LLRF2017

Low Level Radio Frequency Workshop

ALBA

BOOK OF ABSTRACTS

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Oral presentations O-1 to O-32

O-1

ORNL Status report and new projects

Mark Crofford

O-2

LLRF Status and activities at PSI

Roger Kalt

O-3

SSRF Status and new projects

Zhao Yubin

O-4

SLAC Status and new projects

Larry Doolittle[2], Brian Chase[3], Curt Hovater[4], Matt Boyes[1], Andy Benwell[1], Alessandro Ratti[1], Carlos Serrano[2], Gang Huang[2], Joshua Einstein-Curtis[3], Ed Culletron[3], Ramakhrishna Bachimanchi[4], Bo Hong[1], Garth Brown[1]

[1]SLAC National Laboratory, Menlo Park, United States, [2]Lawrence Berkeley Natiional Laboratory, Berkeley , United States, [3]Fermi National Accelerator Laboratory, Batavia, United States, [4]Thomas Jefferson National Laboratory, Newport News, United States

The SLAC National Accelerator Laboratory is building LCLS-II, a new 4 GeV CW superconducting (SCRF) linac as a major upgrade of the existing LCLS. The SCRF linac consists of 35 ILC style cryomodules, each containing eight cavities, for a total of 280 cavities. The design cavity gradients are 16 MV/m with a loaded QL of ~ 4 x 10^7. Each individual RF cavity will be powered by one 3.8 kW solid state amplifier. To ensure optimum field stability a single source single cavity control system has been chosen. It consists of a precision four channel cavity receiver and two RF stations (Forward, Reflected and Drive signals) each controlling two cavities. In order to regulate the resonant frequency variations of the cavities due to He pressure, the tuning of each cavity is controlled by a slow stepper motor with a piezo actuator also used in active compensation of microphonics. Particular care was given to a low noise design to help meet the 0.01%, 0.01 deg amplitude and phase stability requirement at each station. We will describe the design architecture, main system elements as well as test results on LCLS-II cryomodules.

O-5

LLRF developments at KEK and J-PARC

Masahito Yoshii[1], Fumihiko Tamura[2], Yasuyuki Sugiyama[1]
[1]KEK/J-PARC, Tokai-mura, Japan, [2]J-PARC/JAEA, Tokai-mura, Japan

J-PARC Ring Low Level RF are based on full-digital signal processing. Thanks to a good matching with the passive magnetic alloy loaded RF cavity systems, the control systems enable to realize stable proton beam acceleration since 2007. LLRF blocks consist of multi-harmonic RF generation, Phase control, Voltage Level Control and Feedforward Control. The large size of VME 9U crates were selected to implement the multi-harmonic digital data processing with Xilinx Virtex®-II Pro FPGA family and to provide enough Data I/O for debugging. Developing a new system, we have targeted to improve functionality and downsizing of the system. We choose a MicroTCA standard and begun to design new LLRF modules based on it. In this workshop we present the system configuration of the prototype new LLRF systems.

O-6

BNL Status and new projects

Kevin Smith

O-7

Status of CERN LLRF - Operation and New Developments

Wolfgang Hoefle[1]
[1]*Cern, Geneva, Switzerland*

An overview is given of the LLRF systems in operation in the seven CERN synchrotrons and four linacs in operation and under commissioning and their future evolution. Emphasis is given to new developments in particular in the framework of the LHC luminosity upgrades that require a complete overhaul of the systems in the injectors and a new linac. Highlights of the last two years also include commissioning of a new proton beam driven plasma wake field experiment (AWAKE) for electron acceleration, a new anti-proton decelerator (ELENA) and a facility for post-acceleration of radioactive ion isotopes (HIE-Isolde) using high Q superconducting cavities.

O-8

Recent Developments of the Cornell LLRF System

Nilanjan Banerjee[1], John Dobbins[1], Georg Hoffstaetter[1], Roger Kaplan[1], Matthias Liepe[1], Peter Quigley[1], Charles Strohman[1], Vadim Veshcherevich[1]
[1]*Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE), Ithaca, United States*

The Cornell digital LLRF system was first developed for Cornell's storage ring CESR in 2003 keeping in mind the stringent stability requirements of the X-ray ERL Cornell was designing at the time. Since then, both the hardware and software has evolved to keep up with improvements in CESR and for use in the high-current Cornell ERL injector. CBETA, the multi-turn CW SRF ERL that Cornell is currently building, presents an even greater challenge for operating SRF cavities. The loaded Q is very large, the cavities' bandwidths are only about 25 Hz, microphonics detuning is comparable to that bandwidth, while field amplitudes have to be maintained to 2 x 10^{-4} and the phase stability has to be better than 0.1 degrees. In this talk, I will discuss the recent improvements of the Cornell LLRF system giving special emphasis on a new system of automatic tuner control and microphonics compensation using a fast tuner.

O-9

Fermilab Operations and Future Projects

Brian Chase[1], Ed Cullerton[1], Jonathan Edelen[1], Josh Einstein-Curtis[1], Philip Varghese[1]
[1]*Fermilab, Batavia, United States*

This talk presents an overview of Fermilab's present operations and plans for the future. Highlighted are the LLRF team's involvement with a variety of projects including LCLS-II both in system design and cryomodule testing, PIP-II a 800 MeV SRF Linac proposal, G-2 and Mu2e experiments.

0-10

High precision RF control at LBNL

Gang Huang[1], Larry Doolittle[1], Qiang Du[1], Carlos Serrano[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, United States*

FPGA based RF control system enabled the high control precision and provided flexible system configuration. In LBNL, we developed FPGA based RF control system around different machines to achieve stable accelerating field and high precision timing. This paper summarizes the recent progress on the LLRF system development on LCLS-II, ALS, TXGLS and also the laser pulse stacking.

0-11

Design and Implementation of the LLRF System for LCLS-II

Andrew Benwell

O-12

LLRF operation and performance of the European XFEL

Mathieu Omet[1]
[1]Deutsches Elektronen-synchrotron, Hamburg, Germany

The European X-ray Free-Electron Laser (XFEL) at Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany is a user facility under commissioning, providing ultrashort hard and soft X-ray flashes with a high brilliance in the near future. All LLRF stations of the injector, covering the normal conducting RF gun, A1 (8 1.3 GHz superconducting cavities (SCs)) and AH1 (8 3.9 GHz SCs), were successfully commissioned by the end of 2015. The injector was operated with beam transmission to the injector dump since then. After the conclusion of the construction work in the XFEL accelerator tunnel (XTL), the commissioning of 22 LLRF stations (A2 to A23) started with the beginning of 2017. Every station consists of a semi-distributed LLRF system controlling 32 1.3 GHz SCs. Stable operation with beam transport to the main dump (TLD) as well as through undulator sections SA1 and SA3 to the beam dump T4D was achieved. The current state of the LLRF systems as well as the experience gained and performance reached during operation are described.

O-13

Optimization Algorithms and Procedures for SwissFEL LLRF System

Zheqiao Geng[1]
[1]*Paul Scherrer Institut, Villigen Psi, Switzerland*

SwissFEL employs digital LLRF systems to control more than 30 RF stations with either standing wave cavities (e.g. RF Gun) or travelling wave structures working at different frequencies. Due to the tight commissioning schedule, it is challenging to setup an RF station and apply it on beam operation in a short time after the high power RF conditioning is finished. To facilitate the machine commissioning and LLRF performance optimization in daily operation, several automation procedures were designed and implemented for the SwissFEL LLRF system: set up and calibrate LLRF parameters, optimize RF performance (e.g. minimize amplitude and phase jitters), apply RF station on beam operation, beam based calibration and performance optimization. The optimization procedures were implemented with a Python based EPICS framework which provided very good maintainability and extendibility. In this presentation, the algorithms and procedures for LLRF system optimization will be described and the software architecture will be also introduced.

O-14

First commissioning results of CSNS RCS LLRF system

Xiao Li[1]
[1]*Institute Of High Energy Physics, Chinese Academy Of Sciences, Beijing, China*

Firstly, the design of CSNS/RCS LLRF system will be reviewed. And then, the progress of system operation and debugging will be introduced. The main section will focus on the first commissioning results with beam. At last, the next generation hardware platform based on VPX bus will also be discussed.

O-15

LLRF for the PIP-II Accelerator at Fermilab

Jonathan Edelen[1], Brian Chase[1], Joshua Einstein-Curtis[1], Edward Cullerton[1], Philip Varghese[1]
[1]Fermilab, Batavia, United States

This talk will cover the LLRF system for the proposed PIP-II accelerator at Fermilab. We will discuss the overall system design covering both software and hardware aspects, discuss beam performance and beam-based feedback schemes for energy stabilization, and provide an overview of our operational experience with the PIP-II Injector Test.

O-16

LCLS-II LLRF prototype testing and characterization

Lawrence Doolittle[1], Brian Chase[2], Joshua Einstein-Curtis[2], Carlos Serrano[1]
[1]LBNL, Berkeley, United States, [2]FNAL, Batavia, United States

The LCLS-II LLRF system has been designed to meet demanding needs of CW SRF cavities driving an X-Ray laser. Prototype hardware and software has been tested alongside early-production cryomodules, with encouraging results. We will explain the goals for testing and show the methods used to validate the hardware design. Experimental results include in-loop and out-of-loop error measurements, and demonstrate the system's resilience to out-of-bounds microphonics excursions.

O-17

Wideband Control for Magnetron Driven Cavities

Brian Chase, Philip Varghese[1], Ed Cullerton[1], Philip Varghese[1], Jonathan Edelen, Michael Read[2]

[1]Fermilab, Batavia, United States, [2]Calabazas Creek Research, Inc., San Mateo, United States

A rapid phase modulation technique has been developed to regulate both phase and amplitude in narrow band cavities driven by constant power output devices, such as magnetrons. The technique allows the use of low-cost, relatively low-voltage, high-efficiency magnetrons, creating an enabling technology for many commercial and large-scale SRF projects. This technique has been successfully demonstrated in an LLRF system, with the magnetron and SRF cavity at 2.45 GHz. A 100 kW 1300 MHz pulsed magnetron has been developed under the SBIR program and is now in the test stage at Fermilab. The LLRF system implementation of this technique and up-to-date test results are presented.

O-18

LHC LLRF upgrade: Cavity Phase modulation to reduce klystron power in physics

Philippe Baudrenghien[1], Pr Themis Mastoridis[2], John Molendijk[1]
[1]*Cern, Geneva, Switzerland,* [2]*California Polytechnic Institute, San Luis Obispo, USA*

The LHC Low Level and High Power RF systems have been designed for nominal beam currents, that is: ~2800 bunches, 1.1E11 p/bunch resulting in 0.55 A DC current. The LLRF aimed at full compensation of the transient beam loading caused by the various gaps in the beam pattern: Beam dump (> 3.0 us), LHC injection kickers (900 ns), SPS injection kickers (225 ns). Such a compensation requires a lot of klystron power and cannot be sustained at higher beam current. The HiLumi LHC calls for a doubling of beam intensity. We therefore had two choices: Either a major upgrade of the high-power RF (doubling of the klystron power from 300 kW – present – to 600 kW) or a more clever operation of the LLRF. Based on an original proposal by D. Boussard (1995), a study was started in 2012, with the objective of modulating the cavity voltage phase reference to reproduce the modulation driven by the beam. First tests in 2012 and 2013 gave encouraging but not fully satisfactory results. The studies with beam were restarted after the LHC Long-Shutdown (begin 2015) and brought to success in a test in 2016. The new mode of operating the LLRF is used in all physics fills since June 2017.
The method will be presented, together with the FPGA-based algorithm that automatically adapts the reference phase modulation from measurement of cavity voltage (antenna) and klystron output (forward coupler in waveguide).

O-19

Microphonics Compensation for Low Bandwidth SRF Cavites in the CBETA ERL

Nilanjan Banerjee[1], Georg Hoffstaetter[1], Matthias Liepe[1]
[1]*Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE), Ithaca, United States*

Microphonics detuning poses a major challenge on using superconducting radio frequency cavities operating with low bandwidth, as for example in Energy Recovery Linacs. In CBETA, the first multi-turn SRF ERL being constructed at Cornell, the 1.3GHz cavities are designed to limit the bandwidth to 25 Hz. In addition to various engineering measures for reducing vibration, fast tuner systems can be employed to reduce the effective detuning of the cavity. In this paper, we describe a system employing both feedback and feedforward control to generate the drive signal for a piezo-actuator to compensate for transient detuning in a cavity. The algorithm was tested on Main Linac cavities used in the CBETA project and peak microphonics detuning was successfully reduced to almost half its uncompensated value in a stable manner.

O-20

A prototype system of multiharmonic vector voltage control for the J-PARC rapid cycling synchrotron

Fumihiko Tamura[1], Yasuyuki Sugiyama[1], Masahito Yoshii[1]
[1]*J-PARC Center, Tokai, Japan*

Beam loading compensation for the magnetic alloy (MA) cavities is a key for acceleration of high intensity proton beams in the J-PARC rapid cycling synchrotron (RCS). A multiharmonic rf feedforward system is implemented in the existing LLRF control system for the RCS and it served fairly well for the beam tests up to the design beam power, 1MW. During high intensity beam tests, we found some practical disadvantages of the feedforward method due to its open loop configuration. Therefore, We are considering to employ the vector voltage control in the next generation LLRF control systems as well as feedforward for beam loading compensation. We developed a prototype system of multiharmonic vector voltage control in JFY 2016. It handles six harmonics and has features to adapt to frequency sweeps following to the velocity change of the beam during acceleration. We present the system configuration, its commissioning, and the beam test results with a very high intensity beams at the beam power of 900kW.

O-21

A New Damper for Coupled-Bunch Instabilities caused by the accelerating mode at SuperKEKB

Kouki Hirosawa[1,2], Kazunori Akai[1], Eizi Ezura[1], Tetsuya Kobayashi[1], Kota Nakanishi[1], Shin-ichi Yoshimoto[1]
[1]KEK, Tsukuba-city, Japan, [2]SOKENDAI, Tsukuba-city, Japan

SuperKEKB is an electron-positron circular collider upgraded from KEKB. Improvements of components and design are based on nano-beam scheme at the interaction region and large beam current. From the perspective of RF control, core of the problem is large beam current. Specifically, design beam current of 7 GeV electron ring (HER) and 4 GeV positron ring (LER) are 2.6 A and 3.6 A respectively (1.2 A and 1.6 A at KEK achievement). SuperKEKB RF system has normal conducting cavity (ARES) and superconducting cavity, and ARES has an unique structure to reduce undesirable contributions from large beam current. According to our calculation for the design current, cavity detuning will approach the lowest mode (μ = -1) frequency of Coupled-Bunch Instability (CBI) and some modes (μ = -1, -2, -3) instabilities will excite. In KEKB, we used cavity impedance damper for CBI which supports only μ = -1 mode, because only μ = -1 mode CBI occurred at KEKB beam current. For SuperKEKB, we need to suppress higher modes (μ = -2, -3), so we developed the new damper for these higher mode and the lowest mode of CBI (μ = -1, -2, -3). This damper consists of an analog device which has functions of single-sideband filter, and a digital device made of FPGA which works as a bandpass filter. Characteristics of the new damper were evaluated and the result agrees with our required specifications. In this presentation, we will report details of this new developed damper and simulations of CBI suppression by using this damper.

O-22

Introducing Fixed Frequency Clock Operation on the CERN VXS LLRF Platform

Johannes Molendijk[1]
[1]CERN, Geneva, Switzerland

Originally the recently CERN developed VXS FMC carrier platform, initially deployed on the PSB, was operated using a sweeping frequency generated by a master DDS. All modulators and demodulators in this narrow-band system, would use this clock as reference for their LOs. As the system gradually got Introduced in other machines, Low Energy Ion ring (LEIR), Extra Low ENergy Antiproton ring (ELENA) and soon also the Antiproton Decelerator (AD), that all require large revolution frequency ranges, it became essential to enable operating the VXS based LLRF system at a fixed master DDS frequency. This offers seamless operation without the need for harmonic changes and at the same time has the benefit of near maximal ADC / DAC sampling rate and incommensurate sampling.

This contribution highlights the integration of such fixed frequency clock scheme in the already existing VXS based LLRF. An overview is given of the implications of this paradigm change on the methods used for tuning word distribution, modulator and demodulator implementation. The chosen implementations aimed at a most optimal use of system resources to open the path to multi-harmonic operation, employing multiple demodulators and modulators each dealing with an individual revolution frequency harmonic, as needed to operate the CERN PSB, with wide-band finemet cavities that will be installed during the long shutdown of 2019. The new system is currently already used in the ELENA decelerator, where the frequency ranges over a decade and the system has to cope with very small RF signals.

O-23

LLRF synchronization based on White-Rabbit. First results of the system in the IFMIF/EVEDA RFQ conditioning in Rokkasho

Miguel Mendez[1], Moises Weber[2], Cristina De la Morena[2], David Regidor[2], Purificación Méndez[2], Igor Kirpitchev[2], Joaquín Molla[2], Angél Ibarra[2], Jose Gabriel Ramírez[1], Rafael Rodriguez[1], Javier Díaz[1]

[1]Seven Solutions S.L., Granada, Spain, [2]CIEMAT, Madrid, Spain

One of the main issues in the Radio Frequency (RF) systems is the synchronization of the different parts and, principally, the Low-Level-RF (LLRF). This is normally handled with the distribution of a Master-Oscillator (MO) as an analog fan-out from a precise and expensive crystal. This solution is problematic as the installation become bigger since it is very sensitive to losses variations, aging, calibrations exactness, temperature fluctuations and environmental changes. There is an equivalent option using optical fiber to distribute ultra-stable frequency but, once again, the high accurate calibration and commissioning of the equipment increase complexity and costs. As alternative, this publication introduces a new approach based on White-Rabbit technology as a digital mechanism for RF distribution.

White-Rabbit (WR) is a fully deterministic Ethernet-based network for general purpose data transfer and synchronization. It was born at CERN for time and frequency dissemination up to 1000 nodes, demonstrating the capability to provide synchronization accuracy better than 100ns and stability on frequency dissemination better than 2ps. It is self-calibrated and allows plug and play deployment due to a periodically temperature compensation.

The first LLRF based on this technology has been developed by Seven Solutions/CIEMAT in the framework of IFMIF-EVEDA. IFMIF aims to develop, as part of the international Nuclear Fusion Program, a structural materials database for fusion reactors construction.

The innovative IFMIF Linear Prototype Accelerator (LIPAc) is under construction in Rokkasho/Japan in order to validate the final IFMIF accelerators concept. It includes the longest RFQ cavity which is fed by 8 chains of 200kW/175MHz, therefore, a flexible and precise LLRF is needed. The utilization of White-Rabbit as RF balance and synchronization technology allows to control each chain's frequency, amplitude and phase independently, simplifying significantly the facility commissioning and tuning operation.

The first LLRF synchronization results and preliminary RFQ cavity conditioning response are presented.

O-24

Beam Synchronous Processing: Fixed Clock and RF Regeneration. New Paradigms for CERN SPS LLRF

Javier Galindo Guarch[1,2], Philippe Baudrenghien[1], Juan Manuel Moreno Arostegui[2]
[1]CERN, Geneva, Switzerland, [2]Universitat Politecnica de Catalunya, Barcelona, Spain

The use of a swept clock, derived from the RF, and therefore harmonic to the revolution frequency, is widely used at CERN due to the simplification it offers for bunch synchronous processing in machines ramping the energy with changing revolution frequency. This approach however presents several technological drawbacks which add complexity to future upgrades and limit performances. The use of a fixed clock, on the other hand, has many advantages and enables the use for all the potential of digital solutions; microelectronics technology is more suitable for a fixed clock, regulation loops can be better tuned and optimized, reconstruction filters are easily implemented with a fixed clock, the spectral purity of a fixed clock can easily be much better than a swept one, synchronous logic design can handle clock domain crossing easily and RF gymnastics can be better implemented. This paradigm has been selected for the SPS LLRF upgrade. The frequency information will be transmitted on a deterministic link, White Rabbit, from which the fixed reference clock is extracted.

Some LLRF processing must however remain beam synchronous; bunch by bunch dampers, transient beam loading compensation as the One Turn FeedBack (OTFB), and bunch by bunch phase measurements. The paper presents an overview of the technical, technological and historical motivations for such an evolution and change of paradigms. Benefits and drawbacks of the ancient approaches with swept clock are compared with the new ideas. Finally the problem of beam synchronous processing with fixed clock is addressed, and solutions are proposed for the OTFB with possible implementations.

O-25

Drift calibration for the European XFEL

Frank Ludwig[1], Uros Mavric[1], Christian Schmidt[1], Lukasz Butkowski[1], Holger Schlarb[1], Jan Piekarski[2], Krzysztof Czuba[2]
[1]DESY, Hamburg, Germany, [2]WUT, Warsaw, Polen

For a reliable and robust operation of free-electron lasers with bunch-arrival time variations on the sub 10fs scale, the short-term and long-term stability of the cavity field is an important factor. The long-term stability depends mainly on temperature and humidity changes acting on various crucial electronic subcomponents of the accelerator. For the European XFEL we used beside a global beam-based feedback a 2U 19" drift calibration module to remove amplitude and phase variations of the MicroTCA.4 LLRF system on the fs-scale operating at 1.3GHz. In this talk we present the hardware, performance, production issues and operation of the module. Furthermore we present future
activities for using the calibration for continuous wave operation and operating frequencies at 3.0GHz and 3.9GHz.

O-26

Automatic phase calibration for RF cavities using beam-loading signals

Jonathan Edelen[1], Brian Chase[1]
[1]*Fermilab, Batavia, United States*

Precise calibration of the cavity phase signals is necessary for the operation of any particle accelerator. For many systems this requires human in the loop adjustments based on measurements of the beam parameters downstream. Some recent work has developed a scheme for the calibration of the cavity phase using beam measurements and beam-loading however this scheme is still a multi-step process that requires heavy automation or human in the loop. In this paper we analyze a new scheme that uses only RF signals reacting to beam-loading to calculate the phase of the beam relative to the cavity. This technique could be used in slow control loops to provide real-time adjustment of the cavity phase calibration without human intervention thereby increasing the stability and reliability of the accelerator.

O-27

The challenge of operating superconducting cavity at 5 Hz bandwidth

Daniel Valuch[1], Akira Miyazaki[1], Walter Venturini Delsolaro[1]
[1]*CERN, Geneva, Switzerland*

HIE Isolde is a radioactive beam post accelerator at CERN. It is powered by 20 quarter-wave superconducting cavities (32 in the final configuration), running at 101 MHz. The machine was designed to run with unusually narrow cavity operating bandwidth (5-10 Hz) to keep low rms forward RF power.

This work point is very challenging for the LLRF controller, as fast perturbations originating in microphonics, He pressure or the Lorentz force detuning can be as high as 20x the cavity operating bandwidth. The LLRF controller profits from more than 500% power margin available, however the cavity resonance control at high accelerating gradients is very difficult to achieve with standard methods. A new control strategy using the in-loop error signals to estimate the cavity tune state, instead of tune state measurement, was developed and successfully tested.

O-28

Recent Progress in Low Level RF System of the 1.3GHz Superconducting Accelerator at Peking University

Liwen Feng[1], Fang Wang[1]
[1]*Peking University, Beijing, China*

Peking University SRF Group is a superconducting accelerator research facility in China. A digital LLRF system was developed for the operation of 3.5-cell DC-SRF photoinjector and 2x9-cell accelerator in our facility, both at the frequency of 1.3GHz. Stability of the LLRF system is 0.01% for amplitude and 0.02deg for phase. Efforts for both hardware and software were taken during the development of the system. For the hardware, a compact LO/Digital clock generation board using commercial PLL ICs was developed. For the software, a Digital Phase Lock Loop (DPLL) based reference racking algorithm was developed to cancel the LO/Digital clock noise. A statical grammar analyze tool was developed to help eliminate potential errors in fixed-point algorithm. Also, model based design process was introduced in the development. With these efforts, development time of new system was reduced from months to a few days.

O-29

CW operation of XFEL cryomodule – field regulation performance study for high Ql resonators.

Wojciech Cichalewski[1], Jacek Sekutowicz[2], Radoslaw Rybaniec[2], Konrad Przygoda[2], Julien Branlard[2], Holger Schlarb[2], Andrzej Napieralski[1]
[1]DMCS-LUT, Łódź, Poland, [2]DESY, Hamburg, Niemcy

The opportunity of the continuous wave operation of TESLA type multi-cavity setup is being explored since couple of years. The idea of XFEL and/or FLASH(short pulse) accelerators infrastructure adjustment to CW mode implies some potential modifications that will influence different areas of the experiment. One of the challenge is adaptation of the LLRF systems of this vector sum control based facility. This talk summarizes the modifications applied to the XFEL/FLASH type LLRF system towards LP/CW operation. This MTCA.4 based system has been modified firmware/software wise in order to provide easy and efficient way to switch between both CW and long pulse operation scenarios. Recently recognized challenges in CW operation of short pulse dedicated systems are also described. Finally recent results from the accelerating field regulation performance study are discussed. It has to be emphasized that achieved field control precision fulfill XFEL regulation specification for single module (8 cavities) CW operation for average field gradient of 18 MV/m.

O-30

Towards a better understanding of the field control problem

Olof Troeng[1], Bo Bernhardsson[1], Anders J Johansson[1]
[1]*Lund University, , Sweden*

Motivated by the challenging field control requirements for the European Spallation Source, we present two approaches that simplify the understanding of the field control problem.

1. By using a non-standard parametrization of the cavity field equation, where the mode amplitudes are expressed in terms of the square root of the mode energies, it becomes clear how parameters such as the cavity coupling and r/Q affect the achievable field control performance.

2. By using a complex-coefficient representation of the field control loop dynamics it is possible to simplify the stability and robustness analyses relative to the conventionally used real-valued two-input two-output representation. In particular, it simplifies the understanding of how loop phase variations and parasitic modes impact closed loop stability.

O-31

APS-Upgrade RF System Simulations and Plans

Tim Berenc, Michael Borland, Joe Calvey
[1]*Argonne National Laboratory, Chicago, United States*

The Advanced Photon Source is pursuing an upgrade of the storage ring. The upgraded ring will have a reduced number of main accelerating cavities and an added superconducting passive bunch-lengthening cavity. In addition, to support the increase from 100mA to 200mA in as low as 48 bunches, the injector chain will be required to deliver nearly ten times more charge. This will create heavy beam-loading conditions in the particle accumulator ring and the booster. Particle tracking simulations of rf system interaction with the beam, including rf feedback, are guiding the design of rf system upgrades. A sample of these simulations and rf control strategies will be presented along with plans for upgrading the >20 year old analog llrf systems.

O-32

Model Based Fault Diagnosis for the LLRF Cavity Signals of the European-XFEL

Ayla Nawaz[1]
[1]*Desy, Hamburg, Germany*

In order to ensure safe high gradient operation, a reliable Fault Detection and Diagnosis is critical to the LLRF system. Some well known cavity faults, such as quenches have to be detected as fast as possible while the number of false alarms have to be minimized. Other faults that affect the cavity signals should also be detected and when possible the root cause should be identified. Using appropriate cavity models, the advantages of model based fault diagnosis are discussed to handle such faults and further steps to automate the fault diagnosis for the LLRF system are presented.

Posters
P-1 to P-100

P-1

Dual Frequency Laser Gun LLRF System

Tomasz Plawski[1], Ramakrishna Bachimanchi[1], Manuel Diaz[1], Curt Hovater[1], Scott Higgins[1], Clyde Mounts[1], Chad Seaton[1], Dave Seidman[1]
[1]*Jefferson Lab, Newport News, United States*

During the CEBAF 12 GeV Upgrade at Jefferson Lab, a fourth experimental hall, "D", was added to the existing three halls. To produce four beams and deliver them to all halls concurrently requires new frequencies and a new timing pattern of the electron bunches. Since a photo-gun is used to produce electron bunches, the gun's drive laser pulses need to be synchronized with the required bunch rate frequencies of 499 MHz or 249.5 MHz. To meet these new operational requirements, a "4-Laser" LLRF system has been proposed to replace the older VME based system. Very specific requirements (dual frequency operation, multichannel transmitter) on one side and the simple RF drive mode operation on the other imply the use of a commercial off-the-shelf digital platform rather than a system typical for RF cavity field control. We have chosen the Texas Instruments TSW1400EVM FPGA board along with a high-speed 8-Channel, 14-Bit ADS5295EVM board, and a 4-Channel, 16-Bit DAC3484EVM board. The DAC board includes a low jitter clock generator/cleaner for clocking ADCs, DACs and the FPGA. The only custom design section of the system is the RF Front End board. The complete 4-Laser LLRF system has been designed, built, and recently commissioned in the CEBAF Injector. This paper will detail the design and report on commissioning activities.

P-2

Upgrading the J-PARC Ring LLRF systems

Masahito Yoshii, Fumihiko Tamura[2], Yasuyuki Sugiyama[1]
[1]KEK/J-PARC, Tokai-mura, Japan, [2]J-PARC/JAEA, Tokai-mura, Japan

J-PARC Ring Low Level RF are based on full-digital signal processing. Thanks to a good matching with the passive magnetic alloy loaded RF cavity systems, the control systems enable to realize stable proton beam acceleration since 2007. LLRF blocks consist of multi-harmonic RF generation, Phase control, Voltage Level Control and Feedforward Control. The large size of VME 9U crates were selected to implement the multi-harmonic digital data processing with Xilinx Virtex®-II Pro FPGA family and to provide enough Data I/O for debugging. Developing a new system, we have targeted to improve functionality and downsizing of the system. We choose a MicroTCA standard and begun to design new LLRF modules based on it. In this workshop we present the system configuration of the prototype new LLRF systems.

P-3

Renewal and upgrade of the fast beam-based feedback system at FLASH

Sven Pfeiffer[1]
[1]*DESY, Hamburg, Germany*

Linear accelerator facilities require femtosecond precision synchronization between external laser systems and the electron beam. Such high precision is required for the electron bunch injection into a plasma bubble for laser plasma acceleration or for pump-probe experiments. A renewal and upgrade of the fast intra-train beam-based feedback system is planned at the Free Electron Laser in Hamburg (FLASH). This linear accelerator is based on superconducting (SRF) technology operating with pulse trains of maximum 3 MHz bunch repetition rate. Arrival time fluctuations of the electron beam are correctable by introducing small energy modulations prior to the magnetic bunch compressor.
This contribution focuses on the design and the characterization of an ultra-fast normal-conducting RF (NRF) cavity with large bandwidth, mandatory to correct fast arrival time fluctuations. Additional high frequency components needed for cavity operation and its digital low-level radio frequency regulation system were characterized to reach arrival time stabilization towards one femtosecond range. The tunnel installation in January 2018 and the integration with the currently used beam-based feedback system will be outlined.

P-4

MicroTCA.4-based LLRF for the superconducting CW Linac ELBE – Status and Outlook

Michael Kuntzsch[1], Reinhard Steinbrück[1], Rico Schurig[1], Martin Hierholzer[2], Martin Killenberg[2], Christian Schmidt[2], Cagil Gümüs[2], Łukasz Butkowski[2], Matthias Hoffmann[2], Chris Iatrou[3], Julian Rahm[3], Igor Rutkowski[4], Maciek Grzegrzółka[4]
[1]Helmholtz-Zentrum Dresden-Rossendorf HZDR, Dresden, Germany, [2]Deutsches Elektronensynchrotron DESY, Hamburg, Germany, [3]Technische Universität Dresden, Dresden, Germany, [4]Warsaw University of Technology, Warzsaw, Poland

The superconducting linear accelerator ELBE is operated in continuous wave operation (CW). The analogue LLRF system, used since 2001, is going to be replaced by a digital solution based on MicroTCA.4. The new system enables a higher flexibility, better performance and more advanced diagnostics. The contribution will show the performance of the new system at ELBE, the hardware and the software structure. Further it will summarize the last steps to bring it into full user operation and give an outlook to the envisioned beam-based feedback system that will take advantage of the capabilities of the digital LLRF system.

P-5

The NSLS-II digital RF field controller design and operational experience

James Rose[1], Brian Holub[1], Hengjie Ma[1], Carlos Marques[1], Jorge Oliva[1], Nathan Towne[1]

[1]NSLS-II, Brookhaven Lab, Upton, United States

The NSLS-II digital LLRF controller is a versatile platform for RF field control in synchrotrons. With modular FPGA code and conditional compilation the instantiation of feedback, ramp functions and interlock components are conditional depending on the needs of the RF system targeted. A variety of applications within logic such as a 7 channel Network Analyzer that includes electron beam response, a constant-phase amplitude limiter, quench detection and interlock, and feed-forward tables have been in developed and will be described. Operational experience including feedback loop measurements using the network analyzer, post-mortem data with beam and phase-jump measurements will be described. Comparison of traditional analog control vs. the NSLS-II controller at CLS and TPS/TLS will be presented as well.

P-6

Overview and system requirements for SARAF-LINAC LLRF systems

Lu Zhao[1], Guillaume Ferrand[1], M Michel Luong[1], M Romuald Duperrier[1], M Nicolas Pichoff[1], M Claude Marchand[1]
[1]*CEA Saclay, Gif-sur-yvette, France*

CEA is committed to the design, construction and commissioning of a Medium Energy Beam Transfer line and a superconducting linac (SCL) for SARAF accelerator in order to accelerate 5mA beam of either protons from 1.3 MeV to 35 MeV or deuterons from 2.6 MeV to 40 MeV. The Low Level RF (LLRF) is a subsystem of the CEA control domain for the SARAF-LINAC instrumentation. This paper contains the top level and performance requirements needed to design the LLRF system for SARAF-LINAC, these requirements are derived from accelerator physics, operational and maintenance requirements. The functional specifications of LLRF control system has been defined, which can be used to guide hardware/software designs. Moreover, a cavity simulator is under development for testing LLRF control system.

P-7

Preliminary measurements of amplitude and phase in the top-implart proton linear accelerator

Vincenzo Surrenti[1], Alessandro Ampollini[1], Giulia Bazzano[1], Michele Arturo Caponero[1], Paolo Nenzi[1], Luigi Picardi[1], Andrea Polimadei[1], ms Concetta Ronsivalle[1], Emiliano Trinca[1]

[1]*Enea, Frascati, Italy*

The realization of a 150 MeV proton linac, named TOP-IMPLART (Intensity Modulated Proton Linear Accelerator for Radiation Therapy) devoted to cancer therapy application is in progress at ENEA-Frascati. Actually the section up to 35 MeV has been constructed and is under commissioning: it consists of a 7 MeV low frequency (425 MHz) injector followed by four modules SCDTL type operating at 2997.92 MHz, powered by a single 10 MW-4 µsec klystron. At this time in order to keep constant the resonance frequency of the accelerating structures each module is provided with a chiller stabilizing the temperature. In the near future, a tuning post mounted in each SCDTL module will be controlled by its own AFC (Automatic Frequency Control) to ensure greater stability of beam parameters. A system for the measurement of RF amplitude and phase in different points of the RF line has been developed based on a digital IQ (In-phase and Quadrature) demodulator at Intermedia Frequency (12.5MHz). Preliminary measurements have been done relative to amplitude and phase (referred to the klystron output) of the RF fields in each of the four modules and put in relation with the thermal cycles of the structures and RF operational maneuvers of the power line distribution.

P-8

RF Systems for the Low Energy RHIC Electron Cooling Project

Kevin Mernick[1], Michael Blaskiewicz[1], Thomas Hayes[1], Geetha Narayan[1], Fred Severino[1], Kevin Smith[1], Binping Xiao[1], Tianmu Xin, Wencan Xu[1], Alex Zaltsman[1]
[1]*Brookhaven National Laboratory, Upton, United States*

The Low Energy RHIC Electron Cooling (LEReC) project aims to provide significant luminosity improvement for RHIC operation during the BES-II (Beam Energy Scan II) running period. In this mode, RHIC operates below its nominal injection energy to provide Au-Au collisions at center-of-mass energies of 7.7 – 11.5 GeV/n to support the search for the QCD critical point. The electron beam for cooling is required to have the same velocity as the ion beam, corresponding to kinetic energies of 1.6 – 2.6 MeV, at a current of 10 - 50 mA and with an energy spread of < 5e-4. The RF system consists of 4 cavities which accelerate the electron beam and a transverse deflecting cavity for the longitudinal phase space diagnostic. These cavities must accelerate the beam from the 400 keV DC photogun, provide an energy chirp for ballistic stretching in the transport, linearize the bunch energy with a 3rd harmonic cavity, and then remove the energy chirp to minimize energy spread. This poster will describe the overall design of the RF system and the LLRF controls.

P-9

Status of the LLRF Development for the ESR Barrier-Bucket System

Jens Harzheim[1], Frey Michael[2], Kerstin Groß[1],Harald Klingbeil[1,2], Dilyana Domont-Yankulova[1]
[1]Tu Darmstadt (temf), Darmstadt, Germany, [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

For sophisticated longitudinal beam manipulations, the Experimental Storage Ring (ESR) at GSI, Darmstadt, is to be equipped with a Barrier-Bucket (BB) RF System. This system will consist of two broadband RF cavities, each driven by a solid state amplifier, with the purpose to produce two voltage pulses per beam revolution to longitudinally enclose the beam. By shifting the pulses towards each other, the beam can be compressed or decompressed which can be used for particle accumulation.

For the LLRF System, different requirements have to be fulfilled. Besides high requirements on the pulsed gap signal quality (e.g. ringing <2.5%), the system has to provide the flexibility for adiabatic voltage ramp-up and adiabatic pulse shifting with high timing accuracy. A connection to the FAIR Central Control System (CCS) is intended, as Amplitude and phase ramp data will be provided by the CCS.

In this contribution, the planned structure of the ESR BB LLRF system is presented together with first experimental results from a test setup at GSI.

P-10

Overview of LLRF System for iBNCT Accelerator

zhigao fang[1], kenta futatsukawa[1], yuji fukui[1], takashi obina[1], yosuke honda[1], feng qiu[1], takashi sugimura[1], shinichiro michizono[1], shozo anami[1], fujio naito[1], hitoshi kobayashi[1], toshikazu kurihara[1], sasaharu sato[1], tsukasa miyajima[1], toshiyuki ohba[2], nobuaki nagura[2]
[1]*Kek, Tsukuba, Japan,* [2]*Nippon Advanced Technology CO., LTD., naka, Japan*

At the Ibaraki Neutron Medical Research Center, accelerator-based neutron source for iBNCT (Ibaraki - Boron Neutron Capture Therapy) is being developed using an 8-MeV proton linac and a beryllium-based neutron production target. The proton linac consists of an RFQ and a DTL, which is almost the same as the front part of J-PARC. However, here only one high-power klystron is used as the RF source to drive the two cavities with quite different Q-values and responses. From June 2016, a cPCI based digital feedback system was applied to the iBNCT accelerator. It serves not only as a controller for the feedback of acceleration fields, but also as a smart operator for the auto-tuning of the two cavities in the meantime, especially during the RF start up to the full power. The details will be described in this report.

P-11

LLRF System for the Fermilab Muon g-2 and Mu2e Projects

Philip Varghese[1], Brian Chase[1]
[1]Fermilab, Batavia, United States

The Mu2e experiment measures the conversion rate of muons into electrons and the Muon g-2 experiment measures the muon magnetic moment. Both experiments require 53 MHz batches of 8 GeV protons to be re-bunched into 150 ns, 2.5 MHz pulses for extraction to the g-2 target for Muon g-2 and to a delivery ring with a single RF cavity running at 2.36 MHz for Mu2e. The LLRF system for both experiments is implemented in a SOC FPGA board integrated into the existing 53 MHz LLRF system in a VXI crate. The tight timing requirements, the large frequency difference and the non-harmonic relationship between the two RF systems provide unique challenges to the LLRF system design to achieve the required phase alignment specifications for beam formation, transfers and beam extinction between pulses. The new LLRF system design for both projects is described and the results of the initial beam commissioning tests for the Muon g-2 experiment are presented.

P-12

A MTCA.4 based digital LLRF system for the GSI UNILAC

Jens Zappai[1], Bernhard Schlitt[1], Alexander Schnase[1], Gerald Schreiber[1]
[1]*GSI Helmholtzzentrum Für Schwerionenforschung GmbH, Darmstadt, Germany*

The heavy ion linear accelerator UNILAC served for over 40 years as workhorse for nuclear physics experiments at GSI and as injector to the SIS18 synchrotron. Within the scope of the FAIR project it will also act as injector with increased requirements in beam current and beam quality. To meet these requirements and to ensure reliability for the future, a new digital low level RF system is under development. The spectrum of accelerated ions from hydrogen to uranium results in a huge dynamic range in amplitude, duty cycle and beamloading, especially in respect of the 50 Hz mixed mode. To account for the individual demands of the accelerator and to combine these with the advantages of a commercial-off-theshelf system like longterm availability and state-of-the-art technology, the new LLRF system will be based on the modular MicroTCA.4 standard. Design and current status of development will be presented.

P-13

Progress on the ISIS synchrotron digital low level RF system upgrade

Andrew Seville[1], David Allen[1], Robert Mathieson[1]
[1]STFC, Chilton, Didcot, United Kingdom

The ISIS synchrotron at the Rutherford Appleton Laboratory in the UK now routinely uses a dual harmonic RF system to accelerate beam currents in excess of 230 uA to run two target stations simultaneously. The acceleration in the ISIS synchrotron is provided by six fundamental frequency (1RF) and four second harmonic (2RF) RF cavities. The 1RF systems are required to sweep from 1.3MHz to 3.1MHz during the 10ms acceleration period, repeated at 50Hz, with the 2RF systems sweeping from 2.6MHz to 6.3MHz. The existing analogue LLRF control system has been in service for over 30 years and is now showing some signs of old age and spare parts are becoming difficult to source. In order to overcome this and to give more stable control of the phase of the RF voltage at each of the cavities, changes have been made to the LLRF control systems. A new FPGA based combined frequency law generator / master oscillator has been implemented using “off-the-shelf” National Instruments PXI-express based FlexRIO modules. This approach has allowed the relatively rapid deployment and testing of various components of the LPRF system each with different functionality. The system has been successfully used during the ISIS operational cycles over the last eighteen months or so. This presentation reports on the commissioning of the FlexRIO system and plans for the gradual replacement of remaining parts of the LPRF system.

P-14

Operational experience of ALBA's Digital LLRF at SOLARIS Light Source

Pawel Borowiec[1], Angela Salom[2], Francis Perez[2], Lars Malmgren[3], Åke Andersson[3], Robert Lindvall[3], Aleksandar Mitrovic[3], Adriana Wawrzyniak[1], Paulina Klimczyk[1], Maciej Kopec[1], Arkadiusz Kisiel[1], Lukasz Dudek[1], Wojciech Kitka[1]
[1]Jagiellonian University, Synchrotron Solaris, Krakow, Poland, [2]ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain, [3]MAX IV Laboratory, Lund University, Lund, Sweden

Solaris in Krakow – the first Polish synchrotron light source was started an operation with the beam in storage ring from May 2015. The storage ring (SR) and related components are a twin brother of MAXIV 1.5 GeV (SR) installed in Lund. The facility consists of a 1.5 GeV (SR) and a 600MeV S-band linear accelerator with RF thermionic gun. Since linac is not a full energy one, ramping in SR is necessary. The RF systems of the SR work at 100MHz. There are two normal conducting capacity loaded accelerating cavities and two 3rd order Landau passive cavities. Active cavities are fed by 60kW modular solid state amplifier each. From the beginning of operation the LLRF was necessary. Since there were no expertise at the facility and no time for development almost turn-key digital Low Level RF (DLLRF) system has been implemented according to MAXIV solution. Only small adaptation was needed. A DLLRF system consists commercial uTCA boards, with a Virtex-6 FPGA mother board (Perseus 601X), two double stack FMC boards with fast ADCs and DACs and host computer which runs Device Servers for Tango control system. The capabilities of FPGAs allowed including the control of all cavities, the handling of fast interlocks, providing automatic startup and conditioning of cavities, and post-mortem analysis in one DLLRF system. This paper summarizes operational experience about installation, commissioning, learning-curve from entry-level user, beam operation and future upgrades of this DLLRF.

P-15

Evolution and up-gradation of LLRF system of Indus-2 Synchrotron Radiation Source

Nitesh Tiwari[1], Pritam S. Bagduwal[1], Dheeraj Sharma[1], Mahendra Lad[1]
[1]*Raja Ramanna Centre For Advanced Technology, Indore, India*

Indus-2 is a 2.5 GeV Synchrotron Radiation Source (SRS). RF system was designed with four bell shaped RF cavities, RF amplifiers and Low Level RF (LLRF) controls. Initially RF system was installed with analog LLRF system that worked satisfactorily for many years. High power amplifiers of Indus-2 were upgraded in phased manner that required optimization of ACL/PCL parameters after every upgrade. Digital LLRF control system employing FPGA was designed and developed and commissioned. This digital system provides more flexibility, adaptability which is very useful for frequent upgrades in the RF system. First digital LLRF system was designed using Virtex-4 FPGA with controller codes written in VHDL. To take the advantage of industrially developed hardware that offers better EMI/EMC performance, new digital LLRF systems were built on PXI platform. Codes for fast feedback control algorithm were prepared in LabView. Recently a fifth RF station with digital LLRF system has been installed to cater RF power requirement for Insertion Devices. Digital LLRF system has RF Processing Unit (RFPU) that perform the function of down conversion of RF (505.8MHz) to IF (31.6 MHz) using a mixer, synchronized clock generation and amplitude/phase control of main RF using I/Q modulator signal. Presently five digital LLRF control systems employing ACL/PCL have been installed with RF system of Indus-2, providing phase and amplitude stability better then ± 0.5º and ± 0 .5 respectively and Indus-2 is being operated successfully in round the clock manner at designed energy of 2.5 GeV/200 mA. Experience gained and lessons learnt during this development will be presented.

P-16

Progress of the CSNS/RCS LLRF control system

Hong Sun[1]
[1]Institute Of High Energy Physics, Chinese Academy Of Sciences, Beijing, China

The RF acceleration system with ferrite loaded RF cavities has been constructed for the rapid cycling proton synchrotron of the CSNS project. All eight RF cavities will provide a RF voltage of maximum 165kV for accelerating proton beams. RF cavities and high power tube amplifiers adjacent cavity have been installed in the tunnel. The full digital LLRF control systems based on cPCI bus architecture and interlock protection and remote monitoring system based on Epics in the Ring RF station also have been completed. The RF system integration test and long term running conditioning have been done. The preliminary beam commissioning is underway since July 2017. The ring RF system and LLRF control system works well and the proton beams have been accelerated to 1.6GeV with a repeat rate of 25Hz.

P-17

Design of LLRF system for MA-loaded cavity of HIAF

Yan Cong[1]
[1]Institute Of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

According to the task of the HIAF (High intensity Heavy-ion Accelerator Facility) project undertaken by the Institute of Modern Physics, Chinese Academy of Sciences,we need to develop a RF system of a MA core loaded cavity.The RF system is mainly consists of three parts: MA loaded cavity, high power pulse power source, full digital LLRF and computer control system. The LLRF system of the RF plant consists of an amplitude loop, a phase loop, a synchronous phase loop, a radial control loop and a beam loading compensation feed-forward loop.This poster presents the requirements, design for LLRF and the challenge we meet with.

P-18

3GHz Linac RF measurement system using micro-TCA technology

Peter Corlett[1], Simin Chen[1], Ross Hogan[1], Greg LeBlanc[1], Adam Michalczyk[1], Andrew Starritt[1], Karl Zingre[1]
[1]*Australian Synchrotron, Melbourne, Australia*

The Australian Synchrotron is a third generation 3GeV, 200mA light source located in Melbourne, Australia operating since 2007. The facility consists of a full energy injection system (Linac and booster synchrotron) plus a storage ring. The Linac is a 3 GHz travelling wave short pulse (<5us) structure powered by a pair of 35MW klystrons.

The installation of a SLED cavity within the Linac waveguide system has rendered the existing phase and amplitude measurement system obsolete. A new system for measuring waveforms of RF amplitude and phase during the linac pulse has been produced. This provides new diagnostics to operators, and provides interlocks to protect the critical waveguide structures against high reflection and overpower conditions.

The new system is based around microTCA technology, using SIS8300-L2 digitisers with DWC8300 analogue front ends.

A description of the system is presented, including Initial performance results, and future plans for LLRF at the Australian Synchrotron.

P-19

Temperature stabilized LLRF control for new generation linear accelerators

Robert Cerne[1], Borut Baricevic[1], Gasper Jug[1], mag. Primoz Lemut[1], Zarko Lestan[1], mag. Borut Repic[1], mag. Matej Oblak[1], Luka Rahne[1], mag. Damijan Skvarc[1], Luca Piersanti[2], Alessandro Gallo[2], Marco Bellaveglia[2]

[1]*Instrumentation Technologies d.d., Solkan, Slovenia,* [2]*INFN-LNF, Frascati, Italy*

The requirements on photon flux and bandwidth of linac based gamma sources are becoming more and more critical, demanding the use of more complex acceleration schemes (such as multi-bunch operation) and feedback strategies, as in ELI-NP gamma beam source under construction in Magurele by the European consortium Eurogammas. The paper describes the ELI-NP requirements with respect to the LLRF system, how the Libera LLRF platform has been modified to fulfill them and the measured results. A new temperature stabilization scheme was designed in order to compensate long-term thermal drifts. New RF design concepts have been introduced to fulfill the requirements at C and S band within the same system. Furthermore, the development of a new signal processing approach, providing separated amplitude and phase control, together with the capability of generating arbitrary pulse shapes, increases LLRF flexibility and represents a key feature to compensate the beam loading contribution in multi-bunch regime.

P-20

Low-Level RF Control System Development for the HIMM Linac

Ruifeng Zhang[1], Yan Cong[1]
[1]*Imp, Lanzhou, China*

A update plan is proposed by IMP, which is that using a compact linac injector named HIMM-LINAC to replace the cyclotron injector of Heavy Ion Medical Machine(HIMM). HIMM-LINAC consists of a ECR, a RFQ , a IH -DTL and two bunchers. RF system operates in pulsed mode.The Low level RF system is required for the conditioning of the cavities and the stabilization of phase and amplitude of the accelerating field. The stability requirements are 1 degree (peak-peak) in phase and 1% (peak-peak) in amplitude. This poster gives an overview of the low-level RF system for the HIMM linac.

P-21

Digital Low Level RF Systems for Diamond Light Source

Chris Christou[1], Pengda Gu[1], Paul Hamadyk[1], David Spink[1], Angela Salom[2], Francis Parez[2]

[1]Diamond Light Source, Didcot, United Kingdom, [2]ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain

Two new normal conducting cavities have been constructed and will be installed in the Diamond Light Source storage ring in the second half of 2018. A digital LLRF system has been developed with ALBA Synchrotron for these new cavities. The digital system will offer improved functionality in comparison to the analogue systems currently employed at Diamond, and once proven on the new cavities, will be deployed for the existing superconducting storage ring cavities and multi-cell normal conducting booster cavities. The new digital LLRF is based on Virtex6 FPGA and fast ADCs and DACs. One system has been built and verified in the Diamond booster with beam and in the Diamond RF Test Facility with the new design of normal conducting cavity. Test results and plans for the future will be presented.

P-22

LLRF system for a novel, compact, superconducting cyclotron for radioisotope production

Daniel Gavela Pérez[1], José Miguel Barcala[1], Antonio Esteve[1], Ángel Guirao[1], Jesús Marín[1], Concepción Oliver[1], Luis García-Tabares[1], Fernando Toral[1], Cristina Vázquez[1], Francis Pérez[2], Ángela Salom[2]
[1]Ciemat, Madrid, Spain, [2]CELLS, Cerdanyola del Vallès, Spain

The AMIT cyclotron will be a 8.5 MeV, 10 µA, CW, H- accelerator for radioisotope production, including a superconducting, weak focusing, 4T magnet, allowing for a low extraction radius and a compact design. The accelerating cavity is a 60 MHz, quarter wave resonator powered by a modular 8kW solid state amplifier.
The main requirements for the LLRF system concern the stability and resolution of the frequency (1 kHz) and the cavity voltage (0.3%). It was conceived to be simple, cheap, easily integrated into the global cyclotron control system and to take advantage of some components already available in our institute.
The system consists of a modular box mainly including commercial sensors for measuring the amplitude and phase of the signals, a fast interlock system governed by reflected power and the drivers for the movement of the stepper motors for the cavity tuning. The RF signal is generated by a commercial signal generator.
The control logic is integrated in the Siemens PLC responsible for the control of all the systems of the cyclotron. Two main control loops (cavity voltage and cavity tuning) are performed. The main features implemented in the GUI are the possibility of working in closed loop (cavity voltage regulation) or open loop (SSPA power regulation), automatic or manual tuning of the cavity, ramps and automatic conditioning based on vacuum pressure.

P-23

Experience with the PIP-II Injector Test

Jonathan Edelen[1], Brian Chase[1], Joshua Einstein-Curtis[1], Edward Cullerton[1], Philip Varghese[1]
[1]*Fermilab, Batavia, United States*

This talk will provide an overview of the LLRF system currently in use at the PIP-II Injector Test, and discuss operational issues and long term drifts that impact beam performance over time.

P-24

Overview of Improvements for the J-PARC Linac LLRF System

Kenta Futatsukawa[1]
[1]*High Energy Accelerator Research Organization, Tsukuba, Japan*

In the J-PARC linac, the LLRF system with the digital feedback (DFB) and the digital feedforward (DFF) was adopted for the satisfaction of amplitude and phase stability and was operated without serious problems. However, is has been used since the beginning of the J-PARC and are more than ten years into the development. The increase of the failure frequency for this system is expected. In addition, it is difficult to maintain it for some discontinued boards of DFB and DFF and the older OS and developing environment of software. Therefore, we are starting to study the new LLRF system of the next generation. In the present, we are exploring several possibilities of a new way and investigating each advantage and disadvantage.
The project and the status of the development for the new system in the J-PARC linac LLRF are introduced.

P-25

Current status of LLRF development at RISP

Hyojae Jang[1], Kyungtae Seol[1], Oh Ryong Choi[1], Do Yoon Lee[1], Ki Taek Son[1], Hoe Chun Jeong[1]
[1]IBS, Daejeon, South Korea

An ion accelerator, RAON is going to be built in Daejeon, Korea by Rare Isotope Science Project (RISP) team in Institute of Basic Science (IBS). It is planned to generate various high energy heavy ion beams for IF (Inflight Fragmentation) facility and the energy and the beam power for Uranium are 200 MeV/u and 400 kW, respectively. In this accelerator, four kind of superconducting cavities are going to be used to accelerate the beam and they have three different RF operating frequency. Quarter wave resonators and half wave resonators will be used in low energy parts and their frequencies are 81.25 MHz and 162.5 MHz, respectively. In high energy parts, single spoken resonator with two different beta will be used with 325 MHz. Nowadays the development of low level RF system is underway. In this presentation the status and development plan of RAON LLRF system will be described.

P-26

A LLRF Hardware Testbench for LCLS-II

Andrew Benwell[2], Student Jorge Diaz Cruz[1,2], Alessandro Ratti[2], Matt Boyes[2], Larry Doolittle[3], Carlos Serrano[3], Gang Huang[3]
[1]Colorado State University, Fort Collins, United States, [2]SLAC National Accelerator Laboratory, Menlo Park, United States, [3]LBNL, Berkeley, United States

Modern FEL sources such as the LCLS-II under construction at SLAC, present a variety of challenges which require the design of new control systems to meet tight RF system constraints. In a four-laboratory collaboration, we designed a LLRF system that uses a Single Source Single Cavity (SSSC) architecture, with a single Solid State Amplifier (SSA) to each accelerator cavity. Key components of the system include the Precision Receiver Chassis (PRC), which acquires signals from four cavities and the RF Station (RFS) which controls two cavities and drives two SSAs. We tested a system made of one PRC with two RFSs and we were able to demonstrate the ability to meet RF field stability requirements. Heading into the production phase of LCLS-II, we developed a LLRF hardware testbench to characterize a large quantity of these key components. In absence of a superconducting cavity and cryomodule, we developed a narrow bandwidth, high Q cavity emulator and used it to test the LLRF system, allowing the SLAC team to obtain realistic measurements without the burden of an actual cryomodule. We validated these results by comparing with those obtained in cold testing of actual LCLS-II cavities at FNAL and with the CMOC modeling system. In this work we present the testbench design along with phase noise measurements and a demonstration of cavity RF field control, with focus on large scale automated testing.

P-27

Racks, A Comfortable Home for LCLS-II LLRF

Andrew Benwell[1], Matt Boyes[1], Mike DiSalvo[1], John Hugyik[1], John Krzaszczak[1], Andrew McCollough[1], Alex Ratti[1], Larry Doolittle[2], Carlos Serrano[2], Brian Chase[3], Curt Hovater[4]
[1]SLAC, Menlo Park, USA, [2]LBNL, Berkeley, USA, [3]FNAL, Batavia, USA, [4]JLAB, Newport News, USA

A superconducting CW RF linear accelerator is being built at the SLAC National Accelerator Laboratory to provide 4 GeV short bunch-length electrons to LCLS-II undulators at high repetition rate. LCLS-II RF requirements have driven the need for a high precision RF control system (Emma, 2014). A digital LLRF system was designed by a multi-lab collaboration to meet the LLRF needs of LCLS-II (C.Hovater, 2015). Results from initial testing have demonstrated that the system meets and exceeds critical performance requirements (Doolittle, 2017) enabling low phase noise control of superconducting cryomodules as well as the possibility of active compensation for microphonics. The modern, high performance LLRF system will be distributed in the first kilometer of the SLAC klystron gallery, a non-air conditioned structure with well documented ambient temperature stability limitations (Akre, 1997); the klystron gallery can vary 50 degrees F in a single day. To overcome the thermal stability limitations of the klystron gallery, a rack system has been carefully, yet cost effectively, designed to house the distributed LLRF system. The LLRF racks have been strategically placed close to accelerator penetrations to minimize effects from temperature drift on long haul RF cables. Careful attention has also been paid to the internal design of the rack to keep temperature sensitive LLRF chassis thermally stable and microphonics sensitive chassis acoustically stable. The LLRF rack design considerations will be presented with test results demonstrating a variety of metrics including temperature, acoustic, and RF stability.

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P-28

Preliminary Commissioning Plans for the LCLS-II LLRF System

Andrew Benwell[1], Chris Adolphsen[1], Matt Boyes[1], Jorge Diaz-Cruz[1], Paul Emma[1], Alex Ratti[1], John Schmerge[1], Larry Doolittle[2], Gang Huang[2], Carlos Serrano[2], Brian Chase[3], Josh Einstein[3], Ramakrishna Bachimanchi[4], Curt Hovater[4]

[1]SLAC, Menlo Park, USA, [2]LBNL, Berkeley, USA, [3]FNAL, Batavia, USA, [4]JLAB, Newport News, USA

A superconducting CW RF linear accelerator is being built at the SLAC National Accelerator Laboratory to provide 4 GeV short bunch-length electrons to LCLS-II undulators at high repetition rate. Since LCLS-II RF requirements have driven the need for a high precision RF control system (Emma, 2014), a high precision digital LLRF system was designed by a multi-lab collaboration (C.Hovater, 2015). Results from pre-production hardware tests have demonstrated that the system meets and exceeds LCLS-II critical performance requirements (Doolittle, 2017). The LLRF system is now entering a phase of the project that includes production and preliminary planning for commissioning. For LCLS-II, 70 LLRF racks will be commissioned to control 280 1.3 GHz superconducting cavities. The LLRF system hardware and software will further play a key role as the controlling system for the commissioning of the entire RF system, from SSAs through the cryomodules. The commissioning phase of LCLS-II LLRF must quickly and thoroughly demonstrate in situ the efficacy of the production LLRF hardware to control cryomodules. Preliminary plans for hardware commissioning and checkout will be presented as well as our approach to setting up the linac for beam operations. Our plan is being developed with insight provided by experience gained during the commissioning phase of the European XFEL (Branlard, 2017) and experience from an operational CW SCRF facility, CEBAF.

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P-29

Update on FRIB LLRF development and production

Shen Zhao[1], Dan Morris[1], Harsh Maniar[1]
[1]*Facility For Rare Isotope Beams, Michigan State University, East Lansing, United States*

The undergoing Facility for Rare Isotope Beams (FRIB) project at Michigan State University (MSU) uses a continuous-wave (CW) linear accelerator (LINAC) to accelerate heavy ions beams including uranium to over 200 MeV/u with beam power of 400 kW to create rare isotopes. The LINAC includes a room temperature front end (LEBT, RFQ and MEBT), 324 superconducting RF cavities (QWR, HWR), and 2 room temperature rebunchers in the folding segment. The low-level radio-frequency (LLRF) controller is designed to accommodate multiple RF frequencies (40.25, 80.5, 120.75, 161, 322 MHz) as well as different types of tuner (water skid, stepper, pneumatic). The technical challenges in the past few years during the integrated tests and cryo-module testing are reported. Also presented are the current production/installation status.

P-30

Beam loading and LLRF considerations for FCC-ee

Andrew Butterworth[1], R. Calaga[1], J. Esteban-Mueller[1], I. Karpov[1]

The FCC-ee is a high-luminosity, high-precision e+e- circular collider, envisioned in a new 100 km tunnel in the Geneva area. Four different operation modes are foreseen with centre of mass energies ranging from 90 GeV for Z production to 350 GeV at the t-tbar threshold. With a constant power budget for synchrotron radiation, the beam current ranges from 6.6 mA at the highest energy to 1450 mA at the Z pole, where beam loading and higher order mode damping considerations will dominate the RF system design. Separate cavity designs for high intensity and high energy operation are under consideration, and initial calculations of single- and coupled-bunch beam stability have been performed. Cavity fundamental-driven coupled bunch instabilities will dominate at the highest beam intensities and will require strong active damping to counteract them. Transient beam loading compensation of gap transients will require phase modulated RF voltage in the cavity feedback to keep peak power to a reasonable level. An overview of these issues will be presented, and the implications for the LLRF system discussed.

P-31

Adaptive beam loading compensation in room temperature bunching cavities

Jonathan Edelen[1], Brian Chase[1], Edward Cullerton[1], Philip Varghese[1]
[1]*Fermilab, Batavia, United States*

In this paper we present the design, simulation, and proof-of-principle results of an optimization-based adaptive feed-forward algorithm for beam-loading compensation in a high-impedance room temperature cavity. We begin with an overview of prior developments in beam-loading compensation. Then we discuss different techniques for adaptive beam loading compensation and why the use of Newton's Method is of interest for this application. This is followed by simulation and initial experimental results of this method.

P-32

Analysis of Iterative Learning Control in Frequency domain

Ken Fong[1], Mike Laverty[1], Qiwen Zheng[1]
[1]*Triumf, Vancouver, Canada*

An Iterative Learning Controller uses knowledge of previous iterations to perform a adaptive feed-forward control for a repetitive process, such as beam loading in accelerator. This adaptive control can introduce additional instability in the control system. Traditional analysis for ILC stability is in the time domain and uses z-tranform to analysis the performance of the closed-loop control system. This paper illustrates a different approach by working in frequency domain and uses Fast Fourier transform of the open loop gain of the ILC to analysis the stability of the closed-loop system. Through the analysis we have identified several key requirements for stability in ILC.

P-33

Energy-optimal cavity filling

Olof Troeng[1], Bo Bernhardsson[1], Anders J Johansson[1]
[1]*Lund University, , Sweden*

The energy required to build up the cavity fields in large, pulsed, superconducting accelerators is significant, but does not contribute to particle acceleration. In our contribution we show how to the energy-optimal filling strategy can be easily computed for arbitrarily efficiency characteristics of the RF amplifier. We compare the energy-optimal filling strategy to previous approaches and provide a numerical examples for the energy savings for the high-beta section of the linear accelerator of the European Spallation Source.

P-34

Automation of RF Cavity Conditioning

Roger Kalt[1], Jürgen Alex[1], Florian Löhl[1]
[1]*Paul Scherrer Institut, Villigen PSI, Switzerland*

To facilitate and speedup the conditioning process of RF systems consisting of high-voltage modulators, klystrons, waveguides or RF structures or cavities, a set of automation tools was created and is currently in operation at SwissFEL. The two main components are the state sequence controller for the various subsystems of the RF plant and the conditioning algorithm controller. Additional logic is required which allows deciding whether a safe automatic restart after breakdowns or errors is possible.
The tools and algorithms implemented in different strategies are presented and the experiences from the already conditioned RF stations is shown.

P-35

ApplicationCore: A Framework for Modern Control Applications at the Example of a Facility Independent LLRF Server

Martin Hierholzer[1], Martin Killenberg[1], Geogin Varghese[1], Nadeem Shehzad[1], Michele Viti[1], Sebastian Marsching[2], Adam Piotrowski[3], Christian Schmidt[1], Ludwig Petrosyan[1], Tomasz Kozak[1], Pawel Predki[4], J. Wychowaniak[4], Adam Dworzanski[5], Krzysztof Czuba[5]
[1]Deutsche Elektronen-Synchrotron DESY, Hamburg, Germany, [2]aquenos GmbH, Baden-Baden, Germany, [3]FastLogic GmbH, Lodz, Poland, [4]University of Technology, Lodz, Poland, [5]University of Technology, Warsaw, Poland

The ChimeraTK software suite facilitates the development of abstract and reusable control applications. The ApplicationCore library within this suite integrates ChimeraTK's main libraries DeviceAccess and ControlSystemAdapter. It therefore supports a number of protocols for accessing hardware, including PCI Express as used inside MicroTCA.4 crates. On the other hand, applications written using ApplicationCore can natively run on any middleware supported by the ControlSystemAdapter, e.g. EPICS 3, DOOCS and OPC-UA.
The ApplicationCore encourages structuring applications by using a hierarchical and modular data model. How this helps to design maintainable control applications is shown at the example of the new LLRF control server which will be used for multiple MicroTCA.4-based LLRF systems at facilities like ELBE (HZDR, Dresden), TARLA (TAC, Ankara), FLUTE (KIT, Karlsruhe), and FLASH and European XFEL (DESY, Hamburg). Also first experiences with the operation of the server at the ELBE accelerator are shown.

P-36

Digital LLRF control system on BEPC-II

Digital Llrf Control System On Bepc-II Wang Mu Yuan[1]

[1]Institute Of High Energy Physics Institution, Beijng, China

BEPCⅡ is a high-current electron-positron collider at IHEP in Beijing, which has two operation modes: collision and synchronization. Currently, the LLRF control system is analog which facing the problem includes the spare parts replacement cycle long , anti-interference ability under the condtion of heavy beam loading is poor and so on. In addition, when interlock protection occurs, the procedure of reset by analog control is relatively complicated. Meanwhile, the amplititude and phase accuracy is ±1% and ±1degrees either in actual operation. Therefore, In order to solve the above problems, we have already partially reformed the analog system to the digital control system which can get high-precision and more convenient for operation. In a short time, the amplitude accuracy can reach ±0.5% and the phase accuracy can reach ±0.5 degrees obviously. After that, we need to optimize the loop-parameters by software simulation and theoretical calculation in order to achieve higher accuracy and more stable operation.

P-37

Simulation of microphonic effects in high Ql TESLA cavities during CW operations

Andrea Bellandi[1], Julien Branlard[1], Holger Schlarb[1], Christian Schmidt[1], Sven Pfeiffer[1]
[1]*Deutsches Elektronen-synchrotron , Hamburg, Germany*

Because achieving CW operations in high power FELs could be highly beneficial from the users perspective, a possible upgrade of FLASH and XFEL accelerators could be turning them in CW machines. In order to do this, an appropriate simulation of their superconductive cavities in CW must be done. This is needed to explore the operational limits of the cavities given the strict requirements in amplitude and phase of the accelerating field (0.1 ‰ error on amplitude 0.01° error on phase) in FLASH and XFEL. In this poster the results of the simulation of a TESLA cavity in CW operation with different microphonic sources will be discussed and compared with experimental results of CW operation tests at DESY. The simulations will be performed both in open and closed loop considering beam loading effects.

P-38

EPICS and VHDL developments in the LLRF for MYRRHA Project's RFQ prototype.

Joly Christophe[1], Sarlin Wladimir[1], Le Ster Thomas[1]
[1]*Cnrs-ipn, Orsay, France*

The European MYRTE project (for MYRRHA Research and Transmutation Endeavour), that aims to perform research and development work for supporting MYRRHA facility's development, is mainly focused on Accelerator R&D for ADS/MYRRHA WorkPackage (WP2) : the injector demonstrator. In this context, a control and command system is in development at IPNO, by merging both FPGA and EPICS software technologies, for the MYRRHA RFQ low level radio frequency (LLRF) to be produced at IPNO.
Actually, the EPICS platform (Experimental Physics and Industrial Control System) is an efficient tool to design input/output controllers (IOCs) to achieve control, command and supervision applications. On the other hand, FPGA components also provide a relevant hardware solution for control of systems.
The control and command workstation in development at IPNO includes : a VHDL code embedded inside the FPGA to achieve regulation and signal processing tasks, a complete PCIe driver that ensure communications between the FPGA and the EPICS IOC, this one managing a Process Variables database and a channel access server to communicate with remote client applications. Work at IPNO also includes the design of a CSS - BOY (Control System Studio - Best OPI Yet) client supervision application.
This poster presents both EPICS and VHDL developments for the IPNO LLRF, from the hardware data processing (FPGA part) to the outside communication and database management with the use of an embedded IOC in the LLRF.

P-39

Resonance Frequency Tuning of an RF Cavity through Sliding Mode Extremum Seeking

Ramona Leewe[1], Ken Fong[1], Zahra Shahriari[1]
[1] *TRIUMF, Vancouver, Canada*

A new resonance tuning system based on reflected power measurements was implemented in two of TRIUMF's DTL tanks and commissioned in April 2016. A sliding mode extremum seeking algorithm searches for the minimum reflected power point. The system was developed to eliminate the highly temperature dependent RF phase measurement which was previously used to tune the resonance frequency. Measurements over several hours show how the control loop counteracts the RF heating effect on the cavity. Tuning results recorded over a two month period also show that the tuner is able to compensate for diurnal temperature variations.

P-40

STARFISH-PY: A Versatile Toolchain for the Analysis of Synchrotron RF Systems' Data

Dieter Lens[1], Harald Klingbeil[1,2]
[1]GSI, Darmstadt, Germany, [2]Technische Universität Darmstadt, Darmstadt, Germany

During machine experiments in synchrotrons, a large amount of data may be recorded by several types of measurement devices. For RF systems, typical signals are: gap voltage signals of different cavities, beam current signals, reference signals, and slower signals of the RF control loops such as setpoint values or other ramps. For the commissioning or optimization of RF systems, these data may have to be analyzed already during the experiment, e.g. in order to be able to fine-tune parameters of the RF systems or of the settings management. Therefore, the implementation of a software package called STARFISH-PY (Software Tools for Accelerator RF Instrumentation via Command Shell using Python) has been started that consists of a set of command-line tools. The tools are written in Python and C++ and have each been defined to perform a specific task. Binary or text files are used to exchange results between the tools. In this way, several tools may be combined in a batch script to realize much more complex operations. For the data exchange between the tools, standardized file formats have been defined that are dedicated to typical data sets of continuous or segmented measurements. Conversion tools allow using proprietary data files of measurement instruments, e.g. digital storage oscilloscopes. After this, other tools can be used to select, process, or visualize the data. The concept and status of the project is described and a demonstration of the tools is given using the data of recent and older machine experiments.

P-41

Pulsed Digital LLRF Control System for Sub Harmonic Pre-Buncher of IR-FEL

Pritam S Bagduwal[1], Nitesh Tiwari[1], Dheeraj Sharma[1], Mahendra Lad[1]
[1]*Raja Ramanna Centre For Advanced Technology, Indore, India*

Infra-Red Free Electron Laser (IR-FEL) being developed at RRCAT requires 15-25 MeV electron beam injector. This injector has 29.75 MHz Electron Gun, 476MHz Sub Harmonic Pre-Buncher (SHPB) and 2856 MHz LINAC. SHPB is required to reduce the electron bunch size from 1ns to 50ps. A pulsed 476 MHz, 10 kW RF system is used for SHPB RF system. To ensure proper bunching, amplitude and phase of RF fields shall be stable within 0.1% and 0.1° respectively. Due to the inherent advantages of digital system like flexibility, adaptability, low drift errors and high precision, an FPGA based fast control system is design and developed. Considering amplifier stabilization and cavity fill time RF system is powered for 50µs and last 10µs of pulse will be used for the bunching. This system is built around digital I/Q detection and analog I/Q modulation. Required PI controller is implemented in Virtex-5 FPGA. An RF Synchronized signal generation unit is also developed to generate synchronized reference signals of 29.75 MHz, 476 MHz and 2856 MHz for Electron Gun, SHPB and LINAC respectively. This pulsed digital LLRF control system has been installed with SHPB RF cavity and is operating satisfactorily.

P-42

DSP Implementation of an Iterative Learning Controller

Michael Laverty[1], Ken Fong[1], Qiwen Zheng[1]
[1]*Triumf, Vancouver, Canada*

An iterative learning controller is a type of adaptive feed-forward. In this case it has been developed to control the expected high beam loading of the TRIUMF electron linac. Some of the details of the design process are outlined, beginning with the feasibility of adding such a controller to the existing digital signal processor, which currently implements PID control of the cavity amplitude and phase. The method by which the ILC was implemented, the costs in terms of processing overhead, and some early test results are described.

P-43

A noise suppression method based on system identification for the HEPS-TF 166.6 MHz LLRF system

Qunyao Wang[1], Ms. Haiying Lin[1], Pei Zhang[1], Yi Sun[1], Guangwei Wang[1], Muyuan Wang[1]
[1]*Institute of High Energy Physics, Beijing, China*

The most common cavity field feedback control loop is to have one PI(D)-controller for each of the I&Q channels. This however does not have a satisfactory suppression of the low-frequency noise within the bandwidth of the superconducting RF system. These noises are often originated from ripples of the transmitter power, cavity microphonics, system noise from helium pressure fluctuations and vacuum pumping group caused vibrations. Thus a noise suppression method based on system identification has been proposed and is the focus of this paper. PRBS was used as the input signal, while the corresponding cavity field signal was used as the output signal. Both signals were processed by the system identification method in MATLAB and a system transfer function was then obtained. Based on these, two low-pass IIR digital filters, and subsequently a noise suppression loop were finally set up. A noise suppression loop for the 166.6 MHz HEPS-TF LLRF system has been designed and tested on a cavity mock-up in the lab. An effective noise suppression was observed. The design and the tests will be presented in this paper.

P-44

Detuning, RF stability and transient beam-loading studies of RF control for the BESSY VSR higher harmonic SC Cavities

Axel Neumann[1]
[1]Helmholtz Zentrum Berlin, Berlin, Germany

For the feasibility of the BESSY VSR upgrade project of BESSY II two higher harmonic systems at a factor of 3 and 3.5 of the ring's RF fundamental of 500 MHz will be installed in the ring. Operating in continuous wave at high average accelerating field of 20 MV/m and phased at zero- crossing, the superconducting cavities have to be detuned within tight margins to ensure stable operation and low power consumption at a loaded Q of 5e7. This is especially of importance as the three cavity system is operating in Robinson stable regime whereas the higher frequency harmonic system is intrinsically unstable, requiring the RF feedback systems to damp any rise of instability by exact field control. The field variation of the cavities is mainly driven by the repetitive transient beam-loading of the envisaged complex bunch fill pattern in the ring. Within this work combined LLRF-cavity and longitudinal beam dynamics simulation will demonstrate the limits for stable operation, especially the coupling between synchrotron oscillation and RF feedback settings. Further impact by beam current decay and top-up injection are being simulated

P-45

Kalman filter implementation by MTCA4.0 for gun cavity detuning compensation

Andriy Ushakov[1], Axel Neumann[1], Pablo Echevarria[1]
[1]*Helmholtz-Zentrum Berlin, Berlin, Germany*

RF commissioning of the SRF Photo-injector cavity at Helmholtz-Zentrum Berlin for the bERLinPro Energy Recovery Linac accelerator demonstrated the necessity for exact detuning control to fulfill the demanding requirements for stable operation. Detuning in CW operation becomes an issue as of the narrow bandwidth with high loaded quality factor and higher detuning sensitivities of such class of resonators. Therefore the microphonic's level at low frequencies will have a significant influence on the performance in particular on the required forward power. The model describing the cavity's field state is thus a time varying system as detuning changes the state of the cavity. Moreover, the received feedback data like transmitted or reflected power will suffer from sensor errors, environment noises and finally from digitization/calculation errors. The mentioned uncertainties could be reduced by applying a mathematical process called Kalman filtering. As the object law is well known but not ideal in this case, the role of filter is to judge between the theoretically predicted state and the state based on obtained measure and in that way approach the truthful level of the system estimate by every comparison. The classical Kalman Filter theory was adopted to our field and implemented in mTCA4.0 control system as a part of microphonics suppression subsystem. The firmware engages reasonable fraction of DAMC-FMC20 mezzanine card resources where the most calculations are done in floating point format. The current angular frequency and amplitude data are taken continuously from SIS8300-L2 digitizer by low latency link serial interface. The initial cavity transfer function definition is done once offline before operation in PLL loop. The first Gun cavity response estimation by pole fitting algorithm reveals 25 eigenmodes starting from 69 to 780 Hz and helps to define particular central frequencies, damping and stiffness coefficients. Here the first data test results are presented.

P-46

Digital Low Level RF control for Advanced Light Source

Qiang Du[1], Kenneth Baptiste[1], Michael Betz[1], Massimiliano Vinco[1], Lawrence Doolittle[1], Gang Huang
[1]*Lawrence Berkeley National Lab, Berkeley, United States*

A digital LLRF control system has been built and installed as part of the Storage Ring RF system upgrade project at Advanced Light Source in LBNL. In order to enable a configurable two klystrons driving two cavities operation, the system implements low-noise RF front-end, non-IQ digital receiver/digitizer, double rate feedback control loop, and 42 channels distributed RF monitor with integrated fast interlock across multiple chassis and subsystems. Chassis level test shows > 78 dB isolation between feedback channels, and 128 fs RMS time jitter [10Hz, 50MHz] at Klystron drive ports. Preliminary test result shows RF field stability of 0.01% in amplitude and 0.01° in phase at 499.654 MHz for the band above 1 Hz (no beam).

P-47

BIDS, the open source building blocks for a high precision RF control system

Gang Huang[1], Larry Doolittle[1], Qiang Du[1], Carlos Serrano[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, United States*

Beam Instrument Development System (BIDS) is started from the common modules for different RF control projects and approved to be open source by DOE. The system contains basic algorithm implementation, widely used peripheral drivers, FPGA specific features implementation as well as common parts/sub-circuits for hardware development. In this paper, we present the status of the BIDS and explain the use case for these modules.

P-48

EXPLORING POSSIBILITES FOR ACTIVE MICHROPHONIC COMPENSATION OF BNL SRF CAVITIES

Freddy Severino[1], Thomas Hayes[1], Kevin Mernick[1], Geetha Narayan[1], Salvatore Polizzo[1], Carlos Ramirez[1], Kevin S Smith[1], Alexander Zaltsman[1]
[1]*Brookhaven National Laboratory, Upton, United States*

The need to mitigate microphonic induced detuning in Super Conducting Radio Frequency (SRF) Cavities is of critical importance when trying to achieve a very high degree of cavity field regulation given limited amounts of RF power. At the Collider Accelerator Department (C-AD) at Brookhaven National Lab, we recently started exploring various approaches/methods for microphinics compensation using a piezo-electric tuner on two of our SRF cavities. We used our Digital Low Level RF controller to measure piezo to cavity tuning transfer functions using multiple type of stimulus, and obtained a Matlab Simulink model that represents the system. In addition, we designed and implemented a compensator for the first mode in one of the cavities and demonstrated closed loop operation, validating the accuracy in our model. Here we summarize our work so far and plans for future design and implementation of a more comprehensive method of microphonics compensation for both cavities.

P-49

A novel double sideband-based phase averaging line

Zhenyang Lin[1]
[1]*Haidian, Beijing, China*

PRDS (Phase Reference Distribution System) serves as the phase alignment line for delivering high stability phase to different clients. Coaxial cable based solution is one of the most important scheme in PRDS. A novel double sideband based phase averaging line has been developed in Tsinghua accelerator lab, which has optimized the algorithms in the phase signal sender and receiver chassis. The sender chassis generates the 2856MHz reference signal as the forward signal and receives the 2856MHz standard signal and the reflected double sideband signal from the receiver. The forward signal is phase-locked with the 2856 standard signal source, and the forward signal and the sideband signal are adjusted by the virtual delay line in the FPGA to achieve long-range phase distribution and phase lock. The existing chassis can be used as both the sender and receiver. The preliminary experiments result shows the phase stability can achieve about 1% by signal distorted by the phase shifter.

P-50

FRIB LLRF control: issues and improvements

Shen Zhao[1], Dan Morris[1], Harsh Maniar[1]
[1]*Facility For Rare Isotope Beams, Michigan State University, East Lansing, United States*

At FRIB, the LLRF controller is one of the first few electronics devices designed and used to support cavity testing, integrated tests and cryo-module tests. In the past few years, during various tests, different issues were found in both RF control and tuner control. Many improvements have been made to resolve those issues, and lead to the more matured final design. In this poster, more specifically, topics such as smooth transition from open to close loop for RF control, the valve open/close voltage calibration for pneumatic tuner control, the current setting for stepper tuner control will be presented.

P-51

VSWR Protection System and Cavity Frequency Tuning System for RF Power Source at CSNS LINAC

Zhexin Xie[1,2], Zhenchen Mu[1,2], Linyan Rong[1,2], Wenzhong Zhou[1,2], Bo Wang[1,2], Maliang Wan[1,2], Meifei Liu[1,2], Xinan Xu[1,2], Jian Li[1,2], Zonghua Zhang[1,2], Jimin Qiao[1,2]
[1]*China Spallation Neutron Source (CSNS), Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS), Dongguan, China,* [2]*Dongguan Institute of Neutron Science (DINS), Dongguan, China*

When electrical breakdown in the form of arcing in the accelerator cavity, high-power RF signal reflect to the RF power source,which brings severe damage to the RF power source and wave-guide output window. In this paper ,we introduce a Voltage Standing Wave Ratio(VSWR) Protection System to avoid this damage. Once the system detect VSWR greater than the threshold value, the system spread out a signal quickly to cut off excitation source of RF power source within 1 us. In this System, VSWR value and protection number can be displayed in screen, protection time in every pluses can be set manually. This system is now used in CSNS RF-linac RFQ, Buncher,DTL RF power source systems.To avoid high reflected power from accelerator cavity ,a tuner control system was developed to control the accelerator cavity's resonate frequency, the system is also shown at the end of this paper.

P-52

High Density Mixed Signal Hardware Design for Scientific Measurement and Control

Daniel Van Winkle[1], Josef Frisch[1], Steve Smith[1], John Dusatko[1]
[1]*Slac National Accelerator Laborator, Menlo Park, United States*

The SLAC National Accelerator Laboratory has developed a new extensible platform based upon a common carrier in the industry standard Advanced Telecommunications Computing Architecture (ATCA) format. This new platform allows for a large variety of applications to be developed all within a standard (and modified standard) Advanced Mezzanine Card (AMC). Because this architecture is inherently compact, various mixed signal circuitry ends up being packed within a relatively small volume. This paper will highlight some of our high density designs (LLRF cards as well as 4 GHz 4000 channel receiver cards). We will show some key design techniques as well as potential pitfalls and present some results from our finished, operating cards.

P-53

Upgrade of the MicroTCA.4 based LLRF down-converter series for up to 6GHz operation frequency.

Matthias Hoffmann[1], Uros Mavric[1], Frank Ludwig[1], Holger Schlarb[1]
[1]*DESY, Hamburg, Germany*

During the last 5 years, MicroTCA.4 based LLRF hardware was successfully developed and established at DESY, mainly for the European XFEL, but also for FLASH, REGAE, and other facilities.
To offer a wider range of applications for further accelerating facilities, we extended the operation frequency of the exsisting down- and up-converter modules to a range of 300 MHz up to 6 GHz. On this poster we will present our results from simulation, test board measurements and first tests of the ready to use down-converters.

P-54

LLRF for the RFQ prototype of the MYRRHA project

Christophe Joly[1], Thomas Lester[1], Wladimir Sarlin[3], Beng-Yun Ky[1], Jean-François Yaniche[1], Sylvain Berthelot[1], Holger Podlech[2], Dirk Vandeplassche[3]
*[1]Institut de Physique Nucléaire d'ORsay (CNRS-IN2P3), Orsay, France, [2]Johann Wolfgang Goethe Universitaet (IAP),, Frankfurt am Main, Germany, [3]Centre d'études et de recherche Nucléaire (SCK*CEN), Mol, Belgium*

The goal of the European project called MYRTE (MYRRHA Research and Transmutation Endeavour), is to perform research to support the development of the MYRRHA facility (Accelerator Driven System) with a main topic for the Accelerator R&D for ADS/MYRRHA Work Package (WP2): the Injector demonstration. Within this framework, a Low Level Radio Frequency system for the Radio Frequency Quadripole (RFQ) is developed by IPNO with an in-house standalone digital board including 2 FMC boards associated to a FPGA linked to a processor ARM by PCIe. A Phase References generation system has been also realized et tested with the expected performance.
This poster presents the project and focuses to the hardware developments and some results before the tests with the RFQ
planned in 2018.

P-55

Evaluation of the extension of the MTCA.4 board connectivity to the rear side of crates

Uros Mavric[1], Michael Fenner[1], Julien Branlard[1], Holger Schlarb[1], Dariusz Makowski[2], Aleksander Mielczarek[2], Filip Makowski[2]
[1]Desy, Hamburg, Germany, [2]LUT-DMCS, Lodz, Poland

The contribution summarizes recent activities in the extension of the MTCA.4 connectivity to the rear side of standard MTCA.4 crates. The need for such an extension started as a need for a cleaner and more isolated environment from digital areas present in the front side of the crate. Local-oscillator generation, clock generation and their distribution were moved into the MTCA.4 crate and they could benefit from the standard MTCA.4 board management layer and connectivity. For this reason the RTM- backplane manager which sits in the rear side of the management carrier hub was developed as a bridge from the front side to the rear. The backplane manager provides power, management layer and PCIe connectivity to the rear. Special emphasis was put on the layout of the digital signals in the rear MicroRF-backplane in order to avoid the possibility of pollution of high sensitivity signals. Finally an example of practical usage of the new extension is presented.

P-56

NSLS-II LINAC RF Control System: Requirement and Implementation

Hengjie Ma[1], James Rose[1]
[1]*NSLS-II, Brookhaven National Laboratory, Upton, United States*

The NSLS-II light source currently operates its LINAC injector in both single-bunch and multi-bunch beam mode. The support for the complex bunch patterns is also required for the future upgrade. The implications on the LINAC rf are that the rf control needs to have the necessary flexibility and capability to effectively handle the switching between the different beam bunch patterns, and thus the changes in the beam loading conditions, while maintaining the rf field flatness during the period of a multi-bunch train, and thus controlling the beam energy spread. Different from the CW rf in the storage rings, the beam-rf relationship in an electron LINAC is also a factor when considering the rf control system design, including the rf phase referencing. In the technology for the implementing the LINAC rf control, the availability of today's ultra-high speed electronic components allows an array of new design options that did not exist before. Using the direct sampling on 3GHz S-band rf to digitally demodulator/modulator rf vector signals without up/down frequency conversion is one of these new options; and directly interfacing the rf ADC/DAC's to a JESD204B supported multi-core DSP ASIC, instead of FPGA, to perform the subsequent high-speed real-time DSP in the ASIC processor would be another new option for cost-saving in the IP development.

P-57

LLRF Applications and Advancement of MicroTCA Technology

Cagil Gumus, Thomas Walter, Christian Schmidt, Konrad Przygoda, Martin Hierholzer
[1]*DESY, Hamburg, Germany*

MicroTCA (Micro Telecommunications Computing Architecture) is an open, modular crate standard that originated in telecommunications and has been adapted for physics research. Formally introduced by the PCI Industrial Manufacturers Group (PICMG) in 2006, it is now supported by more than 100 organizations worldwide. DESY has contributed to the latest version of the standard MTCA.4, which added precision timing and rear access capabilities. In collaboration with industrial partners, a large portfolio of signal processing boards has been developed and made available commercially through licensing. The latest advance is the addition of piezo-controls for the CW operation of accelerator facilities. The newly founded "MicroTCA Technology Lab" will offer contract development services, facilitate research collaborations, provide high-end measurement/ test services and function as a hub for all MicroTCA-related activities at DESY. Our poster summarizes these developments.

P-58

The upgrade of J-PARC LINAC LLRF system

SONG LI[1]

[1]*Japan Proton Accelerator Research Complex (J-PARC), 2-4 Shirakata, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan*

The J-PARC proton linear accelerator (LINAC) was commissioned in October 2006. The first user operation of J-PARC linac was started in December 2008. The old LLRF system had already been used for more than 10 years since then. Now, the equipment vendor does not supply the same product for long, nor do they maintain. So we have to develop a new system to replace it. The new system use MTCA.4 architecture that had already been used in DESY and SLAC etc. in recent years. The poster will presents recent results of research and technical work on this new LLRF control system development for J-PARC LINAC. It mainly includes the introduction of system architecture, the software and hardware we used, the testing result of new system as well as the developing plan in the future.

P-59

LLRF Upgrade Plans for PSI's Proton Accelerator

Andreas Hauff[1]
[1]Paul Scherrer Institut, Villigen, Switzerland

The high-intensity proton accelerator (HIPA) at PSI is a cascade of three accelerators (Cockroft-Walton accelerator, Injector 2 cyclotron, Ring cyclotron) that deliver a proton beam of 590 MeV energy at a current of up to 2.2 mA. The main cavities of the Injector 2 and Ring cyclotron are operated CW at a frequency of 50 MHz. The original, up to 30 years old analog low-level RF system has to be replaced by a state-of-the-art digital system that improves the operability and maintainability due to better diagnostics capabilities and integration into the control system (EPICS) environment. The concept foresees a new LLRF system that is based on PSI's standard processing board, FMC mezzanine cards and a specific RF front-end to condition the RF signal for direct sampling. The demodulated signals are used for amplitude and phase feedback, monitoring and calculation of the drive signal for the mechanical cavity tuners. The whole RF station is protected by an interlock system that was originally designed for the SwissFEL accelerator.
The commissioning of the first upgraded RF station is scheduled for the second quarter of 2019. A detailed overview about the LLRF system concepts and implementation issues will be given.

P-60

LLRF controls in SuperKEKB Phase-1 commissioning

Tetsuya Kobayashi[1], Kazunori Akai[1], Kota Nakanishi[1], Michiru Nishiwaki[1], Shin-ichi Yoshimoto[1], Kouki Hirosawa[2]
[1]KEK, Tsukuba, Japan, [2]SOKENDAI, Tsukuba, Japan

First beam commissioning of SuperKEKB (Phase-1), which is an asymmetry double ring collider of 7-GeV electron and 4-GeV positron beams, which had started from February, has been successfully accomplished at the end of June 2016, and the desired beam current for Phase-1 was achieved in both rings. This presentation summarize the operation results related to low level RF (LLRF) control issues during the Phase-1 commissioning, including the system tuning, the coupled bunch instability and the bunch gap transient effect.

RF system of SuperKEKB consists of about thirty klystron stations in both rings. Newly developed LLRF control systems were applied to the nine stations among the thirty for Phase-1. The RF reference signal distribution system has been also upgraded for SuperKEKB. These new systems worked well without serious problem and they contributed to smooth progress of the commissioning. The old existing systems, which had been used in the KEKB operation, were still reused for the most stations, and they also worked as soundly as performed in the KEKB operation.

P-61

Hardware Concept for the SLS 2 LLRF Systems

Kristian Ambrosch[1], Mario Jurcevic[1], Roger Kalt[1]
[1]*Paul Scherrer Institute, Villigen, Switzerland*

For the upgrade of the Swiss Light Source in 2023, we propose the concept of a new hardware platform for the LLRF system that is based on our experience with the SwissFEL LLRF. For SwissFEL the concept of having both CPU and FPGA on the same board allowed for a compact design. Here the FPGA was used for the fast pre-processing of the signals and the CPU was used both, for the real-time application running the control loop and the EPICS-based Accelerator Control System (ACS). However, the latency of the PCI-Express connection between FPGA and CPU would be a bottle neck for fast feedback loops if the feedback should run on the CPU. Furthermore, sharing resources between EPICS and real-time applications complicates the software design. Using plain Linux as a common operating system for EPICS and real-time applications makes it difficult to predict the latency of interrupt handling for real-time applications.
Thus, we present a new concept using a Multi-Processor-System-On-Chip (MPSoC) using the novel Xilinx Ultrascale+. On such a platform EPICS applications can run on a Quad-Core Cortex-A53 ARM CPU, while providing a separate Dual-Core Cortex-R5 for real-time applications. This enables us to run real-time applications on a bare metal system where the latency of each interrupt can be determined, while a Linux operating system for EPICS applications runs on a separate CPU. The interconnection between the CPUs and the programmable logic is provided by an AXI interface, which enables a low latency transmission of small data blocks. First ideas and concepts of a LLRF system based on such a platform will be given.

P-62

Linac4 LLRF - An update

Robert Borner[1], Philippe Baudrenghien, Bartosz Bielawski, Javier Galindo, Gregoire Hagmann, Bruno Kremel
[1]*Cern, Geneva, Switzerland*

Installation of the new CERN H- Linac (Linac4) is complete and the machine has been validated with moderate intensity beam. It is designed to accelerate 40 mA, 400 s long bursts of H- to 160 MeV at a repetition period of 1.2 s. The first 160 MeV beams were produced in October 2016, with almost 20 mA accelerated to 160.7 MeV. The beam was sent to a test bench in the PSB transfer line, the so-called Half Sector Test. Linac4 will replace Linac2 (50 MeV protons) after the LHC long shutdown (2019-2020). In the meantime, it will be operated to identify any weaknesses (reliability run).
The same LLRF system, consisting of five VME modules plus a CPU is installed on all 27 cavities, operated at 352.2 MHz. The tuner loop adjusts the cavity resonance via the displacement of a plunger in all cavities except the RFQ that is tuned via regulation in the flow of cooling water. The core of the LLRF is the field regulation. The machine was started with a simple PI controller. With 14 mA beam current the measured field stability was 1.5% and 0.15 degrees for the accelerating cavities and 0.7% and 1 degrees for the bunching cavities. Upgrades are ongoing to improve the regulation: The addition of a Kalman predictor and LQR regulator in the feedback loop, addition of an adaptive feedforward for the sharp transients at the head of the batch, and implementation of a polar-loop, similar to the one installed in the LHC 400 MHz and the SPS 800 MHz, for the compensation of klystron droop and low-frequency noise.

P-63

Additive phase-noise in frequency conversion in LLRF systems

Igor Rutkowski[1]
[1]Warsaw University Of Technology, ISE, Warsaw, Poland

This contribution focuses on phase-noise added during frequency conversion in low level radio frequency (LLRF) control systems. The stability of beams' parameters in linear accelerators depends on the stability of amplitude and phase of the accelerating field. A LLRF control system regulates the electromagnetic field inside accelerating modules based on the input RF signals. Digital LLRF systems typically convert those signals to an intermediate frequency (IF) using an active mixer. This field detection scheme necessitates synthesis of a heterodyne/local oscillator (LO) signal which is often generated using a passive mixer, a scheme known as direct analog synthesis. Additive close–to-carrier phase noise can be observed in one or all of three investigated circuits. According to the author's best knowledge, there is no work presenting research on the phase noise characteristics of an active mixer. The influence of the LO signal power level on the phase noise of the output signal was measured and two hypotheses was made. Further measurements of the modulations' conversion were made to verify one of the hypotheses. The fidelity of the LO signal is partially determined by the phase noise of the IF signal. We considered the possibility of constructing an analytical model for selected types of frequency dividers which are used for IF synthesis. The phase noise of a signal at the output of a passive mixer is typically calculated using a small-signal model based on modulation theory. Measurements' results indicate that the power level of the input signals has a non-linear effect on phase noise beyond the noise floor.

P-64

Commissioning and performance of a phase-compensated optical link for the AWAKE experiment at CERN

Diego Barrientos[1], John Molendijk[1], Thomas Bohl[1], Andy Butterworth[1], Heiko Damerau[1], Wolfgang Höfle[1], Michael Jaussi[1]
[1]*CERN, Geneva, Switzerland*

The Advanced Wakefield Experiment (AWAKE) aims at studying proton-driven plasma wakefield acceleration for the first time. A test facility, currently being built at CERN, uses the proton beam from the SPS machine, with a momentum of 400 GeV/c, to accelerate an electron beam to the GeV scale over 10 meters of plasma. According to simulations, this yields an accelerating gradient of about 1 GeV/m, which is more than 2 orders of magnitude larger than RF cavities currently being used.
The LLRF system for AWAKE is synchronizing the high intensity laser pulses generating the plasma, the electron and proton beams. Laser pulses and electron beam are synchronized physically at the same place and almost no drift in their reference signals is expected. However, the reference signal for the proton beam has to be transported to the SPS beam control system, about 3 km away from the location of the laser. Single-mode optical fibers used for transmitting the reference signals may introduce phase drifts due to changing environmental conditions. However, a very precise synchronization of the beams is required to get the maximum energy transfer from the proton to the electron beam and, therefore, the maximum accelerating gradient.
To minimize the phase drift and manage the beam synchronization, we have developed a VME module with a phase detector with a noise floor in the 10 fs range and digitally-controlled delay lines. A digital feedback loop to compensate the phase drift of the signals is embedded in a Xilinx Spartan-6 FPGA. In this work, we present the results obtained on a test bench with 3 km optical fibers in a chamber with controlled temperature. In addition, the performance of the operational system since its initial commissioning phase in September 2016 will be presented.

P-65

A 1 GHz RF Trigger Unit implemented in FPGA logic

Diego Barrientos[1], John Molendijk[1], Gregoire Hagmann[1]
[1]*CERN, Geneva, Switzerland*

At CERN, Trigger Units (TU) generate pulses synchronized with a radio-frequency (RF) signal. They can generate single pulses to be used in beam observation systems, trains of pulses separated by a certain number of RF periods or infinite train of pulses to generate, for example, the revolution frequency signal of a circular accelerator. Applications of these modules are found in several subsystems in the CERN accelerator complex for timing, observation and synchronization purposes.
In this work, we present a new implementation of a TU using an existing module developed for the chopper trigger system in the CERN Linac 4 accelerator. The design takes profit of the embedded high-speed serializers present in the Xilinx Kintex-7 FPGA working at Double Data Rate (DDR). In this environment, we have been able to emulate TU counters working at frequencies up to 1 GHz inside the FPGA saving on hardware complexity by eliminating external high-speed prescalers and miscellaneous logic. The flexibility of running the complete counter logic in the FPGA allows to create new functionalities, such as producing a square wave divider at any configurable ratio. In addition, an arbitrary digital stream can be generated from user configurable RAM resident data that, for example, mimics a beam signal with complicated filling patterns.

P-66

Upgrade of the Beam-synchronous RF Source System in the CERN PS

Heiko Damerau[1], Damien Perrelet[1]
[1]*CERN, Geneva, Switzerland*

For acceleration and RF manipulations the CERN Proton Synchrotron is equipped with in total 26 RF cavities in the frequency range of 0.4 MHz to 200 MHz. Eleven ferrite-loaded RF cavities cover a frequency range large enough to accelerate beams at harmonic numbers from 6 to 24. To drive the cavities and to distribute signals like the beam synchronous revolution frequency from the low-level RF system, a new master-slave RF source system has been developed and commissioned. The slave multi-harmonic sources are clocked at the 256th harmonic of the revolution frequency and are fully configurable in harmonic, azimuth and phase. Their phase accumulator always runs at the revolution frequency and is resynchronized once at fixed frequency before injection. This guarantees a well-defined phase relationship at any harmonic number for all sources, even at different physical locations. The flexible sweeping clock and synchronization scheme allows operating parts of the beam control system at different clock frequencies such that future extensions like additional feedbacks can be easily integrated.

P-67

The structure and status of the LLRF System for PAL-XFEL

Jinyul Hu[1], W. H. Hwang[1], G.-Y. Moon[1], H.-S. Kang[1], H.-S. Lee[1], C.-K. Min[1], H. Heo[1], O. J. Kim[2], H. S. Lee[2], Y. S. Kim[3], J. H. Chang[3], J. S. Han[3]

[1]Pohang Accelerator Laboratory (PAL), Pohang, South Korea, [2]Mobiis Co., Ltd, Seoul, South Korea, [3]RFPT Co., Ltd, Anyang, South Korea

PAL-XFEL was constructed as a hard X-ray free electron laser(FEL) following LCLS, and SACLA at the end of 2015. PAL-XFEL linac is mainly composed of S-band normal-conducting travelling-wave accelerating cavities and accelerates electron bunches up to 10 GeV. The commissioning and user-service of the machine are realized sequentially and successfully without any critical issues since its construction. The LLRF system of PAL-XFEL is operated stably for over 1.5 years since its initial operation in 2015. The LLRF system is composed of PC based platform, digital back-end, and analog front-ends. The analog parts include local signal and clock generator, upconverting transmitter, and downconverting receiver. At PAL-XFEL including this LLRF system, we achieved the electron energy jitter about 0.02 % (rms), the photon arrival time jitter about 20 fs (rms), and 0.1 nm SASE lasing.

P-68

Polish in-kind Contribution to ESS LLRF Control System

Krzysztof Czuba[1], Szewiński Jarosław[2], Cichalewski Wojciech[3], Andrzej Napieralski[3], Adam Abramowicz[1], Zbigniew Gołębiewski[2], Dariusz Makowski[3], Ignacy Kudla[2], Paweł Krawczyk[2], Marcin Gosk[2], Maciej Grzegrzołka[1], Igor Rutkowski[1]

[1]*Warsaw University Of Technology, Warsaw, Poland,* [2]*NCBJ, Otwock/Świerk, Poland,* [3]*Technical University of Lodz, Lódź, Poland*

The LLRF control system for the European Spallation Source (ESS) is based on a MTCA.4 standard using COTS and and in-house developed components to control accelerating cavities. The overall development of the LLRF system at ESS is coordinated by the Lund University, but part of it, LLRF systems for M-Beta and H-Beta sections, will be designed and delivered within in-kind contribution from Poland by the Polish Electronic Group (PEG) - consortium of three scientific units.
Technical aspects of the ESS LLRF system components delivered within polish in-kind contribution will be presented, especially the LO generation, piezo cavity resonance control, implementation of MTCA.4 LLRF solutions and overall management of the LLRF IKC contribution.

P-69

Cavity simulator for LLRF Hardware-in-the-Loop Simulations

Eukeni Aldekoa[1], Pablo Echevarria[1], Axel Neumann[1], Andriy Ushakov[1]
[1]*Helmholtz Zentrum Berlin, Berlin, Germany*

The availability to study real niobium superconducting cavities, either due to a lack a of a real cavity or due to the time needed for the experiment set up (vacuum, cryogenics, cabling, etc.), can block or delay new studies, the development of new algorithms, etc. Hardware-in-the-loop simulations, where an actual cavity is replaced by an electronics system, can help to solve this issue. In this work a behavioral model of a superconducting cavity implemented in a National Instrument PXI crate including an FPGA board is presented. This cavity simulator developed at Helmholtz Zentrum Berlin includes the equivalent circuit equations for the transmitted and reflected voltages and the IQ modulation and demodulation in such a way that the input and outputs are signals of up to 25MHz. More advanced features were implemented to mimic a cavity in a more realistic way: Q-slope, hard quenches above a user-specified limit, first order Lorentz force detuning and mechanical vibration modes. The basic behavior together with these features have been tested and the system connected to an up/down converter in order to get 1,3GHz input and output signals. As near future plans, it is foreseen to connect an mTCA crate with the LLRF system planned to be used for bERLinPro and BESSY-VSR enabling the possibility to test the algorithms prior of their use in the real cavities.

P-70

FERMI LLRF High Power S-Band RF Test Stand development for breakdown diagnostics of accelerating structures.

Federico Gelmetti[1], Claudio Serpico[1], Massimo Milloch[1], Mauro Predonzani[1]
[1]*Elettra Sincrotrone Trieste Scpa, Trieste, Italy*

FERMI is a single-pass linac-based FEL user-facility covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV) and is located next to the third generation synchrotron radiation facility Elettra in Trieste, Italy. The 1.5 GeV S-band linac is composed of fifteen 3 GHz 45 MW peak RF power plants powering the gun, sixteen accelerating structures and the RF deflectors.
An energy upgrade of the Linac is actually under evaluation and the first prototype of an high-gradient accelerating S-Band structure is now under construction. The new structure will be installed and tested in a new test stand called CTF. The new CTF will be equipped with the present LLRF FERMI System, for RF generation and stabilization, and with a commercial system to elaborate the RF signals and develop the breakdown diagnostics of the structure.

P-71

LCLS-II gun/buncher and APEX LLRF development

Gang Huang[1], Larry Doolittle[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, United States*

The injector of LCLS-II project use the APEX style cavities, including an 185.7MHz VHF gun and two 1300MHz bunchers. The LLRF control for the LCLS-II injector is developed as a combination of the APEX LLRF experience and the LCLS-II LLRF hardware platform. Similar design philosophy also reflected back in the development of APEX LLRF design. In this paper, we summarize the design and bench test of the system as well as the status of the APEX LLRF system.

P-72

Multi-frequency Supported LLRF Front-end

QI CHEN[1,2,3], Lawrence Doolittle[2], Gang Huang[2], Yuan He[1], Xianwu Wang[1]
[1]Institute Of Modern Physics, Chinese Academy Of Sciences, LANZHOU, China, [2]Lawrence Berkeley National Laboratory, BERKELEY, United States, [3]University of Chinese Academy of Sciences, Beijing, China

A cascaded LLRF control system can obtain high performance and reliability for a high beam current proton accelerator like ADS, which is also a better way to gain high efficiency for designing and installation. Several different energy sectors constitute this accelerator, and different types of cavities for different frequency distributed in order, different frequency also will be a challenge to design and uniform LLRF control system. The most import part is compatible different frequency RF front-end, we hope to use one design to cover all frequencies, from 162.5 MHz, 325 MHz, 650 MHz to 1.3 GHz, that would be a challenge for getting the same control precision and also it should be transparency to the upper application. We designed this 8-channel down converter and 2-channel up converter front-end to cover from 162.5 MHz to 650 MHz.

P-73

Piezo control for XFEL

Mariusz Grecki[1], for LLRF group
[1]*Desy, Hamburg, Germany*

The superconducting cavities operated at high Q level need to be precisely tuned to the RF frequency. Well tuned cavities assure the good field stability and require a minimum level of RF power to reach the operating gradient level. The TESLA cavities at XFEL accelerator are tuned using slow (step motors tuners) and fast (piezo tuners) driven by the control system. The goal of this control system is to keep the detuning of the cavity as close to zero as possible even in the presence of disturbing effects (LFD - Lorentz Force Detuning and microphonics). The step motor tuners are used to coarse cavity tuning while piezo actuators are used to fine tuning and disturbance compensation.
The crucial part of the piezo control system is the piezo driver. To compensate LFD the piezo driving with relatively high voltage (up to 100V) and high current (up to 1A) is needed. Since the piezo components are susceptible to destruction with overvoltage, overcurrent, and overtemperature one has to pay special attention to keep the piezos healthy. What makes things worse is that the piezo exchange is not possible after the module is assembled. Therefore the special hardware must be assisting the power amplifier detecting the dangerous conditions and disabling piezo operation when needed. It must be fail-safe so even in a case of failure the piezos shall survive. It must be also robust and it must not disturb or disable normal operation. Due to many channels (16 for master/slave RF), the hardware solution must be well scalable.
The presentation shows the design of XFEL's piezo driver together with PEM (Power and Energy Monitor) supervising the driver operation and preventing piezos from destruction.

P-74

SoC Architectures in LLRF at Fermilab

Brian Chase[1], Ed Cullerton[1], Joshua Einstein-Curtis[1], Philip Varghese[1]
[1]*Fermilab, Batavia, United States*

System-on-Chip (SoC) architectures can provide significant benefits for manageability and data acquisition. Such integrated chips provide for a field programmable gate array (FPGA) directly connected to a processor, which allows for multiple paths of high speed data. In addition, the real-time nature of an FPGA is coupled to the flexible programming and ease of management of an embedded processor, often running Linux.

This discusses several device architectures currently available from multiple vendors, such as Intel's Cyclone and Arria chips and Xilinx's Zynq and Zynq Ultrascale+, concluding with a description of the SoC architecture used at Fermilab for test stands and planned architecture for a future Linac upgrade.

Trade-offs between project complexity and computing power is also discussed.

P-75

SwissFEL C-band downconverter design

Alexander Dietrich[1]
[1]*Paul Scherrer Institut, Villigen, Switzerland*

The SwissFEL C-band LLRF downconverter concept follows a modular approach and offers 24 synchronous measurement channels with superior isolation, high linearity and low noise. Using a discrete dual channel double balanced mixer design with octoquad high barrier junction Schottky diodes helps to optimize the mixer performance at its desired frequency, while keeping the costs per channel low compared to broadband high performance integrated mixers. The microstrip design and non-linear harmonic-balance simulation has been done using Keysight's Advanced Design System and agrees very well with lab measurements. This poster will present the downconverter design, simulations and its achieved performance.

P-76

Design and Development of FMC RF Data Converter Modules for the SNS Ring LLRF Control System

Franklin Frye[1]
[1]Ornl-sns, Oak Ridge, United States

The Ring LLRF system at the Spallation Neutron Source (SNS) has been in operation for over 10 years and has successfully supported beam intensities up to 1.4 MW on target. Insufficient remaining spares coupled with hardware obsolescence issues have led to the development of a completely new Ring LLRF system. The new system is based on a MicroTCA.4 platform using COTS FPGA (Xilinx Kintex) carrier cards with FMC sites and a PCIe connection to a controls accelerator network attached EPICS linux machine. Custom four channel low latency 14 bit ADC / DAC data converter FPGA Mezzanine Card (FMC) modules with clock rates up to 125 MHz and external clock and trigger inputs were developed in house for the new Ring LLRF system. The design, test procedures, results, and future plans are presented for these FMC RF data converter modules.

P-77

Implementation of a One-Turn Delay Feedback with a Fractional Delay Filter

Lorenz Schmid[1], Philippe Baudrenghien[1], Gregoire Hagmann[1]
[1]*Cern, Geneva, Switzerland*

This work presents a new digital filtering method for the 1-turn delay feedback of the SPS, the second largest particle accelerator at CERN. Since this filter's properties are linked to the particle's revolution frequency that changes during the acceleration ramp, the filter needs to dynamically adapt. So far, this was achieved by locking the digital filter's clock to the revolution frequency. However, the new CERN paradigm is now to use a fixed clocking scheme.
A solution was designed relying on a new fractional delay filter embedded in a biquad. The complete system working with a fixed clock frequency will be presented. Based on hardware simulations it demonstrates a continuous filter adaptation during ramping while maintaining its performances in terms of transient beam loading compensation.

P-78

The ESS FPGA Framework and its Application on the ESS LLRF System

Christian Amstutz[1], Maurizio Donna[1], Mehdi Mohammednezhad[3], Anders J Johansson[1,2]
[1]European Spallation Source, Lund, Sweden, [2]Lund University, Lund, Sweden, [3]Sigma Connectivity, Lund, Sweden

Towards the installation of the linear accelerator at the European Spallation Source (ESS), the low-level RF (LLRF) system needs to become ready. The fast control algorithms of the LLRF system will be implemented on a Xilinx FPGA. While the previous developments took place on a prototyping board, the algorithms need to be integrated into the FPGA of the actual digitizer board within an MTCA crate. Besides the algorithm, code that provides access to the peripherals connected to the FPGA is necessary. In order to provide a common platform for the FPGA developments at ESS, the ESS FPGA Framework has been designed. The framework facilitates the integration of different algorithms on different FPGA boards. There are three functions provided by the framework: (1) Communication interfaces to peripherals, i.e. the analog-digital converter (ADC), the digital-analog converter (DAC) and the Dmemory, (2) Upstream communication with the control system over a PCIe interface and definition of the interface to access the board by drivers, and (3) Configuration of the on-board peripherals, e.g. ADCs and clock distribution. To keep the framework easily extensible by IP blocks and to enable seamless integration with the design tools from Xilinx, the AXI bus has been chosen as the communication interconnect. Furthermore, the building of the FPGA configuration, software components and the documentation have been automatized by scripts.
The ESS FPGA framework has been successfully developed and the LLRF control algorithms have been integrated into the framework. For the future, the framework is ready to host other FPGA applications.

P-79

Baseband board set for LCLS-II LLRF

Lawrence Doolittle[1], Gang Huang[1], John Jones[1], Carlos Serrano[1]
[1]*LBNL, Berkeley, United States*

The digitizer and attached processing hardware for an LLRF system together fundamentally determine best-case LLRF performance and capabilities. With that in mind, a flexible two-board platform has been developed, characterized, and applied by the LCLS-II LLRF collaboration. It is a high-performance, moderate-cost design that can be readily adapted to other systems. The first board is a flexible double FMC carrier designed for low noise and high performance, providing eight application-side high speed (12Gb/s) duplex optical fiber connections for both local (rack-scale) and accelerator-wide communication networks. It also implements robust housekeeping and board management, removing the fear of 'bricking' the device during software updates. The second board is a digitizer FMC mezzanine that has eight 100 MS/s ADC inputs and two 200 MS/s DAC outputs, capable of controlling one or two cavities. The use of an FMC interface between the two boards provides a straightforward test and upgrade path. The system is powered by a single power supply, and moderate power dissipation makes it easy to integrate into a custom or semi-custom chassis. The boards were designed with analog performance in mind; careful testing using near-IQ sampling has revealed exceptionally clean RF noise spectra from 0.01 Hz to 1 MHz offset.

P-80

LO and CLK generation modules for LLRF system of European XFEL

Mateusz Zukocinski[1], Krzysztof Czuba[1], Matthias Hoffmann[2], Frank Ludwig[2], Uros Mavric[2], Maciej Urbanski[1]
[1]Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland, [2]Deutsches Elektronen-Synchrotron, Hamburg, Germany

The European XFEL is a new generation of Free-Electron Laser (FEL) machines. Its superior performance is achieved with the new LLRF front-end electronics. The front-end electronics design is focused on achieving ultra-low phase noise which contributes to the quality of the electromagnetic field of superconducting RF cavities in accelerating modules, stability of accelerated electron bunches arrival time and finally to the output laser light of FEL. Other important goals for LLRF system are drift minimization, remote control and diagnostics, high reliability and serviceability. This is achieved introducing to all subsystems highly integrated PCB modules that can accommodate all the system requirements. One of the crucial subsystems of the LLRF front-end is Local Oscillator (LO) generation and Clock (CLK) generation. The LO signal is used in superheterodyne receiver of the LLRF field detector. The CLK signal is used as a low jitter sampling clock for analog-to-digital converters (ADC) of the LLRF digitizer. These high performance signals allow precise control of electromagnetic field in accelerating RF cavities of the LINAC.
This paper presents a family of ultra-low phase noise LO and CLK generation modules developed for XFEL. Results at the level of single femtoseconds of the residual integrated RMS time jitter at 1.354 GHz have been achieved.

P-81

The Consideration of RF Reference Phase Stabilization for the SuperKEKB Injector LINAC

Student Na Liu[1], Associate Takako Miura[1,2], Associate Toshihiro Matsumoto[1,2], Dai Arakawa[2], Hiroaki Katagiri[2], Yoshiharu Yano[2], Shinichiro Michizono[1,2], Assistant Feng Qiu[1,2], student Sigit Basuki Wibowo[1]

[1]*The Graduate University for Advanced Studies (SOKENDAI), Shonan Village, Japan,* [2]*High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Japan*

Stabilization of RF phase reference for long distance transmission is very important for stable RF operation, especially in the large accelerator facilities. For the injector LINAC of SuperKEKB, the phase stability requirement is within 0.1 deg. rms. Coaxial cables and optical fiber links (E/O, O/E and optical fibers) as the distribution medium without feedback control are used for the present system. A more stable RF phase distribution system using single-mode optical fiber links with feedback control is required to improve the phase stability for lower energy drift. The temperature and humidity characteristics of different type optical components (E/O, O/E, optical fibers) were measured as well as the phase noise and long-term stability of the optical fiber links. Different phase detection techniques for low phase drift and high accuracy were compared. The candidate of the feedback control system for RF reference phase stabilization in our facility will be proposed.

P-82

Master Oscillator concept for ESS

Anders Svensson[1], Anders J Johansson[2]
[1]*European Spallation Source, Lund, Sweden,* [2]*Lund University, Lund, Sweden*

The Master Oscillator (MO), being the primary clock and RF source for ESS, will have a significant impact on reliability and performance. The design consists of GPS disciplined Rb source, VCO, Dielectric Resonator Oscillator and Divider Unit. The redundancy concept is described and overall design considerations are investigated. Initial measurement results are reported.

P-83

High Level Applications for SwissFEL LLRF System

Zheqiao Geng[1]
[1]*Paul Scherrer Institut, Villigen Psi, Switzerland*

SwissFEL is a Free Electron Laser (FEL) machine under commissioning at Paul Scherrer Institut (PSI), Switzerland. The SwissFEL accelerator consists of multiple RF stations either with standing wave cavities (e.g. RF Gun) or with travelling wave accelerating structures working at different frequencies. Digital LLRF systems are used to measure the RF fields in cavities or structures and correct the fluctuations in RF fields with pulse-to-pulse feedback controllers. To facilitate the operations of multiple RF stations, the LLRF system should also provide algorithms and procedures to automate the setup, calibration and optimization of the RF systems. In this poster, several typical algorithms will be described, such as calibrating the DAC offset to reduce the RF leakage from vector modulator, calibrating the RF signal group delay and flattening the intra-pulse phase distribution with adaptive feed forward. The algorithms and procedures have been implemented as a LLRFLLRF High Level Applications (HLA) software for SwissFEL. The architecture of the LLRF HLA software will be introduced and the test results at SwissFEL will be also described.

P-84

FPGA-Based Cavity Phase Stabilization for Coherent Pulse Stacking

Yilun Xu[1,2], Russell Wilcox[2], John Byrd[2], Lawrence Doolittle[2], Qiang Du[2], Gang Huang[2], Yawei Yang[2], Chuanxiang Tang[1], Wenhui Huang[1]
[1]Tsinghua University, Beijing, China, [2]Lawrence Berkeley National Laboratory, Berkeley, USA

Coherent pulse stacking (CPS) is a new time-domain coherent addition technique that stacks several optical pulses into a single output pulse, enabling high pulse energy from fiber lasers. We develop a robust, scalable and distributed digital control system with firmware and software integration for algorithms, to support the coherent pulse stacking application. We model the coherent pulse stacking as a digital filter in Z domain and implement the pulse-pattern-based cavity phase detection algorithm on an FPGA. With amplitude and phase of optical pulses fully modulated, a 2-stage (2+1 cavities) 15-pulse stacking system achieves a 11.0 peak-power enhancement factor. Each optical cavity is fed back at 1.5 kHz, and stabilized at an individually-prescribed round-trip phase with 0.7 deg and 2.1 deg RMS phase errors for Stage 1 and Stage 2 respectively. Optical cavity phase control with nm accuracy ensures 1.2% intensity stability of the stacked pulse over hours.

P-85

SOLEIL digital transverse bunch by bunch feedback system upgrade

Rajesh Sreedharan[1]
[1]*Synchrotron Soleil, Gif-sur-yvette, France*

Recent upgrades of the SOLEIL digital transverse bunch by bunch feedback system were made in collaboration with SPRing-8. The previous version, based on Virtex-2 pro, is routinely operated since more than 10 years in both modes, high average current and high bunch current. The new one, based mainly on 2 cascaded Virtex 7, 11 fast ADCs and 12 DACs, was successfully tested under hard transverse instability conditions. Comparative performance results are reported.

P-86

Laser-to-RF Synchronization with Femtosecond Precision

Christian Schmidt[1], Thorsten Lamb[1], Lukasz Butkowski[1], Ewa Felber[1], Matthias Felber[1], Michael Fenner[1], Szymon Jablonski[1], Tomasz Kozak[1], Jost Müller[1], Pawel Predki[1], Holger Schlarb[1], Cezary Sydlo[1], Mikheil Titberidze[1], Falco Zummack[1]
[1]*Desy, Hamburg, Germany*

At FLASH and the European XFEL, laser pulses are distributed as optical reference signals via propagation time stabilized optical fibers to achieve femtosecond synchronization. In order to generate drift-free, low-noise and phase-stable RF signals, Laser-to-RF phase detectors based on integrated Mach-Zehnder Interferometers have been implemented. The 1.3 GHz RF reference signals are tapped from a coaxial distribution system. Phase drifts and slow phase jitter are measured with respect to the femtosecond optical reference and actively corrected directly within the accelerator tunnel. The setup including the Laser-to-RF phase detector, 1.3 GHz RF actuator unit and advanced control electronics was carefully engineered and integrated into a single compact device. The short-term and long-term performance in the accelerator tunnel of the European XFEL is presented and carefully reviewed.

P-87

Detuning and field control of an SRF Photoinjector Cavity for the bERLinPro Energy Recovery Linac

Axel Neumann[1], Andriy Ushakov[1], Pablo Echevarria[1]
[1]*Helmholtz Zentrum Berlin, Berlin, Germany*

Helmholtz-Zentrum Berlin (HZB) is currently constructing an high average current superconducting (SC) ERL as a prototype to demonstrate low normalized beam emittance of 1 mm·mrad at 100mA and short pulses of about 2 ps. To reach the required beam properties, an SRF based photo-injector system was developed and recently underwent RF commissioning. The medium power prototype- a first stage towards the final high power 100 mA design- presented here features a 1.4 x lambda/2 cell SRF cavity with a normal-conducting, high quantum efficiency Cs2KSb cathode, implementing a modified HZDR-style cathode insert. This injector potentially allows for 6 mA beam current and up to 3.5 MeV kinetic energy, limited by the modified twin TTF-III fundamental power couplers. In this contribution first insights in the LLRF operation and detuning control of this special type of resonator is given. Especially the twin coupler operation requires a different field control approach than used with single coupler operated cavities. Further, this class of cavities shows to have higher sensitivity towards Lorentz force detuning increasing the probability of the rise of ponderomotive instability.

P-88

XFEL RF Synchronization System

Dominik Sikora[1], Krzysztof Czuba[1], Paweł Jatczak[1], Dawid Kołcz[1], Maciej Urbański[1], Martin Killenberg[2], Frank Ludwig[2], Heinrich Pryschelski[2], Holger Schlarb[2], Nadeem Shehzad[2]

[1]Warsaw University of Technology, ISE, Warsaw, Poland, [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

An important requirement for the European XFEL RF system is to assure a precise amplitude and phase RF field stability within the accelerating cavities at 1.3GHz of dA/A<3E-5, respectively <0.01 deg in the injector and dA/A<1E-4, <0.1 deg in the main LINAC.

Fulfilling such requirements for the 3.4 km long facility is a very challenging task. Thousands of electronic and RF devices must be precisely phase synchronized by means of harmonic RF signals. We describe the proposed architecture of the Phase Reference Distribution System designed to assure high precision and reliability. A system of RF cable based interferometers supported by femtosecond-stable optical links will be used to distribute RF reference signals.
We present first packaged interferometer based modules providing phase drift suppression factors higher than 100. Modules were designed to distribute a long-term stable RF reference signal over distances of few hundred meters.

P-89

Status update on the 1.3 GHz Master Oscillator of the European XFEL

Bartosz Gąsowski[1], Łukasz Zembala[1], Stanisław Hanasz[1], Tomasz Owczarek[1], Krzysztof Czuba[1], Henning-Christof Weddig[2], Holger Schlarb[2], Julien Branlard[2]
[1]*Warsaw University of Technology, ISE, Warsaw, Poland,* [2]*DESY, Hamburg, Germany*

E-XFEL's Master Oscillator (MO) as a source of the phase reference signal has to both fulfil stringent performance requirements and offer very high reliability. Since those two requirements are often contradictory, the system was partitioned in order to solve these issues separately. The signal generation part was commissioned last year and delivers an ultra high performance (< 25 fs rms jitter, < 10^{-12} frequency stability, +40 dBm power) 1.3 GHz reference signal for the E-XFEL facility. A novel redundancy solution which will maintain a continuous reference signal even in case of a failure is currently in development and is planned to be in operation in early 2018.
The complete system comprises three fully independent Generation Channels (GCs), each delivering full-performance reference signal, and a Redundancy Module (REDM), which in turn includes a fast three-way RF switch, a real-time controller with diagnostics, and a dielectric-resonator filter for energy storage. We present an overview of the system, the current status of development and commissioning, as well as the achieved performance and further plans.

P-90

Cavity Simulator for the European Spallation Source

Maciej Grzegrzółka[1], Igor Rutkowski[1], Krzysztof Czuba[1]
[1]*Warsaw University Of Technology, ISE, Warsaw, Polska*

The Cavity Simulator will reproduce the behavior of superconducting elliptical cavities and high power amplifiers (klystron/IoT) used in medium and high beta sections of the European Spallation Source linac. The device will simulate all RF and analog signals from a single set of cavity and amplifier. It will be used to test LLRF systems after installation in the ESS facility.
The device is based on a high performance FPGA connected to a set of precise data converters with a dedicated analog frontend. Down-conversion scheme is used to digitize the input RF signals and all output RF signals will be generated using vector modulators. For the FPGA a custom firmware will be prepared. It will perform digital signal processing, data acquisition and handle communication over the Ethernet network. A dedicated software running on external PC for remote control of the device will be provided.
In this contribution the conceptual design and the current status of the Cavity Simulator project will be presented.

P-91

New applications of CERN's Digital LLRF family and results obtained

Maria Elena Angoletta[1]
[1]*Cern, Geneva, Switzerland*

An innovative LLRF family has been developed at CERN. Already successfully used in CERN's PS Booster and in the medical machine MedAustron in 2014, the family has been deployed in CERN's Low Energy Ion Ring (LEIR) in 2016 and in the Extra Low ENergy Antiproton (ELENA) ring in 2017. Moreover, additional features for studies and future beams have been requested and are being developed in these installations. The talks gives an overview of some features implemented and shows the beam results obtained.

P-92

The SPS LLRF upgrade project: An update

Gregoire Hagmann, Javier Galindo Guarch[1,2], Gerd Kotzian[1], Lorenz Schmidt[1], Philippe Baudrenghien[1]
[1]*Cern, Geneva, Switzerland,* [2]*UPC, Barcelona, Spain*

The LLRF of the CERN SPS will go through a complete renovation during for the Long Shutdown 2019-2020. The upgrade is driven by the required performances as injector for the LHC: For protons, the bunch intensity must be doubled (2.2E11 p/bunch at transfer to LHC), requiring major modifications to the accelerating system (based on Travelling-Wave Cavities at 200 MHz), namely the shortening of the four existing cavities and the installation of two additional cavities. On the LLRF side, the active compensation of transient beam loading must be improved (Feedforward, One Turn Delay feedback, Longitudinal damper). For LHC ions, the required 50 ns bunch spacing calls for new LLRF gymnastics, namely slip stacking in the SPS, before transfer to the LHC.
The new LLRF will be based on the distribution of a fixed reference clock, plus data (such as the instantaneous Frequency Tuning Word and Phase) using a deterministic link. This “paradigm” leads to a new architecture with several of these deterministic links connecting the various cavity controllers and the beam control (beam-based loops). Studies are ongoing to minimize the phase noise resulting from the regeneration of the reference clock. A prototype is being designed, based on uTCA, as CERN considers this platform as a replacement of the current VME systems in operation. The new philosophy will make new features possible, such as the coupled-feedback on cavities of different lengths. Use of synchronized deterministic links is also very attractive for future machines with RF stations at distant locations, such as for the CERN future collider FCC-ee under study.

P-93

LLRF Resonance Control System for LCLS2

Ramakrishna Bachimanchi[1], Brian Chase[2], Joshua EINSTEIN-CURTIS[2], Curt Hovater[1], Gang Huang[3]

[1]Jefferson Lab, Newport News, United States, [2]Fermi Lab, Chicago, United States, [3]Berkeley Lab, Berkeley, United States

LCLS2 cryomodules have slow and fast tuners for maintaining the resonance on a cavity. Piezo is an electro mechanical device, which acts on fast transients, microphonics detuning and helium pressure changes. Stepper Motor is a mechanical tuner, which acts as the slow tuner and is mainly used for keeping piezo in its tuning range and for detuning and tuning cavities outside piezo's range. This poster describes the design of the resonance control system, firmware associated with it and the data acquired from operating cold cavities at Jlab CMTF and Fermilab CMTS

P-94

Modular Low-Noise Piezoamplifier Driver for SRF Applications

Brian Chase[1], Joshua Einstein-Curtis[1], Dan Klepec[1]
[1]*Fermilab, Batavia, United States*

Superconducting RF (SRF) accelerating cavities are highly sensitive to vibrations, typically called microphonics. In addition, correcting for cavity drift due to system pressure and gradient changes is also a problem for high-Q cavities. Correcting for these factors can be done using piezo transducers, which require a low-noise drive to not further disturb the system.

For the LCLS-II LLRF system, Fermilab has developed a low-noise piezo amplifier driver module that uses a consumer, off-the-shelf (COTS) amplifier on a custom carrier board. This module allows for piezo voltage and current readback at up to 200 kSPS and waveform playout at 500 kSPS for 2 piezo stacks. Test results and operational experience are shown here.

P-95

Phase Reference Distribution System for European Spallation Source

Mateusz Zukocinski[1], Krzysztof Czuba[1], Michal Kalisiak[1], Tomasz Lesniak[1], Krzysztof Oliwa[1], Radoslaw Papis[1], Dominik Sikora[1], Anders Sunesson[2], Wojciech Wierba[1], Rihua Zeng[2]

[1]Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland, [2]European Spallation Source, ERIC, Lund, Sweden

The European Spallation Source (ESS) requires precise phase synchronization of LLRF and Beam Diagnostics systems operating at frequencies of 352.21 MHz and 704.42 MHz. The required phase accuracy at both frequencies is 0.1° for short term (during 3.5 ms pulse) and 2.0° for long term (hours to days) between any two points in the 600 m long accelerator tunnel with LINAC.

The Phase Reference Distribution System (PRDS) is based on passive synchronization scheme where the pick-up cables from RF cavities and beam diagnostics instruments are paired and length-matched to corresponding reference cables from the PRDS. This minimizes phase drift errors between these two cables and enables precise synchronization in harsh radiation environment in accelerator tunnel where active drift compensation techniques cannot be used.

The main part of the PRDS is Phase Reference Line (PRL) which is a fully passive distribution system based on a single 1-5/8" coaxial rigid line placed in the tunnel along the LINAC.

The PRL distributes both reference frequencies (352.21 MHz and 704.42 MHz) from Master Oscillator located in the Klystron Gallery to 58 tap points in the tunnel. Each tap point consists of 1-5/8" coaxial directional coupler together with passive splitting and filtering module. This provides locally multiple frequency-selective outputs, each with 352.21 MHz or 704.21 MHz reference signal.

The total length of the PRL is 580 meters and the total number of signal outputs is nearly 300.

To achieve the best drift performance and fulfill ESS synchronization requirements the PRL will be equipped with temperature stabilization system (+/- 0.1 deg C) and the line will be pressurized with Nitrogen to assure humidity and pressure precise control.

This presentation covers the concept of the PRDS and the PRL, technical assumptions, modeling results, prototype test results and finally status of the PRL installation in the ESS tunnel.

P-96

Design Considerations for the RF Reference distribution System for RISP linac

Kyungtae Seol[1], Hyojae Jang[1], Hoechun Jung[1]
[1]*IBS, Daejeon, South Korea*

The heavy-ion accelerator of the Rare Isotope Science Project (RISP) in Korea has been developed. The RF reference distribution system must deliver a phase reference signals to all low-level RF (LLRF) systems and BPM systems with low phase noise and low phase drift. The frequencies of RISP linac are 81.25 MHz, 162.5 MHz and 325 MHz, and there are 130 LLRF systems and 60 BPMs respectively for SCL1 and SCL3, and 240 LLRF systems and 70 BPMs for SCL2. This paper describes the design considerations for the RF reference distribution system such as distribution frequency, phase stability and temperature influence on system, multiplier noise, reference line attenuation.

P-97

LOW LEVEL UPGRADE FOR THE BROOKHAVEN 200-MEV H-LINEAR ACCELERATOR

Freddy Severino[1], Darryl Goldberg[1], Thomas Hayes[1], Vincent Lo Destro[1], Kevin Mernick[1], Geetha Narayan[1], Kevin S. Smith[1], Alexander Zaltsman[1]
[1]*Brookhaven National Laboratory, Upton, United States*

We recently commissioned a new Digital Low Level RF (LLRF) system for the BNL 200-MeV LINAC using our existing FPGA based embedded controller platform [1]. Key features include fast, low latency feedback loops with feed-forward transient beam loading compensation, pulse rise-time gain adjustment and beam inhibit protection based on cavity field regulation. The digital system also provides a control system interface, remote access to all configuration parameters and fast diagnostic data acquisition and logging. The new system has successfully achieved its main goals of improved cavity field regulation over the 500 us RF pulse, with faster pulse settling time and better long term stability compared to the previous 46 year old controller. This poster aims at sharing our experiences during the design and commissioning stage as well as results of the first year of machine operations with the new system.

P-98

LCLS II Phase Reference System

Chengcheng Xu[1], Bo Hong[1], Josef Frisch[1], Steve Smith[1], Larry Ruckman[1]
[1]*Slac National Accelerator Lab, Menlo Park, United States*

SLAC's LCLS-II is a next generation X-ray FEL that will use a CW 4 GeV superconducting. It will deliver both soft and hard x-ray FEL to users. When LCLS II turns on, it will produce X-ray laser that is 10,000 times brighter than LCLS I and produce X-ray pulses at one million times a second. In order to achieve this high level of performance, it is critical to have a stable RF reference system throughout the machine. We have designed a phase reference system that provides a reference signal for LCLS II at 1300MHz that has a measured integral jitter of 3.5fs from 100Hz to 10kHz. (Requirement is 10.7fs) They system also provides 185.7MHz reference signal for the Timing system, 1320MHz LO for the LLRF system, 476MHz synchronized reference for LCLS I, and other sub-systems. The 1300MHz reference features a bi-directional signal which allows the technic of phase averaging to eliminate phase drift caused by change in cable length. This paper will discuss the overall system design of the phase reference line system, which includes algorithm, hardware design, firmware design, and test result. It will also review the challenges we faced, as well as future improvements we wish to implement.

P-99

Digital Low Level RF Systems for SESAME light Source

Nasha't Sawa'i[1], D Foudeh[1], E Huttel[1], A Kurdi[1], D Teytelman[2]
[1]Sesame, Allan, Jordan, [2]Dimtel, nc, San Jose, United States

SESAME, the first Synchrotron light sources in in the Middle East, it is located in Allan (Jordan) (30 km from Amman), it is consists of a 22 MeV Microtron and an 800 MeV Booster Synchrotron (original from BESSY I, Berlin, Germany) and a 2.5 GeV Storage Ring (new design). The RF system consists of four 500 MHz ELETTRA cavities powered by four 80 kW SSA whereas the first amplifier is produced by SOLEIL and the other three are produced by SIGMA-PHI. The digital Low Level RF system (LLRF9/500) is supplied by Dimtel.Inc
3 Units of LLRF9 had been installed end of 2016 and they are operational, two units for SR and one unit for Booster, LLRF9/500 runs two RF stations, this report describes the Hardware setup and commissioning results of LLRF, and using LLRF for High power RF conditioning.

P-100

Design and status of a MicroTCA.4 based LLRF system for TARLA

Christian Schmidt[1], Avni Aksoy[2], Julien Branlard[1], Łukasz Butkowski[1], Çağıl Gümüş[1], Martin Hierholzer[1], Matthias Hoffmann[1], Michael Kuntzsch[3], Konrad Przygoda[1], Holger Schlarb[1]

[1]DESY, Hamburg, Germany, [2]TARLA, Ankara, Turkey, [3]HZDR, Dresden, Germany

The Turkish Accelerator and Radiation Laboratory in Ankara (TARLA) are constructing a 40 MeV Free Electron Laser in continuous wave RF operation. In order to control and monitor the four superconducting (SC) TESLA type cavities as well as the two normal conducting buncher cavities a MicroTCA.4 based LLRF system is foreseen. This highly modular system is further used to control the mechanical tune of the SC cavities by control of piezo actuators and mechanical motor tuners. We are going to describe the system setup and integration in the existing accelerator environment, hardware and software wise.