardware, gateware, firmware and software under an open-source paradigm. This includes collaboration with commercial companies and other institutes. I will also mention the interaction with Knowledge and Technology Transfer paradigms based on "maximising impact", which may sometimes result in the choice of a proprietary dissemination strategy. I will conclude with some thoughts on how these two practices can be made to work together and reinforce each other, hoping to trigger comments and questions so we can have an interesting discussion session.	Oral	Open Hw-Fw-Sw		
52	Status of the LCLS-II SRF Systems and LLRF Commissioning	The SLAC National Accelerator Laboratory has completed the installation and checkout of RF systems for the SRF based accelerator LCLS-II, an ultra-bright Free Electron Laser. The LCLS-II is composed of 296 SRF cavities plus 2 NC cavities, each with its own LLRF control system and dedicated RF amplifier. At the time of this abstract submission, beam transport through the injector is imminent and beam through the linac is planned soon after. This LCLS-II status talk will briefly describe the RF system, summarize RF checkout, and discuss SRF commissioning of the LCLS-II linac.	Oral	Superconducting RF	Alessandro Ratti, Andy Benwell (SLAC), Andre McCollough (SLAC), B. Chase (Fermilab), Bachimanchi Ramakrishna (Jefferson Laboratory), Carlos Serrano (Lawrence Berkeley National Laboratory), Daron Chabot (SLAC), Ed Cullerton, Gang Huang (LBNL), Hovater Curt (Jefferson Laboratory), Jing Chen (SLAC), Jorge A Diaz-Cruz (SLAC National Accelerator Laboratory), Joshua Einstein-Curtis (RadiaSoft), Lawrence Doolittle (Lawrence Berkeley National Laboratory), Mark Petree (SLAC), Richard Kelly (SLAC), Shree Murthy (LBNL), Sonya Hoobler (SLAC)	
98	ESS LLRF status and activities	The commissioning of the ESS linac is ongoing and the five first normal conductive (NC) cavities have recently been operated with beam. An overview of the LLRF systems in use, first commissioning results with initial beam, and experiences are presented. The initial Piezo compensation tests obtained at the Medium Beta cavity test stand is also presented.	Oral	Superconducting RF	Anders Svensson (European Spallation Source (ESS))	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
31	Fermilab PIP-II Injector Test - LLRF System Design and Performance	PIP-II IT is a test facility for the PIP-II project where the injector, warm front-end and the first two superconducting cryomodules were tested. The warm front-end consists of an Ion source, an RFQ and three buncher cavities. The superconducting cryomodules consist of an 8-cavity half-wave-resonator(HWR) cryomodule operating at 162.5 MHz followed by an 8-cavity single-spoke resonator(SSR1) cryomodule operating at 325 MHz. The LLRF systems for both cryomodules are based on a common SOC FPGA based hardware platform. Resonance control for the HWR is provided by a pneumatic system based on helium pressure, while the SSR1 cryomodule uses a piezo/stepper motor type control. The data acquisition and control system can support both CW and Pulsed mode operation. Beam loading compensation is available which can be used for both manual/automatic control in the LLRF system. The user interfaces include EPICS, Labview and ACNET. Testing of the RF system with 2 mA beam accelerated to 20 MeV has been completed.. The design and performance of the field control and resonance control system operation with beam are presented in this paper.	Oral	Superconducting RF	P. Varghese (Fermi National Accelerator Laboratory(FNAL))	B. Chase (Fermi National Accelerator Laboratory(FNAL)), S. Raman (Fermi National Accelerator Laboratory(FNAL)), P. Hanlet (Fermi National Accelerator Laboratory(FNAL)), D. Nicklaus (Fermi National Accelerator Laboratory(FNAL)), A. Syed (Fermi National Accelerator Laboratory(FNAL)), L. Doolittle (Lawrence Berkeley National Laboratory(LBNL)), C. Serrano (Lawrence Berkeley National Laboratory(LBNL))
59	Testing of a modified Active disturbance Rejection Control (ADRC) algorithm for microphonics rejection in Superconductive Radio Frequency (SRF) cavities	SRF cavities are characterized by low energy loses derived from their extremely high intrinsic quality factor. In accelerators geared towards new applications such as new light source linacs, such cavities are operated with extremely high loaded quality factor due to the negligible beam loading involved. In those particular cases, the bandwidth of RF systems is very narrow, so they become much more sensitive to dynamic detuning caused by mechanical perturbations. The work presents the test of a modified ADRC algorithm capable of greatly minimizing the peak detuning of cavities operated in those circumstances. The modifications made to the algorithm enables the open loop stability analysis and eases the design and implementation of the controller. The ultimate objective is to test the controller in a 9-cell tesla cavity using the test bench displayed in HoBiCat. For that matter and in order to prevent any undesired obstacle, a HIL system developed by HZB for SRF cavities has been used to test and adjust the parameters of the algorithm. The obtained results are presented here.	Oral	Superconducting RF	Ander Elejaga Estiballes (UPV/EHU), Pablo Echevarria Fernandez (Helmholtz Zentrum Berlin), Josu Jugo (University of the Basque Country)	Axel Neumann (HZB), Andriy Ushakov (HZB)
75	Operational Experience of the SELAP Algorithm for LLRF Control System at JLAB	The JLAB LLRF 3.0 system has been developed and is replacing the 30-year-old LLRF systems in the CEBAF accelerator. The LLRF system builds upon 25 years of design and operational RF control experience (digital and analog), and our recent collaboration in the design of the LCLS-II LLRF system. The new system also incorporates a cavity control algorithm using a fully functional phase and amplitude locked Self Excited Loop (SELAP). The first system (controlling 8 cavities) was installed and commissioned in August of 2021. Since then the new LLRF system has been operating with cavity gradients up to 20 MV/m, and electron beam currents up to 400 mA. The second system was installed and commissioned in May of 2022. In addition to this, the new software and firmware are installed and being tested in LLRF 2.0 system. This paper discusses the operational experience of the LLRF SELAP algorithm along with other software and firmware tools such as klystron characterization, cavity characterization, quench detection and dynamic power allocation for beam current.	Oral	Superconducting RF	Ramakrishna Bachimanchi (Jefferson Lab), Clyde Mounts (JLAB), Scott Higgins (JLAB), James Latshaw (Jefferson Lab), Tomasz Plawski (Jefferson Lab, Virginia, USA), Curt Hovater (Jefferson Lab)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
86	Mitigating instabilities in SRF resonance control loops	LLRF systems usually include a resonance control loop, in which an actuator adjusts the frequency of the cavity's electrical resonance. Electrical measurement of the cavity detune frequency and a control algorithm complete the feedback loop. In SRF cavities with a piezoelectric actuator, this loop is responsible for compensating cavity Lorentz forces and drifts in helium pressure (in some cases an elaborate controller attempts to cancel narrow-band microphonics terms). Having the mechanical linkage between actuator and cavity in a cryogenic environment introduces a non-obvious complication: high-Q mechanical resonances in the audio band, sometimes with Q over 1000. These resonances can push a simple integrator-based controller into instability, unless the gain-bandwidth-product is made unreasonably low. This presentation shows theory and experiment for a better mitigation of these instabilities, which is general and needs no tuning. Operational success has been demonstrated with LCLS-II cryomodules.	Oral	Superconducting RF	Larry Doolittle (LBNL)	
21	Performance of multiharmonic vector voltage control feedback for the J-PARC Rapid Cycling Synchrotron	Magnetic alloy (MA) cavities are employed in the J-PARC RCS. The wideband response of the MA cavity enables the dual harmonic rf operation for the bunch shape control, which mitigates the space charge effects, while the wake voltage in a single MA cavity consists of several harmonics. Multiharmonic beam loading compensation is required for high intensity beam acceleration. We decided to employ the vector feedback instead of the multiharmonic rf feedforward, which is implemented in the original LLRF control system. We reported in the LLRF17 workshop on the development of the prototype of the multiharmonic vector rf voltage control feedback. The performance of the prototype was good, but not fully satisfied the requirements. We implemented the feedback in the next-generation LLRF control system with several updates, for example, the number of the harmonics to be controlled and the filters. The new system was deployed in 2019. The system was tested with high intensity beams up to the design intensity of 8.3e13 ppp, which corresponds to the beam power of 1 MW, and the performance of the system is satisfactory. We present the configuration of the new system and the beam test results.	Oral	Beam Measurements and Feedback Control	Fumihiko Tamura (Japan Atomic Energy Agency)	Yasuyuki Sugiyama (KEK), Masahito Yoshii (KEK)
40	Feedback stablilisation of longitudinal quadrupole coupled-bunch oscillations in the CERN PS	Longitudinal coupled-bunch oscillations are observed with LHC-type beams in the CERN Proton Synchrotron (PS). They cause degradation of the longitudinal beam quality and beam loss. A dedicated feedback system with a wide-band Finemet cavity as a longitudinal kicker suppresses all dipolar oscillations. The existing feedback has been upgraded and extended to also damp quadrupolar modes. The additional signal processing operates in parallel to the dipole-mode feedback and involves a hybrid time- and frequency-domain scheme. A bunch-by-bunch peak detection filter is applied to the longitudinal beam signal before its down-conversion to baseband to reject dipole-mode oscillations, and the output signal is modulated such that zero kick is applied to the centre of each bunch. This technique allows the system to retain the advantages of a frequency-domain approach without incurring long delays associated with narrowband filters. Having developed and verified the new scheme in longitudinal beam dynamics simulations, experimental damping of quadrupole coupled-bunch oscillations has been successfully demonstrated with beam in the PS.	Oral	Beam Measurements and Feedback Control	Alexandre Lasheen (CERN), Ben Woolley (CERN), Heiko Damerau (CERN), Jan Paszkiewicz (CERN)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
8	Optimization of RF phase and beam loading distribution among RF stations in SuperKEKB	SuperKEKB is the e-/e+ collider which targets the world highest luminosity. In recent operation, SuperKEKB achieved a new world record 4.71×10^34 cm^(-2) s^(-1) for luminosity with beam current 1.4A. In the future, beam current will be increased further to aim at the design value of 3.6A and much higher luminosity. The RF system consists of 38 cavities (30 klystron stations), which share the huge beam loading brought by high current beam with each other cavities. For beam stability and power efficiency, it is important to distribute beam loading properly among RF cavities. It is equivalent to adjust the acceleration phase of each cavity. However, it is difficult to evaluate acceleration phase using only the pickup signal. Therefore, we established a method to evaluate the beam loading balance among RF stations from the RF power measurement for each cavity, and to adjust the acceleration phase. This presentation introduces a method for evaluating and optimizing the beam loading (acceleration phase) among stations in SuperKEKB, which has a large number of RF stations, and its operation.	Oral	Beam Measurements and Feedback Control	Shunto Ogasawara (KEK)	Tetsuya Kobayashi (KEK), Michiru Nishiwaki (KEK), Kazunori Akai (KEK), Kota Nakanishi (KEK)
99	Iterative Learning – Gone Wild	Before AI and neural nets, the excitement was about iterative learning control (ILC): the idea to train robots to perform repetitive tasks, or train a system to reject quasi-periodic disturbances. The excitement waned after the discovery of “bad learning transients” in systems which satisfy the ILC asymptotic convergence stability criteria. The transients may be of long duration, persisting long after eigenvalues imply they should have decayed, and span orders of magnitude. The field recovered with the introduction of tests for “monotonic convergence of the vector norm”, but no deep and truly satisfying explanation was offered. Since 2016, this author has demonstrated that an entirely new class of solutions, namely solitons, satisfy the recurrence equations of ILC and offer a deep explanation of “bad learning”. A soliton is a wave-like object that emerges in a dispersive medium that travels with little or no change of shape at an identifiable speed. This paper is the first public presentation of the soliton solutions, which may occur for both causal (i.e. look back) and acausal (i.e. look ahead) learning functions that have diagonal band structure for their matrix representation.	Oral	Beam Measurements and Feedback Control	SHANE KOSCIELNIAK (TRIUMF)	
102	Measurement of Cavity Detuning in Storage Ring RF Systems	In this contribution I will describe a method for determining cavity detuning in the CW storage ring RF systems. This method uses a vector network analyzer integrated in the LLRF system to determine the reflection coefficient versus frequency at the cavity feed port. Resulting measurement can then be fitted to extract cavity center frequency as well as other parameters of interest. The major advantage of this measurement approach is that it is relatively insensitive to the feedback loop settings. Bench measurement results will be shown.	Oral	Beam Measurements and Feedback Control	Dmitry Teytelman (Dimtel, Inc.)	
35	Longitudinal beam-based feedback system at the European XFEL	For pump-probe experiments, where the FEL photon pulses interact together with an external laser, a highly temporal stability is mandatory. The longitudinal beam-based feedback system at the European XFEL stabilizes the arrival time, measured by a bunch arrival time monitor (BAM). To compensate fast arrival time fluctuations of the bunch trains, the energy in front of a bunch compression chicane is modulated by the low level RF (LLRF) system of the superconducting RF (SRF) cavities. Measurements at the EuXFEL shows train-to-train arrival time stabilities down to the sub-10 fs level if the longitudinal intra bunch-train feedback (L-IBFB) is activated at the LLRF system.	Oral	Beam Measurements and Feedback Control	Björn Lautenschlager (DESY), Christian Schmidt (DESY), Holger Schlarb (DESY), Jiri Kral (DESY), Julien Branlard (DESY), Marie Kristin Czwalinna (Deutsches Elektronen-Synchrotron), Sebastian Schulz (DESY), Sven Pfeiffer (DESY)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
3	Consolidation of SwissFEL LLRF system	SwissFEL LLRF system was well designed with precise RF detection, reliable amplitude and phase feedback, and high degree automation. After the start of user operation, new requirements on robustness and reproducibility have been raised for LLRF. Efforts have been spent to consolidate the LLRF system. We implemented lookup-table-based algorithms for the fast setup of klystrons for desired operating points. Amplitude feedback loops manipulating the klystron high-voltage were implemented for C-band klystrons operating in saturation for long-term stability. We optimized the reference tracking scheme for preserving the beam phase after rebooting or power cycling any LLRF components. The race conditions between LLRF triggers and clocks were smartly handled in LLRF firmware. This poster illustrates these consolidations and their results at SwissFEL.	Poster	Poster Session	Mario Jurcevic (PSI - Paul Scherrer Institut), Roger Kalt (PSI - Paul Scherrer Institut), Waldemar Koprek (PSI - Paul Scherrer Institut), Zheqiao Geng (PSI - Paul Scherrer Institut)	
6	The Status of LLRF at ATLAS and New Upgrade	ATLAS, the world's first accelerator to use RF superconductivity for ion acceleration has undergone a major upgrade to increase the beam transmission efficiency and intensity. A first of its kind, the new CW RF quadrupole (RFQ) was built to replace three superconducting (SC) resonators (β=0.008 and 0.016). In addition, a new cryomodule of seven 72.75 MHz (β=0.077) SC quarter-wave resonators has also been developed and put into the operation since 2014. The new SC cavities demonstrated world-record accelerating fields (operated at 2.5MV/cavity) for similar type of cavities. This year, an upgraded 109 MHz cryomodule of 8 quarter-wave SC resonators is installed. New RF systems have been developed and installed for the RFQ and the new SC cavities. For upgraded 109 MHz cryomodule, a digital low level RF (LLRF) system developed by Brookhaven National Laboratory is installed and configured. Numerous modifications have been developed to improve the operational reliability and performance of both SC cavities and RFQ. In this paper, current status of ATLAS RF systems and LLRF control systems will be presented. This work was supported by the U.S. DOE, ONP (Contract No. DE-AC02-06CH11357).	Poster	Poster Session	David Novak, Sergey Sharamentov, Yong Luo, Clay Dickerson, Matthew Hendricks, Michael Kelly	
9	RF Performance Characterization of the SLS-2 500 MHz LLRF Prototype in the Lab	For the SLS-2 project and the 500 MHz RF upgrades, the LLRF will be renewed and the previously analog system is going to be replaced by a digital one. The new system is built into two separated chassis, an analog frontend and a CompactPCI Serial based digital backend interconnected with coaxial cables. The custom design analog frontend implements two up- and eight down-conversion channels 50 to 500 MHz and vice versa. The digital backend consists of low latency high speed ADCs and DACs connected to the same FPGA/MPSoC that processes the signals in the digital domain. This poster focus on several generic- and RF-type performance characterization measurements of the actuator- and the DAQ-paths of the LLRF system, done in the lab environment.	Poster	Poster Session	Alexander Dietrich (PSI - Paul Scherrer Institut), Benoit Stef (PSI - Paul Scherrer Institut), Roger Kalt (PSI - Paul Scherrer Institut), Lorenz Joris Moser (PSI - Paul Scherrer Institut), Radoslaw Rybaniec (PSI - Paul Scherrer Institut)	
10	Design and Implementation of a Digital Tuning System for 50 MHz Cavities	At PSI, the high intensity proton accelerator (HIPA) delivers a proton beam of 590 MeV energy at a current of up to 2.4 mA. The RF cavities are operated in CW mode at a frequency of 50 MHz. The initial system was built about 30 years ago with the technology at that time which was predominantly analogue. With the modern replacement of the analogue system, the cavity operation and maintenance will be improved remarkably. Seamless integration to the control system (EPICS) will represent another advantage. Exception handling or additional operation modes are much easier to implement with the digital approach. This poster focuses predominantly on the design and implementation of the digital tuning system. First measurement results show the ability to tune the cavity.	Poster	Poster Session	Mario Jurcevic (PSI - Paul Scherrer Institut)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
11	CompactPCI Serial Based Generic and Modular Processing Platform at PSI	CompactPCI Serial has been selected as one of the Next Processing Platforms (NPP) for development of future electronic systems at PSI. In this contribution, we describe the new platform and the pilot application for the Swiss Light Source (SLS) LLRF upgrade. We detail Hardware/Firmware/Software architectures, present automated testing procedures, as well as share the hands-on experience gained during first months of system's operation in the lab.	Poster	Poster Session	Benoit Stef (PSI - Paul Scherrer Institut), Ian Johnson (PSI), Radoslaw Rybaniec (PSI - Paul Scherrer Institut)	
12	Direct Conversion X-Band RF Front End	A new 16 channel LLRF front end was developed at PSI for the two X-band RF stations at SwissFEL. This poster summarizes operational experience and performance achieved with new direct up-conversion LLRF front end. In addition, comparison between the dual conversion to the new direct conversion front end is given.	Poster	Poster Session	Alexander Dietrich (PSI - Paul Scherrer Institut)	
14	DLLRF for ALBA 3rd Harmonic System	ALBA is a 3rd generation synchrotron light source located in Cerdanyola del Vallès (Barcelona, Spain). The facility comprises a 3 GeV electron storage ring (SR), injected from a 110 MeV Linac through a full energy booster synchrotron. The RF system consists of six normal conducting cavities in the storage ring, fed with IOT based transmitters that are able to provide up to 3 MV to the beam. In the framework of the 3rd harmonic cavity project for the ALBA-II upgrade, a Digital LLRF for the 1.5 GHz RF system based in the commercially available MTCA.4 digitizer and downconverter boards provided by Struck Innovative Systeme has been developed. The main hardware components, the basic firmware functionalities and real measurements of the DLLRF system for the 3rd harmonic cavities will be presented.	Poster	Poster Session	Agustin Gomez (ALBA Synchrotron), Francis Perez (ALBA Synchrotron - CELLS), Pol Solans (ALBA Synchrotron - CELLS)	
15	Startup Sequencer for Tuning and Starting up High Power RF into 50 MHz accelerator cavity	The two cyclotrons at the High Intensity Proton Accelerator (HIPA) at PSI are equipped with eight high-power CW RF cavities at 50 MHz and one flat-top cavity at 150 MHz with input power levels up to 500 kW. The purpose of the startup sequencer is to establish continuous (CW) high power RF operation as safe, fast and reliable as possible from both cold and warm cavity initial states. Precise impedance matching and resonance frequency tuning are mandatory pre-conditions before continuous high power is allowed. Due to multipactoring, the cavity is forbidden to operate in certain levels between zero and nominal power. For this reason, slow RF ramping is not possible and a pulsed startup scheme is used. Pulses with fast transitions through the forbidden regions help suppress the multipactoring effects and guarantee smooth measurements of RF phase and amplitude during the startup. The new type digital LLRF startup sequencer has integrated diagnostics and exception handling for debugging purpose. Two fast RF feedback controllers for the startup and nominal operation are implemented with smooth transition. Real RF-experience and testing has been done on the test stand with the cavity.	Poster	Poster Session	Matthias Stoll (PSI - Paul Scherrer Institut), Karina Ambrosch (Paul Scherrer Institut), Benoit Stef (PSI - Paul Scherrer Institut)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
16	DIGITAL LLRF FOR THE CANADIAN LIGHT SOURCE	The Canadian Light Source, at the University of Saskatchewan, is a 3rd generation synchrotron light source located in the city of Saskatoon, Canada. The facility comprises a 250 MeV LINAC, a full energy booster and a 2.9 GeV storage ring. The radiofrequency system in the booster consist of two 5-cell cavities feed with a single SSPA. The analogue LLRF for the booster has been recently replaced by a digital LLRF based in the ALBA design with a Picodigitizer, a stand-alone commercial solution provided by Nutaq. Also, the firmware of the new DLLRF is configurable to allow operation with a superconducting cavity feed with one amplifier, thus providing the possibility to replace the CLS SR LLRF as well. The main hardware components, the basic firmware functionalities and the commissioning measurements of the new DLLRF for the CLS booster will be presented in this paper.	Poster	Poster Session	Pol Solans (ALBA Synchrotron - CELLS), D. Beauregard (Canadian Light Source), C. Boyle (Canadian Light Source), Agustin Gomez (ALBA Synchrotron - CELLS), J. M. Patel (Canadian Light Source), Francis Perez (ALBA Synchrotron - CELLS), Angela Salom (CELLS), H. Shaker (Canadian Light Source), J. Stampe (Canadian Light Source)	
17	New Digital LLRF System for CNAO Linear Accelerator	CNAO is one of the six hadrontherapy centers able to treat cancer with proton beams and carbon ions. It is a synchrotron with a diameter of 77 meters, equipped with a LINAC as the injector. The stability of the RF in the LINAC being fundamental for the quality of the beam injected into the ring impelled CNAO to decide to upgrade the actual analogic LINAC LLRF to a digital one. This proceeding describes the CNAO Linear Accelerator LLRF upgrade, and the Libera LLRF system modifications and extensions necessary to fulfill the CNAO requirements. The newly introduced features include: the ability of the LLRF system to process a dual-trigger source, the extension to additional interlock inputs, and the introduction of trigger output signals of configurable timing. It furthermore describes the upgrade of the CNAO LLRF with specific drive-power limitation functions, integrated within a non-linear high-power amplifier response calibration and the commissioning results of the CNAO Linear Accelerator Digital LLRF system.	Poster	Poster Session	Borut Baricevic (Instrumentation Technologies d.o.o.), Borut Repic (Instrumentation Technologies), Cristiana Priano (CNAO Foundation), Damijan Skvarc (Instrumentation Technologies), Enrico Vacchieri (CNAO Foundation), Giovanni Debernardi (CNAO Foundation), Luciano Falbo (CNAO Foundation), Luka Bogataj (Instrumentation Technologies), Luka Rahne (Instrumentation Technologies), Manuel Cargnelutti (Instrumentation Technologies), Marko Sajn (Instrumentation Technologies), Matej Oblak (Instrumentation Technologies), Matjaz Skabar (Instrumentation Technologies), Paolo Meliga (CNAO Foundation), Peter Paglovec (Instrumentation Technologies), Robert Cerne (Instrumentation Technologies), Sebastjan Zorzut (Instrumentation Technologies), Simone Garlaschelli (CNAO Foundation), Stefano Foglio (CNAO Foundation)	
18	Implementation of LLRF control software outside of DESY using EPICS	Originally, the LLRF control software, developed for the accelerators at DESY (XFEL, FLASH,...), was exclusively based on DOOCS. The development of the ChimeraTK framework enables the LLRF control applications to use other control systems than DOOCS (i.e. EPICS, OPC-UA), as well. Recently, EPICS-based LLRF control applications have been implemented at LLRF control systems outside of DESY. This submission will give an introduction to EPICS-based ChimeraTK applications in general and present some of the specific implementations.	Poster	Poster Session	Patrick Nonn (DESY / MSK), Andrea Bellandi (Deutsches Elektronen-Synchrotron)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
19	Status of the ISIS Synchrotron Digital LLRF System	The ISIS synchrotron routinely uses a dual harmonic RF system to accelerate beam currents in excess of 230 µA to two target stations. Commissioning of a new PXI-based LLRF system was reported at the LLRF'19 workshop. Since then, the system has been deployed for all ISIS user cycles. Further developments include using the IQ loop error signals for RF cavity tuning and we plan to extend this approach to replace more of the analogue modules still used in the tuning loop. We have used the new system to implement power saving during the last two ISIS user cycles by triggering the full accelerating Voltage demand to coincide only with the 10Hz beam to the second Target Station rather than our usual 50Hz to both targets. This approach has reduced the power requirement by approximately 500kW during the TS2 only operational cycles. More recently, we have upgraded the FPGA modules, Frontend Transceivers, PXI crate and controller to avoid clock synchronisation issues seen after re-boots on the previous system and to avoid end of life obsolescence for the older modules. This work and our plans for future development of the ISIS digital LLRF systems will be presented in further detail.	Poster	Poster Session	Andrew Seville (STFC)	David Allen (STFC), Ian Gardner (STFC), Robert Mathieson (STFC)
20	Development of a Digital LLRF System for RAON SCL3	Recently the test of superconducting cavities and the cryomodules of the low energy linear accelerator part (SCL3) of a heavy ion accelerator, RAON are have been finished. They are installed and the preparation process for the commissioning is ongoing in Daejeon, Korea by Rare Isotope Science Project (RISP) team in Institute of Basic Science (IBS). The purpose of this accelerator are the generation of rare isotope by ISOL (Isotope Separation On-Line) and its acceleration for the nuclear physics experiment. The operating RF frequency for SCL3 are 81.25 MHz and 162.5 MHz. Every cavity can be controlled independently for the flexibility to accelerate the various A/q ions. Recently the development, evaluation and installation of the digital LLRF based on the FPGA technology have been finished. The self-excited loop (SEL) and the generator-driven-resonator (GDR) algorithm are implemented and they were tested in the SRF test facility. In this presentation the status and test result of RAON LLRF controller will be described	Poster	Poster Session	Hyojae Jang	Youngkwon Kim, Danhe Gil, Yuchul Jung, Hyunik Kim
22	MTCA.4 based LLRF control system for the J-PARC MR	The J-PARC Main Ring (MR) has achieved the delivery of the 30 GeV proton beam with the beam power of 515 kW to the neutrino experiment as of April 2021. The Longitudinal coupled bunch instabilities (CBI) has been observed above 450 kW operation due to the cavity impedance. To mitigate the CBI, we designed the prototype modules of the low-level-rf (LLRF) system based on the MTCA.4 platform. The multi-harmonic vector rf voltage control function was implemented in the module to suppress the beam induced wake voltages in the RF cavity, which is considered to be the main source of the CBI. Suppression of the CBI with the prototype system was a key and led to achieve the beam power of 500kW in the MR. Following the prototype's success, we developed the new LLRF system based on MTCA.4. The original LLRF system was replaced with the new system in 2021. We present the configuration of the new system and the beam test results.	Poster	Poster Session	Yasuyuki Sugiyama (KEK)	Fumihiko Tamura (Japan Atomic Energy Agency), Masahito Yoshii (KEK)
25	PETRA IV 500MHz LLRF system	For the new PETRA IV project at DESY a new LLRF system based on MicroTCA.4 is foreseen. It will be used to control 24 cavities at 500MHz and 24 cavities at 1.5GHz. In this contribution we will present the setup of a first prototype of the LLRF system for the single cavity LLRF system operating at 500MHz continuous wave.	Poster	Poster Session	Arvid Eislage (DESY), Frank Maschewski (DESY), Hilda Tamras (DESY), Holger Schlarb (DESY), Julien Branlard (DESY), Martin Hierholzer (DESY), Matthias Hoffmann (DESY), Ruediger Onken (DESY), Stefan Wilke (DESY), Sven Pfeiffer (DESY)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
26	Progress of Diamond Digital Low Level RF	The first version of digital low level RF (DLLRF) for the Diamond Light Source storage ring and booster was developed with ALBA Synchrotron. Six systems have been built so far. Two of them are in routine operation controlling two normal conducting HOM-damped cavities in the Diamond storage ring. A third system is being used for cavity testing in the RF test facility. The fourth system is being commissioned to the control the second normal conducting booster cavity. The fifth DLLRF system is being prepared for the third normal conducting RF cavity in storage ring. A new DLLRF system based on SIS8300-KU with RTM has been developed and tested in the last few years. We are aiming to develop a common platform for the different RF systems in Diamond, including the storage ring, the booster and the linac. It will also be our baseline design for the future Diamond II. Firmware, software and supporting hardware have been developed and tested. The linac version with arbitrary waveform generator mode was tested successfully to generate flat top pulse from SLED at high power test in the linac. The storage ring version was also tested successfully in the RF test facility.	Poster	Poster Session	Pengda GU (Diamond Light Source)	Chris Christou (Diamond Light Source)
27	Summary of the LLRF activities within the recent FLASH shutdown	The FLASH facility is currently re-commissioned after an almost 10-month shutdown for the FLASH2020+ project. Within this period several subsystems of the machine have been renovated or completely rebuild. One of the major tasks was the exchange of the accelerating modules ACC2 and ACC3 to European XFEL type cryomodules. Furthermore, the master oscillator which successfully operated for 15 years has been completely exchanged. Both demanded major re-cabling and adaptation of the interfaces to the existing infrastructure. A summary of the LLRF activities and experiences of the re-commissioning work is presented.	Poster	Poster Session	Christian Schmidt (DESY)	Bartlomiej Szczepanski (DESY), Daniel Kuehn (DESY), Heinrich Pryschelski (DESY), Julien Branlard (DESY), Marco Diomede (DESY), Matthias Hoffmann (DESY), Thorsten Lamb (DESY), Valeri Ayvazyan (DESY)
29	Performance and Design of a Precision RF Signal Chassis at Los Alamos Neutron Science Center	Accelerator low-level RF (LLRF) systems have demanding requirements on signal distribution circuity. The RF feedback control paths from the cavity are not corrected for error and demand a high level of attention to performance. This chassis allows the frequency dependent (805 MHz or 201.25 MHz) circuits to be separated from the modular frequency independent digital low level RF system. The same digital system hardware is used throughout the linear accelerator (LINAC) with RF cavity type dependent software. The prototype of this chassis suffered from too much RF crosstalk between the cavity and reference signals. This paper reviews the challenges associated with this chassis, the updates that were made from the prototype to the production version, and the decision for one chassis to contain the frequency dependent circuits. We also review the requirements for temperature stability of the chassis, cavity, and reference signals. Performance testing of the chassis is reviewed including the design process for automating the test procedures which allows for quick and efficient testing of the chassis, resulting in significant time savings throughout the process.	Poster	Poster Session	Paula Van Rooy (Los Alamos National Labratory)	Mark Prokop (Los Alamos National Laboratory), Sung Il Kwon (Los Alamos National Laboratory), Phillip Torrez (Los Alamos National Laboratory), Lawrence Castellano (Los Alamos National Laboratory), Aaron Archuleta (Los Alamos National Laboratory)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
36	SPS/LHC setting-up tools using Python	Commissioning of the LLRF systems of CERN accelerators consists of a number of time-consuming procedures, involving calibration and fine-tuning of numerous parameters. In the recent years, a system of Python scripts was developed to automate the setting up of the LLRF of the LHC and the SPS. Targeted at RF experts, the scripts provide high-level interface to the underlying physical system, managing I/O communication and performing data analysis and parameter optimisation. Designed with maintainability and portability in mind, the system can be expanded to be used with other accelerators at CERN. In addition to the scripts, a dedicated IP (Intellectual Property) core was designed to be easily deployed in RF systems. The IP core is an excitation mechanism built into the FPGA firmware to perform measurements of transfer functions (Baseband Network Analyzer, BBNA) and to inject band-limited noise to study Coupled-Bunch Instability (CBI), growth rates and longitudinal diffusion. The excitation core works in conjunction with the embedded acquisition IP core (acqCore) to record the excitation and the response of a system. The recorded data allow offline computing of the transfer function.	Poster	Poster Session	Dominika Agnieszka Dlugosz (CERN), Julien Egli (CERN)	Gregoire Hagmann (CERN), Philippe Baudrenghien (CERN), Bartosz Bielawski (CERN), Helga Timko (CERN), Saul Novel Gonzalez (CERN), Andrew Butterworth (CERN)
37	SPS bunch-by-bunch phase measurement with µTCA AFCZ FMC	In the Super Proton Synchrotron (SPS) during multi batch injection, we must distinguish between bunches that have been circulating in the machine, and newly injected bunches. This required a new Low Level RF (LLRF) module to measure phase of the individual bunches that are circulating in the machine. Individual bunch measurement is also needed to properly operate two phase loops during ion slip stacking. To facilitate this, an FMC ADC mezzanine card was chosen with a sampling rate of up to 6.4 GSPS. This was paired with the AFCZ µTCA carrier board on which the signal processing of the data would be carried out. The design of the FPGA firmware presented some interesting challenges as the signal processing algorithms must process many samples in parallel due to the high throughput of data. In this case the ADC sampling clock is twenty times faster than the FPGA processing clock. The hardware and processing architecture will be presented with details of the algorithms and how they cope with the high data throughput associated with using an ADC with a multi GSPS sampling rate.	Poster	Poster Session	Robert Borner	
39	Revolution frequency invariant reconstruction of bunch profiles in fixed frequency clock systems	During the last few years, the LLRF systems of all CERN small synchrotrons (PSB, LEIR, AD, ELENA) have been upgraded to a fixed frequency clock scheme. As a result, the beam profiles obtained from the digitization of pick-up signals will have a different number of samples as the revolution frequency varies. In this work, we present a method to reconstruct the time-domain signal of the bunch profile by using the demodulated values of 16 harmonics of the revolution frequency. This method uses a digital Multi Harmonic Local Oscillator (MHLO) efficiently using the FPGA resources and individual demodulators with out-of-band filtering. The constant number of samples for the bunch profiles allows a better visualization of the evolution of the bunch shapes during the cycle.	Poster	Poster Session	Diego Barrientos (CERN), John Molendijk (CERN), Bartosz Bielawski (CERN)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
43	LLRF for PolFEL Accelerator	Polish Free Electron Laser PolFEL is a new facility located in the National Centre for Nuclear Research in Swierk (Otwock, Poland). PolFEL will be based on the 200 MeV linear superconducting electron accelerator made of the TESLA type cavities, targeting VUV, IR and THZ wavelengths. The accelerator will operate in the single cavity regulation mode using solid state amplifiers. It will be able to operate in the pulsed wave (PW) mode, but the main operational mode will be continuous wave (CW). To achive goals described above, custom and flexible LLRF system will be designed. PolFEL is currently closing design phase and soon it will go into construction phase, so this contribution will present concept of the LLRF system, proposed technologies and techniques as well as first results of tests performed in the laboratory with the prototype system and copper cavity.	Poster	Poster Session	Dominik Rybka (NCBJ), Jarosław Szewiński (NCBJ), Konrad Chmielewski (NCBJ), Maciej Sitek (NCBJ), Piotr Bartoszek, Tomasz Kowalski (NCBJ)	
44	SRF Cavity Emulator for PIP-II LLRF Lab and Field Testing	There are many stages in the LLRF and RF system development process for any new accelerator that can take advantage of hardware emulation of the high power RF system and RF cavities. LLRF development, bench testing, control system development and testing of installed systems must happen well before SRF cavities are available for test. The PIP-II Linac has three frequencies of SRF cavities, 162.5 MHz, 325 MHz and 650 MHz and a simple analog emulator design has been chosen that can meet the cavity bandwidth requirements, provide tuning errors to emulate Lorentz force detuning and microphonics for all cavity types. This emulator design utilizes a quartz crystal with a bandwidth of 65 Hz at an IF of ~ 4 MHz, providing a Q of ~ 1.3 x 10e7 at 650 MHz. This paper will discuss the design and test results of this emulator.	Poster	Poster Session	A. Syed (Fermi National Accelerator Laboratory(FNAL))	B. Chase (Fermi National Accelerator Laboratory(FNAL)), P. Varghese (Fermi National Accelerator Laboratory(FNAL))
46	Analog Cavity Emulators to Support LLRF Development	The goal of a LLRF system is to control an actual RF cavity with beam. While digital simulations have a place, having an analog circuit to stand in for the cavity can be tremendously helpful in validating hardware+firmware+software under development. A wide range of cavity emulators have been developed in collaboration with SLAC, and LBNL. Cavity emulators are typically based on quartz crystals and frequency conversion hardware. The choice of crystal frequency and coupling mechanism depends in part on the bandwidth and coupling of the cavity it's intended to emulate. Examples of bandwidth range from 800 Hz (SLAC) as a stand-in for a SRF cavity, to 31 kHz (LBNL) for a room-temperature accumulator-ring cavity. An external LO is used to tune the emulated cavity frequency. The coupling properties are also of interest if the scope includes emulating reverse power waveforms. LLRF system checks such as closed-loop bandwidth, and determining cavity detuning can be performed interactively and as part of a Continuous Integration (CI) process. This paper describes the design, implementation, and performance of the cavity emulators.	Poster	Poster Session	Shreeharshini Murthy (Lawrence Berkeley National Laboratory), Larry Doolittle (LBNL), Andrew Benwell (SLAC National Accelerator Laboratory)	
49	High beta and low beta 650 MHz PIP-II cavity testing at Fermilab 650STC	The Fermilab 650 STC (Spoke resonator Test Cave) is used as a horizontal test facility for the PIP-II 650 MHz Low Beta(LB) and HB superconducting cavities provided by INFN(Italy) and RRCAT(India). The cavities are 5-cell elliptical doublet type with betas of 0.61 and 0.9.Testing of two HB cavities has been completed and testing with a LB cavity is in progress. Coupler thermal testing, tuner range and sensitivity characterization, Lorentz force detuning (LFD) measurements, cavity sensitivity to helium bath pressure variations and cavity conditioning are some of the tests completed in the initial segment. LLRF studies are conducted in the second stage of the testing. Cavity detuning measurement calibration, microphonics studies, piezo tuner performance, field control and resonance control performance parameters are some of the system measurements completed. The test procedures, data and performance of the cavities are described in this paper.	Poster	Poster Session	P. Varghese (Fermi National Accelerator Laboratory(FNAL))	B. Chase (Fermilab), Ahmed Syed (FNAL), S. Raman (Fermilab), A. Sukhanov (Fermi National Accelerator Laboratory(FNAL)), P. Hanlet (Fermilab)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
50	PIP-II 650 MHz Cryomodule Test Stand LLRF System	The Fermilab 650 MHz Cryomodule Test Stand is a facility for independently testing HB/LB 650 MHz and SSR2 (325 MHz) cryomodules without beam. The first cryomodule tested will be the HB 650 which consists of six cavities. The LLRF system is built with the same LLRF controller as the LCLS-II project with mostly identical firmware and software components allowing for the small differences in system architectures. The EPICS user interface includes a number of test, analysis and logging features that provide comprehensive test documentation for characterizing all cavities and the cryomodule. Cavity bandwidth and loaded Q measurement, SSA linearity, Cavity resonance finding, Piezo transfer function and capacitance measurements, Detune frequency are some of the test features available with the LLRF system. The LLRF system is installed and has been tested with a cavity emulator to exercise system features. The first 650 MHz HB cryomodule is expected to arrive in October, 2022. The LLRF system and the test stand measurement features are described in this paper.	Poster	Poster Session	P. Varghese (Fermi National Accelerator Laboratory(FNAL))	B. Chase (Fermi National Accelerator Laboratory(FNAL)), S. Raman (Fermi National Accelerator Laboratory(FNAL)), P. Hanlet (Fermi National Accelerator Laboratory(FNAL)), A. Syed (Fermi National Accelerator Laboratory(FNAL)), L. Doolittle (Lawrence Berkeley National Laboratory(LBNL)), C. Serrano (Lawrence Berkeley National Laboratory)
53	LCLS-II LLRF System Checkout Lessons Learned	The SLAC National Accelerator Laboratory has completed the installation and checkout of hardware for the SRF based accelerator LCLS-II, an ultra-bright Free Electron Laser. The LCLS-II is composed of 296 SRF cavities, each with its own LLRF control system. During production, care was taken to preserve the low noise design performance needed for controlling the 5x107 QL SRF cavities. A novel continuous checkout process was run for months before and after SRF commissioning began. Production hardware has also been sent to collaboration SRF facilities for performance evaluation, firmware/software development, and cryomodule testing. So, how did it go? This work will discuss practical aspects of LLRF system installation, checkout, and integration. Test methods, results, statistics, and lessons learned will be presented.	Poster	Poster Session	Alessandro Ratti, Andre McCollough (SLAC), Andy Benwell (SLAC), B. Chase (Fermilab), Carlos Serrano (Lawrence Berkeley National Laboratory), Curt Hovater (Jefferson Laboratory), Ed Cullerton, Gang Huang (LBNL), Jing Chen (SLAC), Jorge A Diaz-Cruz (SLAC National Accelerator Laboratory), Joshua Einstein-Curtis (RadiaSoft), Lawrence Doolittle (Lawrence Berkeley National Laboratory), Mark Petree (SLAC), Ramakrishna Bachimanchi (Jefferson Laboratory), Richard Kelly (SLAC), Shree Murthy (LBNL), Sonya Hoobler (SLAC)	
55	Clock and LO Phase Noise Correlation Effects on RF Sampling	Sampling the RF signals is a challenging problem for the modern LLRF Control System. One of the analog-to-the digital conversion problems is the clock jitter's influence on the output signal. As clock jitter impact increases with the input signal frequency, it is primarily a problem in precise RF systems, where signal frequencies are high. This issue can be minimized by lowering the input signal frequency using the down-converter circuit. This approach increases the complicity of the RF front-end and requires the generation of an additional Local Oscillator (LO) signal. Reducing the noise introduced in the digitizer circuit is essential in a high-performance system. Phase noises of both the LO and clock signals contribute to it. The most obvious method of improving the performance is reducing the absolute values of both signals' phase jitter. Because phase noises of LO and clock signals are mostly non-deterministic, it is also very likely that the correlation between the phase noises of those signals matters. This contribution investigates the impact of the correlation between clock and LO signals phase noises on the digitizer circuit noise performance.	Poster	Poster Session	Krzysztof Czuba (Institute of Electronic Systems), Maciej Grzegrzółka (Institute of Electronic Systems, Warsaw University of Technology), Šerlat Andžej (Institute of Electronic Systems, Warsaw University of Technology)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
56	Preliminary design of LLRF system for Korea-4GSR	The Korean 4th Generation Storage Ring (4GSR) project is being under construction with the plan of commissioning at the end of 2027. The beam energy of this facility is 4 GeV, and a 500 MHz EU- HOM-damped normal cavity will be adopted to generate the ultra-low emittance beam of 58 pm rad with the beam current of 400 mA. This paper covers the design considerations of the low level RF (LLRF) system for digital feedback control of the 4GSR RF system and the preliminary design for its implementation. In addition, the configuration of the RF system and peripheral control devices related to the LLRF system will be presented.	Poster	Poster Session	Yong-Seok Lee (Pohang accelerator laboratory (PAL))	Young-Do Joo (Pohang accelerator laboratory (PAL)), In-Ha Yu (Pohang accelerator laboratory (PAL)), Mu-Jin Lee (Pohang accelerator laboratory (PAL)), Se-Hwan Park (Pohang accelerator laboratory (PAL)), Jeong-Hoon Kim (Pohang accelerator laboratory (PAL)), In-Soo Park (Pohang accelerator laboratory (PAL)), Young-Uk Sohn (Pohang accelerator laboratory (PAL))
57	Master Oscillator to Phase Reference Line Connection with Active Drift Compensation for the European Spallation Source	An essential requirement for ESS is to assure a precise phase synchronization of LLRF and Beam Diagnostics systems, operating at 352.21 MHz and 704.42 MHz. The long-term required phase accuracy is 0.1° between adjacent outputs and 2.0° between any two points. The phase synchronization system consists mainly of a Master Oscillator (MO) in the Klystron Gallery and a Phase Reference Line (PRL) - a passive RF system based on a single coaxial rigid line, distributing references along the tunnel. MO reference signals are amplified, and the high-power signals are combined in a diplexer and distributed to the tunnel by a coaxial cable over a concrete duct for cables called STUB. The amplifiers can drift significantly and differently at both frequencies. Ambient temperature variations in the Klystron Gallery, the STUB, and the tunnel can bring another phase drifts in the phase distribution system. That is why the active drift compensation system was developed to stabilize the phase reference in the PRL input. This paper shows the design and implementation of the MO to PRL RF connection, including the active drift compensation, the phase stability results, and the diagnostic system.	Poster	Poster Session	Dominik Sikora (Warsaw University of Technology)	Pawel Jatczak (Warsaw University of Technology), Krzysztof Czuba (Warsaw University of Technology), Morten Jensen (European Spallation Source (ESS)), Luciano Carneiro Guedes (European Spallation Source (ESS))
61	The ESS cavities dedicated piezo driver evaluation status	The LLRF system for the ESS proton linac also comprises a piezo driver subsystem responsible for the fine superconducting cavity tuning. The DMCS tailored the design of this device to the specific needs of the elliptical (M-Beta and H-Beta) resonators and the spoke structures, too. This device provides two independent channels to control piezo voltage signals. It can generate either unipolar (from 0 to 200 V) or asymmetric (from -40 V to 160 V) or bipolar (from -200V to 200V) voltage excitation. The output signal can be the DC or the AC one, with the possibility of synchronization to the LLRF RF signal, too. The work summarizes efforts of the Piezo Driver system evaluation and testing in the different ESS facilities dedicated to cryomodules and cavities testing. This paper also discusses the verification of the device performance in the piezo parameters testing and initial LFD compensation for different cavity types.	Poster	Poster Session	Wojciech Cichalewski	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
62	Development of pulse-by-pulse RF switching in PAL-XFEL LLRF for dual beamlines	Though XFEL(X-ray Free Electron Laser) machines can produce X-ray pulses over 100 million times brighter than storage-ring-based machines, the XFEL machines have very limited beamlines of 1~3. PAL-XFEL machine includes one hard and one soft X-ray beamlines, but only one beamline can be serviced at each shift period. Efforts to operate the beamlines of PAL-XFEL simultaneously have been made in a manner that bunches of repetition rate 60Hz are directed to each beamline in pulse-by-pulse and real-time style. Because function of real-time and pulse-by-pulse RF-parameter switching was also essentially required for PAL-XFEL LLRFs not had been considered at all, a development was performed by software modification of PAL-XFEL LLRFs without changing any related hardwares. PAL-XFEL including this function of LLRFs was operated without any problem in test operation. It is expected usual and simultaneous service of beamlines near future.	Poster	Poster Session	Jinyul Hu (PAL, POSTECH)	Chang-Ki Min, Geonyeong Mun, Changbum Kim, Sang-Hee Kim, KwangHoon Kim, Seonghoon Jung, Donghyun Na, Yong Jung Park, Soung Soo Park
64	BESSY-II new digital mTCA.4-based LLRF control for the booster upgrade	In the framework of the BESSY-VSR upgrade, the beam injection from the booster to the storage ring has to be modified in order to inject shorter bunches. For this purpose, a new PETRA-type 5 cell cavity has been installed in the booster ring and a second one is to be installed. These two new normal conducting 500MHz cavities are to be powered by two already installed and tested 80kW Solid State Amplifiers, which will be driven by a new digital mTCA.4-based LLRF system. The so-called “single cavity” firmware developed by DESY is being used together with the ChimeraTK adapter to connect the mTCA to the EPICS control system. The chosen hardware to implement the control loop is a pair of SIS8300KU and a DWC8VM (low frequency version), while the tuner is driven by a PhyMotion chassis connected to the EPICS system as well. In order to commission the LLRF system, a test-stand has been set up comprising a HOM-damped 500MHz cavity, a 80kW SSA, a mTCA crate and a PhyMotion crate. Once the system is tested and debugged, it will be deployed to driven the new booster cavities.	Poster	Poster Session	Andriy Ushakov (HZB), Axel Neumann (HZB), Pablo Echevarria Fernandez (Helmholtz Zentrum Berlin), Tobias Löwner (Helmholtz Zentrum Berlin)	
65	Controller latency improvements at REGAE	REGAE is a facility for UED experiments (ultrafast electron diffraction) based on a normal conducting S-band gun and buncher cavity. Their RF regulation is performed by a single cavity controller, implemented by an FPGA firmware and operating at 125 MHz. With a variant of the Struck SIS8300-KU controller board that is equipped with 250 MSps ADCs we were able to increase the frequency of the complete digital processing chain to 250 MHz. This includes the ADCs, field detection, feedback controller and DAC. Doubling the frequency reduced the overall controller latency by almost a factor of two. In the poster we show which firmware components had to be optimized or rewritten to achieve the 250 MHz clock rate.	Poster	Poster Session	Michael Büchler (DESY)	Matthias Hoffmann (DESY), Çağıl Gümüş (DESY), Łukasz Butkowski (DESY)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
69	A New Longitudinal Diagnostic System for CERN's Antiproton Machines	A new powerful longitudinal diagnostics system is being developed for the two CERN's antiproton machines, the Antiproton Decelerator (AD) and the Extra Low Energy Antiproton ring (ELENA). The system is based upon a fast computer, fully integrated in CERN's controls infrastructure, with high processing power and hosting a Linux server running real-time software for online data analysis. Its deep memory makes it particularly suitable for AD's and ELENA's long cycles. The system can measure beam intensity for both bunched and debunched beams. For bunched beams, characteristics such as bunch length and peak values will be available, as well as turn-by-turn beam profiles. For debunched beams, Dp/p and average frequency can be measured. The system will provide essential input for RF and cooling systems setup and monitoring. It will also be used by operators to monitor the performances of the two machines and the overall efficiency of CERN's antiproton chain. This paper shows preliminary beam results as well as future steps and plans for exporting the same system to other CERN machines.	Poster	Poster Session	Maria Elena Angoletta (CERN)	Diego Barrientos (CERN), Bartosz Bielawski (CERN), Michael Jaussi (CERN), Saul Novel Gonzalez (CERN), John Molendijk (CERN), Anthony Rey (CERN), Martin Soderen (CERN), Maciej Suminsky (CERN)
70	Synchronization System Overview for the Polish Free-Electron Laser (PolFEL)	The PolFEL is a Polish Free-Electron Laser project under construction at National Centre for Nuclear Research in Świerk. An essential requirement for the PolFEL is to assure a precise phase synchronization of LLRF and Beam Diagnostics systems operating at 1300 MHz. The synchronization system consists of a phase synchronization system and the timing system. The phase synchronization system contains a Master Oscillator (MO) with a power amplifier, a power distribution module, and a coaxial cable distribution over the machine in the star topology. MO reference signal is amplified to a power level of about +32 dBm. The power distribution module with coaxial cables provides 20 reference signals of a minimum +10 dBm power level to LLRF, timing, and Master Laser Oscillator systems. This paper shows the PolFEL synchronization system design overview, MO phase noise results, power level measurements at the power distribution module prototype, and the phase drift considerations.	Poster	Poster Session	Dominik Sikora (Warsaw University of Technology)	Krzysztof Czuba (Warsaw University of Technology), Jarosław Szewiński (NCBJ)
71	Disturbance Observer Application for the Compensation of the Phase Drift of the LANSCE DTL LINAC Solid State Power Amplifier	The front end of Los Alamos Neutron Science Center (LANSCE) linear accelerator (linac) uses four 201.25-MHz Drift-Tube Linac (DTL) modules to accelerate the H+ and H- beams to 100 MeV. Three of the 201.25-MHz DTL tanks, Modules 2, 3, and 4, are powered by diacrodes and the first DTL tank, module 1, is powered by a tetrode. A 20-kW solid-state power amplifier (SSPA) is used to provide 15 kW of drive power to the tetrode. The SSPA is water-cooled and consists of 24 push-pull LDMOS transistors operating at 45% of their power saturation capability, providing ample power headroom and excellent linearity. However, the phase of the SSPA is perturbed at +/-20 degrees over a few ten minutes partially caused by the temperature dependent phase variation of the air-cooled SSPA driver circulator. This phase variation consumes most of the phase control margin of the cavity field feedback controller. In order to mitigate the effect of the SSPA's phase variation on the cavity field, a disturbance observer has been designed and implemented on the cavity field control FPGA. In this paper, the disturbance observer design and functions as well as its short- and long-term performance are described.	Poster	Poster Session	Mark Prokop, Paula Rooy, Sungil Kwon (AOT Division, Los Alamos National Laboratory), Philip Torrez	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
72	Using the Sirepo Platform for Beamline Simulations	The Sirepo platform is designed to offer GUIs for popular simulation codes used in the accelerator space, along with integration with a JupyterLab Python environment. This includes srw, radia, elegant, and warp, mad-x, opal, and synergia, as well as ongoing development for an online controls and fault detection interface. This open-source platform is available through sirepo.com, as well as a premium solution for deployment on-site. The integrated environment across multiple codes allows for easy optimization, verification, and scripting in custom beamlines, rings, and linacs. Sirepo makes it easier for engineers, students, and scientists alike to build accelerator simulations necessary for better understanding subsystem requirements. Here we provide a general introduction to Sirepo and a tutorial on how to build simple beam-line models using our interface.	Poster	Poster Session	Jonathan Edelen (RadiaSoft), Joshua Einstein-Curtis (RadiaSoft)	
73	MATLAB Scripts for RF Commissioning at the LANSCE LINAC	The linear accelerator (LINAC) at the Los Alamos Neutron Science Center (LANSCE) consists of Pre-buncher, Main-Buncher, low-energy beam transport (LEBT), four 201.25-MHz Drift Tube Linacs (DTLs) and forty-four 805-MHz Coupled Cavity Linacs(CCLs). As a part of the upcoming LANSCE Modernization project, low-level RF (LLRF) systems of four 201-MHz DTLs and twenty-six 805-MHz SCLs are digitized. Hence the network-based control of the cavity field and RF commissioning are possible. Each LLRF and high-power RF (HPRF) systems have many process variables (PVs) located on different computer control screens provided by the Extensible Display Manager (EDM). Several MATLAB m-scripts have been developed to efficiently process the necessary PVs while auto-start, amplitude/phase calibration, gain tuning of the cavity field feedback controllers, gain and phase tuning of the beam feedforward controllers, and high power RF trip recovery, processes are configured and validated. This paper addresses the sequence of RF commissioning of the LANSCE LINAC from the time of RF-turn-on to beam feedforward control and its relevant EDMs and MATLAB m-scripts.	Poster	Poster Session	Aaron Archuleta (Los Alamos National Laboratory), Lawrence Castellano (Los Alamos National Laboratory), Mark Prokop (Los Alamos National Laboratory), Paula Van Rooy (Los Alamos National Labratory), SUNGIL KWON (Los Alamos National Laboratory, AOT DIvision), Phillip Torrez (Los Alamos National Laboratory)	
76	The LCLS-II Gun & Buncher LLRF Controller Upgrade	LCLS-II is currently in its commissioning phase at SLAC. It is an X-ray FEL driven by a CW superconducting LINAC. The beam injector plays a crucial role in the overall performance of the accelerator, and is critical to the final electron beam performance parameters. The LCLS-II injector comprises of a 185.7 MHz VHF copper gun cavity, and a 1.3 GHz two-cell L-band copper buncher cavity. The FPGA-based controller employs feedback and Self-Excited Loop logic in order to regulate the cavity fields. It also features several other functionalities, such as live detune computation, active frequency tracking, and waveform recording. The LLRF system drives the cavities via two 60 kW SSAs through two power couplers, and thus stabilizes the fields inside the plant. This paper describes the system architecture including the analog front-end, the FPGA logic, and shows performance results.	Poster	Poster Session	Christos Bakalis (Lawrence Berkeley National Laboratory)	Andrew Benwell (SLAC National Accelerator Laboratory), Larry Doolittle (LBNL), Carlos Serrano (Lawrence Berkeley National Laboratory), Gang Huang (LBNL), Daron Chabot (SLAC), John Dusatko (SLAC National Accelerator Laboratory), Daniele Filippetto (Lawrence Berkeley National Laboratory)
77	The self exited loop cavity field controller and the cavity simulator implemented in MTCA.4.	The superconducting cavity vertical test stand at DESY is going to be updated with the MTCA.4 based system. The digital self exited loop (SEL) LLRF controller has been developed to fulfill the requirements for the controller to drive the cavity with high QL up to 1e10 and high cavity detuning up to 10kHz. In order to test the SEL controller, additionally the real-time cavity simulator has been developed. The electrical and mechanical model of a cavity represented by a differential equation, is implemented inside the FPGA. The model takes the forward power as an input and produces a probe signal based on given detuning and half-bandwidth parameters of a cavity. Microphonic disturbance is also added to simulate the high Ql operation. Both, the cavity simulator and the SEL controller have been implemented in the SIS8300KU, DRTM-DW8VM1 pair boards.	Poster	Poster Session	Lukasz Butkowski (DESY), Cagil Gumus (DESY)	Julien Branlard (DESY)

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
78	Next Generation FRIB LLRF Controller	The Facility for Rare Isotope Beams (FRIB) opened for full user operation in May 2022 and is currently prototyping a 644 MHz superconducting (SC) cavity and cryomodule for an energy upgrade of the accelerator to 400 MeV/u. The low level radio frequency (LLRF) controllers in operation are based on Xilinx Spartan 6 field programmable gate array (FPGA) and support frequencies up to 322 MHz. With requirements for higher frequency operation there was a need to upgrade the current LLRF controller. A next generation prototype controller was designed, developed and fabricated using Xilinx Zynq System on Chip (SoC) FPGA with high-speed JESD204 serial interface to fast 14-bit analog to digital (ADC) and 16-bit digital to analog (DAC) data converters and capable of high frequency direct sampling. A brief overview of the prototype LLRF controller, its features, improvements along with Experimental Physics and Industrial Control System (EPICS) Input/Output Controller (IOC), fast data capture at native resolution, remote update management implementation and future projects will be discussed in this paper.	Poster	Poster Session	Shriraj Kunjir (FRIB)	Enrique Bernal (FRIB), Shen Zhao (FRIB), Dan Morris (FRIB)
84	Status of the Helmholtz Zentrum Berlin Sealab LLRF infrastructure	The preparation of the LLRF Control equipment of the SeaLab project for the commissioning is going on. The current hardware configuration comprises gun and booster cavities under server PC control and the standalone transverse deflecting cavity controller. The ongoing infrastructure works, i.e. cabling traces termination/patch panels connection, network installation and power lines distribution, are going to lead to the final equipment relocation to the RF equipment hall till the end of this year. The control EPICS system was preconfigured to monitor the LLRF equipment and its status. The hardware upgrade, i.e. exchange by the newer ADC/VM and Mezzanine boards, is planned for this autumn. Beside that the basis for the future scientific studies in the SeaLab become the Xilinx RFSoC. Number of applications are migrating from mTCA equipment to RFSoC, because of more rapid prototyping, reach peripheral devices, and open architecture supported by Xilinx. Among them are system analyzer, detuning control, RF system observer, and self-excited loop. The first RFSoC tests on the Tesla cavity in the Hobicat facility are planned for September and the results are going to presented.	Poster	Poster Session	Andriy Ushakov (Helmholtz Zentrum Berlin), Axel Neumann (HZB), Pablo Echevarria Fernandez (Helmholtz Zentrum Berlin), Patrick Nonn (DESY / MSK)	
85	Experimental characterization of the LLRF system performance at the HiRES accelerator	The High Repetition rate Electron Scattering (HiRES) accelerator at LBNL uses a CW, normal-conducting RF electron gun and bunching cavity to deliver high-stability, high repetition rate electron pulses for scientific applications, such as ultrafast electron diffraction (UED) and FELs. Beyond-state-of-art stability is required for the electron beam energy in order to achieve femtosecond temporal resolution in experiments. The LLRF system has recently been upgraded, including minimization of channel crosstalk and optimized feedback bandwidth, resulting in short-term electron beam energy stability better than 1E-4, to the benefit of the final temporal resolution in UED experiments. Furthermore, an ad-hoc timing system allows for heterogeneous data, including beam images, RF waveforms and scalars, to be acquired and stored synchronously and consequently used to train machine learning-based (ML) algorithms for high accuracy predictions of the beam energy and arrival time. We will present experimental results on stability of RF signals, beam energy and time of arrival, together with preliminary work on the development of a ML-based virtual diagnostic for energy and time of arrival.	Poster	Poster Session	Antonio Gilardi (Lawrence Berkeley National Laboratory), Carlos Serrano (LBNL), Daniele Filippetto (Lawrence Berkeley National Lab), Christos Bakalis (Lawrence Berkeley National Laboratory), Dan Wang (Lawrence Berkeley National Laboratory), Frederick Cropp (UCLA), Gang Huang (LBNL), Lawrence Doolittle (Lawrence Berkeley National Laboratory), Qiang Du (LBNL), Sergio Paiagua (Lawrence Berkeley National Laboratory)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
87	Chatter reduction in sliding mode tuner controller using skipping surface	TRIUMF ISAC 1 tuning controllers operate using minimum seeking sliding mode controller to minimize the reflected power in their cavities. As with all minimum seeking algorithms, chatter present in the controller can degrade its performance and cause necessary mechanical wear. By observing the rate at which the minimizing function approaches the sliding surface, it is possible to determine whether a change in direction is necessary, thereby reducing the amount of chatter throughout the minimum seeking process.	Poster	Poster Session	Ken Fong (TRIUMF), Qiwen Zheng (TRIUMF), Ramona Leewe (TRIUMF)	
88	Low Level RF for a Compact, Portable C-Band LINAC	Compact particle accelerators are increasingly needed in medical, industrial, and defense settings. Such an accelerator requires a highly efficient, lightweight, and space-efficient footprint; this leverages particularly unique requirements on RF, power, and thermal budgets. RadiaSoft has been working with SLAC on developing the LLRF system for a structure consisting of 26 pairs of accelerating cavities, a buncher, and thermionic cathode in such an energy- and space-constrained footprint, utilizing a novel accelerating structure. This talk provides the detail of our system architecture and design focusing on system constraints for space and weight.	Poster	Poster Session	Jonathan Edelen (RadiaSoft), Joshua Einstein-Curtis (RadiaSoft), Julian Merrick (SLAC), Sami Tantawi (SLAC)	
91	Narrow Bandwidth Active Noise Control for microphonics rejection in superconducting cavities at LCLS-II	LCLS-II is an X-Ray Free Electron Laser (XFEL) commissioned in 2022, being the first Continuous Wave (CW) hard XFEL in the world to come into operation. To accelerate the electron beam to an energy of 4 GeV, 280 TESLA type superconducting RF (SRF) cavities are used. A Loaded Q (QL) of 4×10^7 is used to drive the cavities at a power level of a few kilowatts. For this QL, the RF cavity bandwidth is 32 Hz. Therefore, keeping the cavity resonance frequency within such bandwidth is imperative to avoid a significant increase in the required drive power. In superconducting accelerators, resonance frequency variations are produced by mechanical microphonic vibrations of the cavities. One source of microphonics noise is rotary machinery such as vacuum pumps or HVAC equipment. A possible method to reject these disturbances is to use Narrowband Active Noise Control (NANC) techniques. Such a technique was already tested at DESY/CMTB and Cornell/CBETA. This proceeding presents the implementation of a NANC controller using the LCLS-II Low Level RF (LLRF) control system. Tests on the rejection of LCLS-II microphonics disturbances are also presented.	Poster	Poster Session	Andrea Bellandi (Deutsches Elektronen-Synchrotron), Jorge Diaz Cruz (Stanford Linear Accelerator Center)	Sonya Hoobler (Stanford Linear Accelerator Center), Julien Branlard (Deutsches Elektronen-Synchrotron), Alessandro Ratti (Stanford Linear Accelerator Center), Sebastian Aderhold (Stanford Linear Accelerator Center), Andy Benwell (Stanford Linear Accelerator Center), Axel Brachman (Stanford Linear Accelerator Center), Dan Gonnella (Stanford Linear Accelerator Center), Janice Nelson (Stanford Linear Accelerator Center), Ryan Douglas Porter (Stanford Linear Accelerator Center), Lisa Zacarias (Stanford Linear Accelerator Center)
96	PIP-II Resonance Control System	The PIP-II Resonance Control System has the goal of providing the electronics to mechanically tune four superconducting cavities as directed by two RF control stations or via LAN manual commands (python LEEP scripts). This solution leverages the LCLS-II Resonance Control chassis design, but with an Intel based FPGA carrier and is largely compatible with LCLS-II screens. This resonance control system will have a 2 Hz/step resolution with up to 256 micro steps per full step. This system also employs piezo driver control with intended resolution better than 1 Hz and a control bandwidth of ~ 500 Hz. The piezo driver boards have ADCs sampling key piezo signals and the DAC output. Cavity detuning information is received over a QSFP fiber interface from the RF station(s). The waveforms of these sampled signals are displayed on EPICS screens for live troubleshooting and diagnostics.	Poster	Poster Session	Bachimanchi Ramakrishna (Jefferson Laboratory), Brian Chase (Fermilab), Curt Hovater (Jefferson Lab), James Latshaw (Jefferson Lab), Tomasz Plawski (Jefferson Lab, Virginia, USA)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
100	Iterative Learning –Deep Dive	The stability and convergence of an Iterative Learning Controller (ILC) may be assessed in time domain, by actually iterating the equations for a variety of inputs, or by finding the eigenvalues (lambda) of the iterated system (lambda-domain), or by forming the Z-transform and applying analogues of the Nyquist criteria. Two often-used criteria are (i) Asymptotic Convergence (AC) of the difference vectors, and (ii) monotonic convergence (MC) of the vector norm. Both criteria have lambda and Z domain counterparts. In this paper we apply all three methods and both convergence tests to a simple plant, namely an RF cavity oscillator with proportional and integral control, with an ILC wrapper to reject a periodic beam-loading disturbance. One, two and three-term (causal and acausal) learning function are used. Simplicity of the system means all convergence tests can be applied analytically. We can then ask the questions: do all the tests work, and do they agree on the stability? For this particular system, the Z-domain AC test agrees with the lambda-domain MC test. Moreover, soliton solutions appear in time domain for gain parameters constrained only by the AC test in lambda-domain.	Poster	Poster Session	SHANE KOSCIELNIAK (TRIUMF)	
101	Future Plans for the CLS Storage Ring LLRF	The Canadian Light Source (CLS) operates a single-cell CESR-B superconducting RF cavity system in the 2.9 GeV storage ring, powered by a 310 kW klystron. After the successful implementation of ALBA's digital low-level radio frequency system (DLLRF) in the dual cavity booster ring at CLS, plans are in place to test the same system in the storage ring RF. The DLLRF also leaves open future possibilities for migrating from klystron to solid state power amplification, as well as adding a second superconducting cavity to the storage ring RF. We will discuss the design of the control system, operational parameters, and comparison to the existing LLRF system.	Poster	Poster Session	Connor Boyle (Canadian Light Source), Denis Beauregard (Canadian Light Source), Jonathan Stampe (Canadian Light Source), Pol Solans (ALBA Synchrotron - CELLS)	
109	Electron-Ion Collider Common Platform System Architecture	The Electron-Ion Collider (EIC), to be constructed at Brookhaven National Laboratory (BNL), is a roughly 10 year 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 GeV to 140 GeV and luminosity up to 1034 cm-2s-1. The project is a partnership between BNL and the Thomas Jefferson National Accelerator Facility (Jefferson Lab, JLAB). The EIC Common Platform is an effort to design and implement a flexible, high-performance electronics platform for required Low Level Radio Frequency (LLRF), Timing, Machine Protection, Instrumentation, Power Supply, and general-purpose Accelerator Controls systems. The fundamental architecture of the Common Platform, centered on a Xilinx Zynq UltraScale+ MPSoC-based carrier board and a variety of function specific daughtercards, is an evolution of the LLRF Platform in use at the BNL Collider-Accelerator Department since 2009. The preliminary architectural design of the Common Platform and its application for LLRF controls is described.	Poster	Poster Session	Geetha Narayan (Brookhaven National Lab)	

Id	Title	Description	Type	Session	Authors (affiliation)	Co-Authors (affiliation)
110	Ultra Low Noise Clock Distribution for Electron-Ion Collider Common Platform	The Electron-Ion Collider (EIC), to be constructed at Brookhaven National Laboratory (BNL), is a roughly 10 year project to design and construct a facility to collide polarized high energy electron beams with polarized proton and heavy ion beams at center of mass energies from 20 GeV to 140 GeV and luminosity up to 1034 cm-2s-1. The project is a partnership between BNL and the Thomas Jefferson National Accelerator Facility (Jefferson Lab, JLAB). The EIC Common Platform (CP) is an effort to design and implement a flexible, high-performance electronics platform for required Low Level RF (LLRF), Timing, Machine Protection, Instrumentation, Power Supply, and general-purpose Accelerator Controls systems. The EIC CP, like its predecessor, the LLRF Platform used at BNL Collider-Accelerator since 2009, will rely on a common ultra-low-noise 100 MHz system clock for operation. We will be presenting the preliminary design work for clock generation, distribution and clean-up while paying special attention to the most challenging phase noise requirements of the EIC hadron storage ring and crab cavities.	Poster	Poster Session	Freddy Severino (Brookhaven National Laboratory)	
111	Development and Integration of New Low-level RF System for MedAustron	Medaustron is a cancer treatment facility with ion therapy. It is based on a synchrotron accelerator with proton and carbon beams. The treatment has been successfully running since 2016, treating about 400 patients a year. Even at this young age of the facility, though, there are problems arising regarding the sustainability of the current system as some of the components are nearing end of lifecycles. This situation called for the development of a new LLRF system, that would be based on current technology, thus ensuring long term maintainability. The system that is currently in development in cooperation between MedAustron and Instrumentation Technologies, is based on the uTCA platform and it unifies several systems in one. With its wide bandwidth signal generation capabilities it will be able to replace the current linac (216MHz) and synchrotron (0.4-10MHz) LLRF systems. At the same time it will provide readout for phase probe measurements in the linac, and pick-ups and Schottky analysis in the synchrotron. The system is controlled by the MedAustron Control System (NI-PXIe) through the fiberlink connection (SFP+) with possibility of establishing other links (EPICS, DOOCS, ...).	Poster	Poster Session	A. Bardorfer (Instrumentation Technologies), B. Baricevic (Instrumentation Technologies), C. Kurfuerst (EMG MedAustron GmbH), G. Muyan (EBG MedAustron GmbH), M. Repovz (EBG MedAustron GmbH), M. Wolf (EBG MedAustron GmbH), Matjaz Skabar (Instrumentation Technologies), Miha Cerv (EBG MedAustron GmbH), Peter Paglovec (Instrumentation Technologies), S. Myalski (EBG MedAustron GmbH)	