Thirteenth CW and High Average Power RF Workshop

Report of Contributions

https://indico.cern.ch/e/1415344

Contribution ID: **1** Type: **Talk**

Test abstract

Lorem ipsum

Author: Prof. VALUCH, Daniel (CERN)

Presenter: Prof. VALUCH, Daniel (CERN)

Track Classification: Control, interlocks, safety

Contribution ID: **2** Type: **not specified**

SNS tour

Thursday 12 September 2024 09:00 (45 minutes)

Presenter: GUIDE, tour (SNS)

Contribution ID: **3** Type: **not specified**

Graphite reactor

Thursday 12 September 2024 10:00 (45 minutes)

Presenter: GUIDE, tour (SNS)

Contribution ID: **4** Type: **not specified**

Super computer

Thursday 12 September 2024 10:45 (45 minutes)

Presenter: GUIDE, tour (SNS)

Contribution ID: **5** Type: **Talk**

Development of new solid-state RF amplifiers at SIRIUS

Monday 9 September 2024 14:50 (25 minutes)

SIRIUS is a 4th generation synchrotron light source built and operated by the Brazilian Synchrotron Light Laboratory (LNLS) currently operating in top-up mode at 100 mA beam current, driven by a temporary RF system comprised of one PETRA 7-cell cavity and two 65 kW solid state amplifiers (SSAs). In the upcoming update, two SRF cavities will be installed along with two more SSAs, which will allow the operation with 200 mA and, by the end of 2026, a third harmonic cavity will be installed and it will be possible to reach the nominal beam current of 350 mA. For the final RF system, four new 65 kW SSAs, which are being developed in house, will be installed. These amplifiers consists of 900 W amplifier modules combined through a cavity combiner and this presentation will showcase the project's current status, along with the results obtained from the characterization of the SSAs modules, the 10-way quarter-wavelength and 8-way Wilkinson power dividers, and the cavity combiner.

Author: FREIRE, Vitor (CNPEM)

Co-authors: PONTES BARBOSA LIMA, André (CNPEM); KAROLLYNE RAMIRO FURUKAWA, Danyelli (CNPEM); DAMINELLI, David (CNPEM); KOJI GODINHO HOSHINO, Felipe (CNPEM); CARVALHO DE ALMEIDA, Iago (CNPEM); RAMIRES DO CANTO SANTOS, Ranieri (CNPEM)

Presenter: FREIRE, Vitor (CNPEM)

Session Classification: Session 2a

Track Classification: Solid state systems

Contribution ID: **6** Type: **Talk**

A High Power 805 MHz RF Amplifier for LANSCE using GaN Devices

Tuesday 10 September 2024 11:15 (25 minutes)

Los Alamos Neutron Science Center uses a coupled-cavity linac (CCL) to accelerate H- beam from 100 to 800 MeV. This was the first CCL put into operation (1972) and is powered by forty-four 1.25 MW 805 MHz klystrons developed in the same era. Replacement klystrons have had mortality rates higher than tubes made over 25 years ago. This has caused us to embark on a new initiative to develop a replacement RF amplifier that fits in place of one klystron with HV modulator tank, that is also functionally equivalent or better in RF performance. Conventional LDMOS transistors based on silicon have reduced power above 500 MHz, and are also limited in peak power by the maximum drain voltage. Changing wireless infrastructure is causing leading manufacturers to introduce and discontinue products all within a decade, unlike the old klystron producers. Long term operation of LANSCE requires continuity of RF device availability. We have chosen leading-edge high voltage Gallium Nitride (GaN) on Silicon Carbide transistors to be able to reduce the number of active devices and the complexity of power combing. GaN has inherent higher channel temperature and voltage breakdown ratings. We are testing devices for 3.6 kW of saturated power at 100 volts, and improvements are underway to increase this. Power supplies and combining technology are also under study as part of the overall system.

Author: Mr T. M. LYLES, John (Los Alamos National Laboratory)

Co-authors: Mr VALLADARES, Jesus (Los Alamos National Laboratory); Mr BRADLEY, III, Joseph (Los Alamos National Laboratory); Ms SANCHEZ BARRUETA, Maria (Los Alamos National Laboratory); Mr RUSSELL, Steve (Los Alamos National Laboratory); Mr KWON, Sung-il (Los Alamos National Laboratory); Mr W. HALL, Thomas (Los Alamos National Laboratory)

Presenter: Mr T. M. LYLES, John (Los Alamos National Laboratory)

Session Classification: Session 3b

Track Classification: Solid state systems

Contribution ID: **7** Type: **Talk**

A Protection Method for Solid State Amplifiers from High Voltage Transients

Wednesday 11 September 2024 16:10 (25 minutes)

The RF system for the Alternating Gradient Synchrotron (AGS) at Brookhaven National Lab (BNL) consists of a Tetrode Based Power Amplifier (PA) driven by a Solid-State Feedback Amplifier (SSFB). Due to the nature of the tetrode, the Screen Voltage is prone to arcing to the Grid. This creates a transient at the Screen Voltage (2kV) which appears on the output of the SSFB damaging the devices. Due to the low frequency of the system (300kHz –5 MHz) a circulator cannot be used. To prevent downtime, costly device replacement, and better reliability a protection method must be investigated. This poster will go through the analysis of the transients and explore protection methods including Gas Discharge Tubes (GDT) & Transient Voltage Suppressor Diodes (TVS).

Author: LUKACH, Daniel (Brookhaven National Lab)

Presenter: LUKACH, Daniel (Brookhaven National Lab)

Session Classification: Session 6b

Track Classification: Gridded tubes

Contribution ID: **8** Type: **Talk**

Status and upgrade plan of SPring-8 RF system

Tuesday 10 September 2024 08:15 (25 minutes)

SPring-8 is a 3rd generation synchrotron facility. The electron beam energy and current are 8 GeV and 100 mA. There are four RF stations to generate 16 MV total accelerating voltage at a frequency of 508.58 MHz. Each station has eight single-cell cavities driven by one 1MW-CW-klystron. About 27 years have passed since the start of the user operation was in 1997, an upgrade project, SPring-8-II, is being actively pursued by 2028. By introducing a multi-bend achromat lattice and combined function magnets, the beam emittance will be reduced from 2.5 nmrad to around 100 pmrad with a beam energy of 6 GeV and a current of 200 mA. Required accelerating voltage is 8 MV. So the number of the cavity will be reduced to half, keeping the current klystrons and low-level RF. In this presentation, operational status and upgrade plan of the RF system will be shown.

Author: OHSHIMA, takashi (RIKEN)

Co-author: INAGAKI, Takahiro

Presenter: OHSHIMA, takashi (RIKEN)

Session Classification: Session 3a

Track Classification: Project reports, new projects

Contribution ID: **9** Type: **Talk**

New GaN driver amplifier for RHIC 197 MHz rf system

Tuesday 10 September 2024 10:50 (25 minutes)

A new radiofrequency (rf) driver amplifier is being designed to replace 3 kW rf amplifiers that are part of the 197 MHz rf system in the Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Laboratory. A prototype was built using a gallium nitride device able to operate up to 100 V on the drain side. First measurements indicate that a single unit can generate power in excess of 1.7 kW at over 70% power-added efficiency. This work presents details about its electromagnetic and thermal design, and other important specifications regarding operation in RHIC.

Author: HOFFMANN WALLNER, Mark (Brookhaven National Laboratory)

Co-author: Mr SOWINSKI, Michael (Brookhaven National Laboratory)

Presenter: HOFFMANN WALLNER, Mark (Brookhaven National Laboratory)

Session Classification: Session 3b

Track Classification: Solid state systems

Contribution ID: **10** Type: **Talk**

Development of a 120kW CWRF Solid State Power Amplifier System at 500MHz

Wednesday 11 September 2024 08:15 (25 minutes)

High power of RF energy fed into single cavities is needed for state-of-the-art particle accelerator facilities and their upgrades. Delivering this from a single tube-based source, such as klystrons, tetrodes or IOTs, is generally possible but bears the risk of a single point of failure. Additionally, tube technology is obsolete and availability on the market continuously decreasing. Solid-state power amplifier based on transistor technology has advantages, such as the implementation of redundancy for compensation of failed units and improved system control via software. The overall wall-plug efficiency can also be superior.
These advantages are key driving factors of changing the RF sources at accelerator facilities from tube technologies to transistor-based systems. But combining multiple transistors is necessary and key for providing the required RF power into the cavities. Here, we introduce a sequential combining based on our solid state power amplifier system architecture delivering up to 120kW RF power at 500MHz.
The combination and interplay of totally 144 LDMOS transistors within one system not only requires adequate phase and amplitude matching for keeping the losses low and the overall efficiency high. It also needs the implementation of a superior software control for exploiting the full potential and advantages of this solid state technology as particle accelerating RF source.
In this presentation we will report on the challenges for implementation and setting up the hardware and software control of this system.
The machine has been delivered in Q3 2023 to the PETRA III synchrotron.

Author: LAU, Marcus

Co-authors: BAUM, Felix (TRUMPF); WEBER, Jens (TRUMPF); POPP, Michael

Presenter: WEBER, Jens (TRUMPF)

Session Classification: Session 5a

Track Classification: Solid state systems

Contribution ID: **11** Type: **not specified**

Challenges and breakthroughs in recent RF Solid State PA design by Radian Combiner design with Initiatives for SDGs

Monday 9 September 2024 17:30 (30 minutes)

R&K, an independent company, has achieved production of 2.3 million 1.9GHz microwave power amplifiers for mobile-comm's-base-stations and then also supplies wideband power amplifiers for automobile EMC testing for domestic automobile industries. Then 16 years ago, we started designing and producing some hundreds kW RF SSA for accelerator applications as alternatives to Klystron / tube.
The measure characteristics of SSA is a possibility to design a band in a very wide frequency range available from few MHz to 14 GHz, and its upgradability of max-power in few kW to few MW design even after system completed. Recently, SSA is being recognized the significant advantages over vacuum tubes in terms of size, low power consumption, higher efficiency, low cost, and adaptive power design. In addition to these, we have learnt that SSA has very low phase noise and low envelope noise that cannot be achieved with vacuum tubes.

Author: Mr KOBANA, Riichiro (R&K Company Limited)

Presenter: Mr KOBANA, Riichiro (R&K Company Limited)

Session Classification: Industry session 1

Track Classification: Industrial session

Contribution ID: **12** Type: **Talk**

Progress Report – Transition from Klystrons to Solid State RF at the Advanced Photon Source

Tuesday 10 September 2024 14:00 (25 minutes)

The transition from klystrons to solid state rf power sources at the Advanced Photon Source is well underway, with the first four 352MHz/160kW solid state rf systems scheduled for installation in the fall of 2025. R&D efforts leading up to the transition to solid state will be discussed, including the design and testing of 352MHz prototype solid state rf amplifiers at the 12kW, 32kW, and 200kW level, and the design and testing of a 16-input/200kW combining cavity and four-port waveguide combiner. The influence this R&D effort had on the final design of the 352MHz/160kW systems will be discussed.

Author: HORAN, Douglas (Argonne National Laboratory)

Presenter: HORAN, Douglas (Argonne National Laboratory)

Session Classification: Session 4a

Track Classification: Project reports, new projects

Contribution ID: **13** Type: **Talk**

Status and operational readiness of the ESS RF Systems

Monday 9 September 2024 15:15 (25 minutes)

The RF systems for the first phase for the European Spallation Source accelerator is nearing completion. A total of 91 high power systems will be installed to support an average power capability of a 2 MW beam on target. ESS is a long-pulse machine which will operate at 14 Hz, with 2.86 ms pulses. Commissioning to a low power dump is expected to start early 2025 ahead of commissioning to the target, which is scheduled for later in the year. This talk will provide a summary of the status and maturity of the installed RF systems and will describe some of the key achievements and difficulties experienced during installation and more recently during high power testing of so many systems. Additionally, we report on the start of the warm coupler conditioning of the cavities using the installed RF systems.

Author: JENSEN, morten (European Spallation Source ERIC)

Presenter: JENSEN, morten (European Spallation Source ERIC)

Session Classification: Session 2a

Track Classification: Project reports, new projects

Contribution ID: **14** Type: **Talk**

High Power RF Load Challenges at ESS

Wednesday 11 September 2024 10:25 (25 minutes)

All high power, klystron based, RF systems at ESS rely on high power loads and circulators to protect the klystrons from excessive reflected power and to enable full power testing of the full amplifier chains. The high power testing of the system have revealed significant technical issues with the load design, resulting in damage and poor performance. We report on the high power investigations carried out at ESS with support from the load manufacturer. This talk will describe the key technical challenges and the technical solutions, which are being adopted, and will report on the results of tests with the the prototype mitigations in place.

Author: BORG, Walther (European Spallation Source)

Co-author: JENSEN, morten (European Spallation Source ERIC)

Presenter: BORG, Walther (European Spallation Source)

Session Classification: Session 5b

Track Classification: Power transmission and distribution

Contribution ID: **15** Type: **Talk**

Current Status and Future Plans of TPS High Power RF System

Tuesday 10 September 2024 10:25 (25 minutes)

Taiwan Photon Source (TPS) is a 3 GeV third-generation light source operating at a storage current of 500 mA. It currently operates with two RF stations, each capable of providing 300 kW of RF power. In the original design, each RF station employed a 500 MHz klystron-type RF transmitter. In August 2023, we switched one of the klystron-type RF transmitters to a 500 MHz home-made solid-state power amplifier, and it has been operating stably during user beam time. To accommodate the construction of more beamlines in the future, we plan to increase the total output power of each RF station to 375 kW through power combination. This report describes the operational status, including that of the SSPA, and the future plans for power combination along with the results of existing power combining tests.

Authors: Dr LIU, Zong-Kai (National Synchrotron Radiation Research Center); Mr CHUNG, Fu-Tsai (National Synchrotron Radiation Research Center); Mr CHANG, Shian-Wen (National Synchrotron Radiation Research Center); Mr CHEN, Ling-Jhen (National Synchrotron Radiation Research Center); Dr CHANG, Fu-Yu (National Synchrotron Radiation Research Center); Mr LI, Yi-Ta (National Synchrotron Radiation Research Center); Dr HUANG, Chao-Hui (National Synchrotron Radiation Research Center); Mr YEH, Meng-Shu (National Synchrotron Radiation Research Center); Dr LO, Chih-Hung (National Synchrotron Radiation Research Center); Dr CHANG, Mei-Hsia (National Synchrotron Radiation Research Center); Dr LIN, Ming-Chyuan (National Synchrotron Radiation Research Center); Dr WANG, Chaoen (National Synchrotron Radiation Research Center)

Presenter: Dr HUANG, Chao-Hui (National Synchrotron Radiation Research Center)

Session Classification: Session 3b

Track Classification: Project reports, new projects

Contribution ID: **16** Type: **Talk**

AR RF HPA 60 kW CW Factory Acceptance Test results and installation activities status at LBNL, USA

Wednesday 11 September 2024 14:00 (25 minutes)

Two units of 500 MHz 60 kW CW AR RF High Power Amplifiers (HPA) has been designed and manufactured as per LBNL's Engg Specifications & Requirements Document through a joint effort between engineers at LBNL and engineers at vendor R&K Company Ltd, Japan. The HPA design documents were reviewed by LBNL and also desk reviewed by NRTL company UL to USA standards prior to conducting the Final Design Review (FDR) and the recommendations from such review were duly incorporated & resolved. Prior to conducting Factory Acceptance Test(FAT) the HPA's were successfully preliminary field evaluated by NRTL–UL at vendor factory site. Thereafter detailed and extensive FAT were carried out at vendors factory for checking conformance to various specifications & requirements in various HPA subsystems viz., RF, AC, DC, LCW, Mechanical, Controls, Interfacing, EMI/EMC etc. Detailed HPA functionality & interlocks checks for HPA operation from local HMI and also from remote EPICS IOC were carried out. This paper presents such UL preliminary inspection, Reliability Testing in hot temperature (continuous operation at 60 kW CW output for 100 hours at 35 degC ambient) and FAT Results and how some HPA technical issues faced during such tests were successfully resolved. Overall the FAT was successful and the two HPA units were safely shipped to LBNL with all transit shock/ vibration monitors intact. This paper also presents some of challenges faced in HPA site installation work activities like rigging & anchoring heavy HPA (each ˜ 3 Tons), Electrical Panel & wireways, LCW installation (˜ 40 gpm flow), and RF dummy Load (80 kW) installation etc., in preparation to conduct the Final field evaluation by NRTL UL inspector at LBNL and then after AHJ approval to conduct soon the Site Acceptance Tests (SAT) which will be a subset of FAT tests.

Author: BASAK, Shree Subhasish (Lawrence Berkeley National Lab, USA)

Co-authors: Dr FLUGSTAD, Benjamin (Lawrence Berkeley National Lab, USA); Mr NETT, David (Lawrence Berkeley National Lab, USA); Mr HIRANO, Kazuhiro (R&K Company Ltd); Mr BAPTISTE, Kenneth (Lawrence Berkeley National Lab, USA); Mr BENDER, Kevin (Lawrence Berkeley National Lab, USA); Mr SAQIB, Najm (Lawrence Berkeley National Lab, USA); Mr KOBANA, Richiro (R&K Company Ltd); Mr SUEISHI, Toshinori (R&K Company Ltd)

Presenter: BASAK, Shree Subhasish (Lawrence Berkeley National Lab, USA)

Session Classification: Session 6a

Track Classification: Solid state systems

Contribution ID: **17** Type: **Talk**

Calibration of the analog beam-signal hardware for the beam power limit system at the Proton Power Upgrade Project at the Spallation Neutron Source

Tuesday 10 September 2024 08:40 (25 minutes)

A programmable signal processor-based credited safety control that calculates pulsed beam power based on beam kinetic energy and charge was designed as part of the Proton Power Upgrade (PPU) project at the Spallation Neutron Source (SNS). The system must reliably shut off the beam if the average power exceeds 2.145 MW averaging over 60 seconds. This paper discusses the calibration of the analog beam signal components for implementation into the Safety Programmable Logic Controllers (PLCs) and Field Programmable Gate Arrays (FPGAs).

Author: DEIBELE, Craig (Oak Ridge National Laboratory)

Co-authors: Dr BARBIER, Charlotte (ITER); MICHAELIDES, Chrysostomos (Oak Ridge National Laboratory); WILLIS, Dave (Oak Ridge National Laboratory); Dr KASEMIR, Kay (Oak Ridge National Laboratory); MAHONEY, Kelly (Oak Ridge National Laboratory); Dr BOBREK, Miljko (Oak Ridge National Laboratory); BONG, Patrick (Oak Ridge National Laboratory); ALLISON, Trent (Osprey Digital Control Systems); TAN, Yugang (Oak Ridge National Laboratory)

Presenter: DEIBELE, Craig (Oak Ridge National Laboratory)

Session Classification: Session 3a

Track Classification: Control, interlocks, safety

Contribution ID: **18** Type: **Talk**

Vertical test on a 2-cell 1.5-GHz SRF cavity

Monday 9 September 2024 17:05 (25 minutes)

A 2-cell 1.5-GHz SRF cavity was tested in a vertical test Dewar in NSRRC, Taiwan. The Dewar was filled with liquid helium at a temperature of 4.2 K. RF power was feed in throug an probe at the cavity axial center line. The quality factor of this SRF cavity at various field strength was measured. The system setup, probe design, and the measured results are reported in this presentation.

Author: LIN, Ming-Chyuan

Presenter: LIN, Ming-Chyuan

Session Classification: Session 2b

Track Classification: Other

Contribution ID: **19** Type: **Talk**

Circulator Compensation & New Developments of IR Based Compensation

Tuesday 10 September 2024 17:30 (30 minutes)

High power RF transmission line supplied by Microwave Techniques LLC (MT), formerly MEGA Industries, can be found in nearly every high-power microwave application around the world. Through the acquisition of Ferrite Microwave Technologies (FMT), MT engineers have had the opportunity to focus on circulator technology and compensation methodology. It is well understood that the low loss ferrite material used in high-power circulators exhibit a strong temperature dependence, and active compensation is required for optimal system performance and amplifier protection. Traditional active compensation methodologies have involved monitoring and optimizing return loss or measuring coolant/circulator body temperature and adjusting magnetic bias on predetermined slopes.
This presentation discusses a new compensation methodology based on direct IR measurements of the ferrite temperature. Monitoring ferrite temperature using IR doesn't suffer from thermal delays and doesn't require active RF power to function allowing for a high degree of precision and speed even with quick changes or outages in RF power. Data logged results from an IR compensated ISM 100Kw circulator, tested under varying power levels and load impedances, are evaluated and compared to traditional compensation methodologies. Particular attention will be paid to transient conditions, phase, second to second changes, power ramping and the importance of data collection for optimizing circulator performance.

Author: STURGIS, Jacob (Microwave Techniques)

Presenter: STURGIS, Jacob (Microwave Techniques)

Session Classification: Industry session 2

Track Classification: Industrial session

Contribution ID: **20** Type: **Talk**

S-Band Power Variator for Dual Energy LINACs based on Fast Ferrite Tuners

Wednesday 11 September 2024 10:50 (25 minutes)

Power variators (PV) or variable attenuators are required to control the RF power transfer to accelerator cavities and to realize dual energy LINACs operated at Megawatt peak power. Dual energy LINACs are used in medical radiation therapy (dual photon energy and imaging mode), as well as in industrial X-ray inspection systems for enhanced material detection in cargo scanning and non-destructive testing (NDT). PVs may consist of a passive waveguide network - including 3-dB-couplers, power splitters/ combiners, loads/ absorbers and tunable phase shifters as actuators for attenuation control - connected between the Magnetron or Klystron tube and the LINAC. Most solutions are based on stepper- or servo-motorized mechanical waveguide phase shifters. With a response time in the range of some hundred milliseconds or seconds those devices are not suitable to perform pulse to-pulse power variation at an RF pulse repetition rate of several hundred Hz.
This contribution introduces a fast ferrite phase shifter (Fast Ferrite Tuner, FFT), where the phase shift is delivered by the continuously tunable permeability of a biased microwave ferrite. A reflection-type ferrite waveguide phase shifter was designed for Magnetron-driven S-Band LINACs operated at 2998 MHz, 4 MW peak power, 4 kW average power with typical RF pulse length between 4 and 10 µs. The ferrites are in a shorted WR284 waveguide-section, water cooled and pressurized with SF6 at a pressure of 2 bar gauge. The ferrite bias is provided by permanent magnets and coils embedded in a closed magnet system formed of laminated iron yokes. A continuous tuning of permeability and phase is achieved by applying a tuning coil current of ± 10 A. A special narrow line width YIG ferrite material is chosen, and it is operated above ferromagnetic resonance, to obtain a high tunability of the effective permeability at very low loss.
Test results are presented for the FFT phase shifter device, achieving a differential phase shift of more than 110° at a power loss of only < 0.05 dB (0° state) and < 0.15 dB (90° state). The response time for a full phase-range switch is about 1 ms, using a four-quadrant power supply at ± 10 A, ± 48 V.
A reflection-type power variator unit is introduced, consisting of a compact arrangement of a magic-T power splitter, a load and FFT phase shifters. The unit provides continuous or switched-mode power variation in the range of 0 to 4 dB by using a single FFT or from 0 to >20 dB by using two FFT phase shifters. The low response time of the FFT allows for pulse-to-pulse power variation up to 1 kHz pulse repetition frequency, as demonstrated in an S-band dual energy LINACs with 3-dB power variation.
It is shown, how a reflection-type FFT power variator can be embedded in a 4-port circulator environment, to combine a variable attenuator with an isolator function. Inserted in the RF chain of a LINAC system, the subsystem provides reliable isolation between tube and PV as well as between PV and LINAC. Using such an isolated power variator in a dual energy LINAC permits to operate a pulsed Magnetron at a constant nominal peak power without high-voltage modulation. This way the lifetime of the Magnetron is improved, and the tube is effectively prevented from damage. A closed-loop power control via the FFT driver electronics enables precise and continuous adjustment of the photon energy as well as high energy stability, as required in high-resolution systems.

Author: Dr WEIL, Carsten (AFT microwave GmbH)

Co-author: Mr SCHWARZHORN, Joachim (AFT microwave GmbH)

Presenter: Dr WEIL, Carsten (AFT microwave GmbH)

Session Classification: Session 5b

Track Classification: Power transmission and distribution

Contribution ID: **21** Type: **Talk**

Status update and operational experience of the 200 MHz SSPA system for the CERN SPS.

Tuesday 10 September 2024 16:10 (25 minutes)

CERN has been operating two 1.6 MW peak power SSPA systems at 200 MHz for the past 4 years. This novel amplifier system combines 16 x 80 x 2kW peak power amplifiers in cavity combiners, then uses a network of high power hybrid combiners to reach the desired power levels. The SPS operates both in high power CW (750kW in the seconds range) and high power pulsed mode (1.6 MW in the microseconds range) which is highly stressing to the amplifiers. Operational experience and a review of reliability difficulties alongside troubleshooting methods will be presented.

Author: Dr PITMAN, Sam (CERN)

Co-author: MONTESINOS, Eric (CERN)

Presenter: Dr PITMAN, Sam (CERN)

Session Classification: Session 4b

Track Classification: Solid state systems

Contribution ID: **22** Type: **Talk**

What's new with the last 10 years of operation with the CERN SPS tetrode amplifiers?

Monday 9 September 2024 08:45 (25 minutes)

The talk will cover operation and operational aspects of megawatt CW tetrode amplifiers, summarizing the following topics:
- What are the typical faults and problems and their impact on availability.
- What do we need to do as preventive maintenance to reduce the down time in operation.
- What is the level of remote diagnostics and how much we can "fix remotely".
- What is a typical intervention time, what are typical interventions.
- What maintenance/operation activities we do regularly.
- How many people are needed to operate those, and what do they do on daily basis and in shutdowns, how to keep trained people for when we need them during technical stops.
- Availability and procurement strategy of spare parts, short and long term, obsolescence.
And of course, as it is the aim of the workshop, what have been the most impressive (and impacting) faults that occurred over the last decade.

Authors: MONTESINOS, Eric (CERN); CALVO, Sebastien Jerome (CERN)

Presenters: MONTESINOS, Eric (CERN); CALVO, Sebastien Jerome (CERN)

Session Classification: Session 1a

Track Classification: Gridded tubes

Contribution ID: **23** Type: **Talk**

Klystrons at CERN: operational experience and plans for the future

Tuesday 10 September 2024 14:25 (25 minutes)

Sixteen years after the circulation of the first beam in the LHC, Cern is preparing to upgrade the RF systems for the high luminosity LHC phase. This contribution will give an overview of the experience gained during operation of the LINAC4 and LHC klystron-based systems, and then describe the current status of the preparation for the upgrade which will be implemented during Long Shutdown 3 (LS3), planned from 2026 to 2028.

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Co-authors: CHAUCHET, Alan (CERN); NICOU, Christophe (CERN); SYRATCHEV, Igor (CERN); CATALAN LASHERAS, Nuria (CERN); Mr MARTINEZ YANEZ, Pablo (CERN); ALONSO ARIAS, Paz (CERN); GONZALEZ ANTON, Sergio (Staff Member)

Presenter: MARRELLI, Chiara (CERN)

Session Classification: Session 4a

Track Classification: Klystrons

Contribution ID: **24** Type: **Talk**

Status of the 400 kW Solid-State Power Amplifier Station at 352 MHz for the European Spallation Source (ESS)

Monday 9 September 2024 11:30 (25 minutes)

This paper discusses the current progress of the 400 kW Solid-State Power Amplifier operating at 352 MHz for the European Spallation Source (ESS), developed by ESS in collaboration with Uppsala University. It details the initial measurements of critical components, including the Solid-State Power Amplifier (SSPA) module, which has a nominal output power of 1.6 kW.

The ESS plans to align 26 SSPA stations to power the superconducting cavities, with each station delivering a pulsed power of 400 kW. Achieving this high power level requires the integration of at least 264 SSPA modules, each with a nominal output power of 1.6 kW.

A power combining strategy using cavity combiners is utilized, initially integrating 64 SSPAs to reach the 100 kW level, and for additional redundancy, 80 modules are considered. Four 100 kW units are then combined in a secondary stage using a progressive combiner to achieve the 400 kW output level.

The design emphasizes efficiency and compatibility, maintaining a footprint identical to the existing tetrode station at ESS, approximately 4 square meters. The system is expected to achieve a high wall plug efficiency exceeding 65% and will operate at a 10% duty cycle to meet the future requirements of the ESSnuSB project.

Author: Dr DANCILA, Dragos

Co-authors: MOHADESKASAEI, Seyed Alireza (Uppsala University); Mr LAGOGUEZ, Bruno (ESS); Mr MÖRK, Gustav (ESS); Mr MICIC, Slavisa (ESS); JENSEN, Morten (European Spallation Source)

Presenter: Dr DANCILA, Dragos

Session Classification: Session 1b

Track Classification: Solid state systems

Contribution ID: **25** Type: **Talk**

130 kW - 500 MHz Amplifiers Commissioning and Operation in Elettra

Monday 9 September 2024 10:40 (25 minutes)

In the framework of the low emittance high brilliance Elettra 2.0 project four 130 kW continuous way 500 MHz Solid State Amplifiers (SSA) have been installed and commissioned. These SSAs are already used for the RF plants in operation at Elettra having replaced the aged klystron and IOT based amplifiers. The Elettra user up time has improved since their placing in service providing a reliability check for the next Elettra 2.0 storage ring. The SSA assembly, commissioning and their features are presented here together with the reuse of the IOT based amplifier for the Booster operation

Author: Dr PASOTTI, Cristina (Elettra Sincrotrone Trieste S.C.p.A.)

Presenter: Dr PASOTTI, Cristina (Elettra Sincrotrone Trieste S.C.p.A.)

Session Classification: Session 1b

Track Classification: Solid state systems

Contribution ID: **26** Type: **Talk**

Spallation Neutron Source RF - Past, Present, and Future

Monday 9 September 2024 14:00 (25 minutes)

Operation of the Spallation Neutron Source (SNS) RF Systems provide a broad study of high-power equipment and sources including solid state amplifiers, tetrodes, klystrons, waveguide circulators and fundamental power couplers. While not unique to the SNS, over 20 years of operating at high average and peak powers have yielded insights to overcoming technical problems of interest to the wider accelerator RF community. The recent addition of new superconducting RF stations provides a good point in time to review the SNS operational experience, the lessons learned from that experience, and address the future of SNS RF.

Author: Mr MOSS, John (Oak Ridge National Laboratory)

Presenter: Mr MOSS, John (Oak Ridge National Laboratory)

Session Classification: Session 2a

Track Classification: Project reports, new projects

Contribution ID: **27** Type: **Talk**

Installation Of New Solid-State Amplifiers For CEBAF's Pass 5 Extraction Cavities

Wednesday 11 September 2024 08:40 (25 minutes)

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab initially delivered a 4 GeV electron beam simultaneously to three experimental halls. Through two major energy upgrades, it now delivers an 11 GeV beam to three halls and a 12 GeV beam to a fourth hall. These upgrades necessitated modifications to the Separation System, including increasing RF power, re-configuring the cavities, and upgrading the RF power amplifiers. An aging Inductive Output Tube (IOT) system and operational challenges prompted the installation of Solid-State Amplifiers (SSAs) to amplify the RF required for the 750 MHz cavity portion of the system. This presentation will discuss the operational challenges and the rationale behind selecting Solid-State Amplifiers for this application.

Authors: HOVATER, Curt; GELHAAR, David; FARRISH, Larry; SPATA, Mike; SHIN, Young-Min

Presenter: WISSMANN, Mark

Session Classification: Session 5a

Track Classification: Solid state systems

Contribution ID: **28** Type: **Talk**

Plan for 8kW and 13 kW Klystron Tests and Commissioning at CEBAF

Tuesday 10 September 2024 16:35 (25 minutes)

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab was upgraded to 12 GeV in 2014, necessitating the use of high-power klystrons. The C75 and C100 cryomodules, which enable the 12 GeV operation, are capable of achieving higher gradients and are powered by 8 kW and 13 kW klystrons, respectively. Over the past decade of operating at 12 GeV, we have observed a decline in power output due to issues with power supplies, mistuned cavities, and other hardware failures. At Jefferson Lab, klystron tubes can be diagnosed on a test stand designed for 8 kW and 13 kW tubes. We will present test stand results for selected tubes that exhibited lower than expected output power, including an attempt to retune a tube.

Author: GOMEZ, Xavier (Thomas Jefferson National Accelerator Facility)

Co-authors: VALENTINE, Evonda (Thomas Jefferson National Accelerator Facility); FARRISH, Larry (Thomas Jefferson National Accelerator Facility); HOLBEN, sam (Thomas Jefferson National Accelerator Facility); DAVIS, Tim; BAUMGARTNER, William (Thomas Jefferson National Accelerator Facility); SHIN, Young-Min (Thomas Jefferson National Accelerator Facility); NELSON, Rick (Thomas Jefferson National Accelerator Facility)

Presenter: GOMEZ, Xavier (Thomas Jefferson National Accelerator Facility)

Session Classification: Session 4b

Track Classification: Klystrons

Contribution ID: **29** Type: **Talk**

Bead-Pull Measurement and Re-tuning of SNS RFQ02

Wednesday 11 September 2024 16:35 (25 minutes)

To support the reliable operation, there have been three RFQs developed at SNS. SNS RFQs are 4-vane type structures designed to accelerate H- beam from 65 keV to 2.5 MeV with estimated transmission efficiency above 90%. The RFQ02 was installed to the SNS Front End and started operating for beam production in 2018. After a few years of operation, field tilts were observed in all four quadrants with pickup probe measurements, and beam transmission reduced by about 20%. It was swapped out from SNS Front End with the new RFQ (RFQ03) in March 2023. Bead-pull measurements and re-tuning were performed on the RFQ02 before it was moved to the Beam Test Facility (BTF) as a ready spare. A bead-pull system with Arduino UNO was developed at SNS for the RFQ tuning at low RF power. The tuning algorithm was developed utilizing the superposition of the perturbations caused by the slug tuners to minimize the field profile difference as well as the frequency deviation compared to the designed value. The bead-pull was performed with the RFQ02 in air, so frequency corrections for the effects of air permittivity and atmospheric pressure were considered in the retuning based on CST Microwave Studio calculations. The final bead-pull measurement after re-tuning shows the magnetic field difference between quadrants is less than 0.6%. The resonance frequency under vacuum was 402.525 MHz (target value 402.5 MHz). The detailed results of the re-tuning will be presented.

Author: Dr REN, Haitao (Oak Ridge National Laboratory)

Co-authors: MOSS, John (Oak Ridge National Laboratory); KIM, Sang-Ho (Oak Ridge National Laboratory); LEE, Sung-Woo (Oak Ridge National Laboratory); GEORGE, Toby (Oak Ridge National Laboratory)

Presenter: Dr REN, Haitao (Oak Ridge National Laboratory)

Session Classification: Session 6b

Track Classification: Other

Contribution ID: **30** Type: **Talk**

Enhanced RF Window Monitoring and Protection at the Spallation Neutron Source*

Tuesday 10 September 2024 09:05 (25 minutes)

The Spallation Neutron Source (SNS) is implementing camera-based systems to enhance the reliability of high-power RF vacuum windows in its Drift Tube Linac (DTL) and Coupled Cavity Linac (CCL) sections. In the DTL, a high-speed camera will detect electron glow discharges sometimes associated with multipacting, a critical issue leading to window damage. This effort is part of a broader project to address multipacting and improve overall window performance. For both the DTL and CCL sections, infrared cameras will monitor ceramic window temperatures. A recent cooling system failure resulted in excessive temperatures and a CCL window failure, highlighting the need for this system. Both camera-based systems are under development, with initial results showing promise for improved window operation and protection.

Authors: TOBY, George (Oak Ridge National Laboratory); Dr REN, Haitao (Oak Ridge National Laboratory); Mr MOSS, John (Oak Ridge National Laboratory); KIM, Sang-ho (SNS/ORNL); LEE, Sung-Woo (Oak Ridge National Laboratory); Mr MINER, Timothy (Oak Ridge National Laboratory)

Presenter: TOBY, George (Oak Ridge National Laboratory)

Session Classification: Session 3a

Track Classification: Power transmission and distribution

Contribution ID: **31** Type: **Talk**

RF Conditioning Operations and System Updates of the High-Power RF Test Facility in the Spallation Neutron Source

Tuesday 10 September 2024 17:00 (25 minutes)

The conditioning of RF components and their proper storage are crucial for stable and reliable Linear Accelerator (LINAC) operation. The Radio-Frequency Test Facility (RFTF) was built to test the RF subsystems and to condition the RF windows and couplers of the LINACs at the Spallation Neutron Source (SNS). It consists of two waveguide systems operating at 402.5 MHz and 805 MHz, powered by klystrons rated up to 5 MW peak power at 8% duty cycles. The system utilizes the High Power Protection Module (HPM) for interlocks from vacuum and arc detection. A Python EPICS control software and the CS-Studio (Phoebus) user interface were developed and implemented to automate and optimize the conditioning process, providing real-time monitoring of RF power levels, temperature, and vacuum pressure. The system has been used for evaluating, testing, and conditioning the klystrons, circulators, and SRF couplers for the Proton Power Upgrade (PPU) project. This presentation introduces the RF conditioning system updates through software developments and hardware upgrades made at the SNS RFTF and discusses the utilization of the system for the PPU projects at SNS.

Author: LEE, Sung-Woo (Oak Ridge National Laboratory)

Co-authors: TOBY, George (Oak Ridge National Laboratory); Dr REN, Haitao (Oak Ridge National Laboratory); NOT SUPPLIED, John ds.LDAP.sn (Oak Ridge National Laboratory); MINER, Timothy (Oak Ridge National Laboratory)

Presenter: LEE, Sung-Woo (Oak Ridge National Laboratory)

Session Classification: Session 4b

Track Classification: Power transmission and distribution

Contribution ID: **32** Type: **Talk**

Klystron Commissioning Experience at ESS

Tuesday 10 September 2024 14:50 (25 minutes)

The commissioning of klystron systems for the first phase of the European Spallation Source with an average power capability of a 2MW beam on target is complete. More than 70 site acceptance tests of high power pulsed klystrons have been carried out over the last years. This talk will describe some of the difficulties experienced during on-site testing and the technical solutions developed and implemented in partnership with the klystron manufacturers.

Author: Dr KRÄMER, Patrick (European Spallation Source ERIC)

Presenter: Dr KRÄMER, Patrick (European Spallation Source ERIC)

Session Classification: Session 4a

Track Classification: Klystrons

Contribution ID: **33** Type: **Talk**

THE INTERLOCK SYSTEMS FOR HIGH POWER RF SSA SYSTEMS AT ARGONNE APS AND ATLAS

Wednesday 11 September 2024 11:15 (25 minutes)

Currently, the radiofrequency (RF) power source to the Argonne Advanced Photon Source (APS) storage ring is under an upgrade from several 1 MW klystrons to solid state amplifiers (SSAs). It is very important to have new interlock systems ready for the new SSA systems. This presentation shares our experience on a new machine protection system (MPS) subsystem development. Other interlock subsystems including personal safety system, programmable logic controller (PLC), accelerator access & interlock systems and power monitor interlock will be discussed briefly too. Some experience of newly developed facility radiation safety interlock system, high voltage and water interlock system for superconducting cavities at Argonne Tandem Linac Accelerator System (ATLAS) is also presented.

Author: LUO, Yong

Co-authors: GOEL, Aditya (Argonne National Lab); NASSIRI, Alireza; POPOVIC, Branko (Argonne national lab); HORAN, Douglas (Argonne National Laboratory); TRENTO, Gianfranco (Argonne National Laboratory); MADDEN, Tim (Argonne national lab)

Presenter: LUO, Yong

Session Classification: Session 5b

Track Classification: Control, interlocks, safety

Contribution ID: **34** Type: **Talk**

PRESENT DAY RF GROUP POWER SYSTEMS AT THE ADVANCED PHOTON SOURCE

Tuesday 10 September 2024 11:40 (25 minutes)

The Advanced Photon Source (APS) user facility began operation by delivering first x-ray on March 26, 1995. Over the many years, the RF Group maintains and improves four different types of rf powers systems. One system consists of a high-power pulsed klystron within the Linear Accelerator (LINAC), two different types of rf power systems within the Positron Accumulator Ring (PAR), and a Booster and Storage Ring klystron power system. Beginning with the LINAC, the 2.856GHz modulator system is currently under the third upgrade iteration, with the second upgrade equipment still in operation since 1999. The PAR's 9.77MHz CW fundamental amplifier commenced operation some 28 years ago and the pulsed 117MHz harmonic amplifier system introduced solid-state operation in 2021. Then 352MHz Booster and Storage Ring klystron power supply systems supported operation since the start of the APS. This talk will focus on the description of the RF Group's present power supply systems, performance upgrades, and reliability. Plus, hardware failures will be mentioned.

Author: TRENTO, Gian (Argonne National Laboratory)

Co-authors: MEYER, David (Argonne National Laboratory); SMITH, Terry (Argonne National Laboratory)

Presenter: TRENTO, Gian (Argonne National Laboratory)

Session Classification: Session 3b

Track Classification: Project reports, new projects

Contribution ID: **35** Type: **Talk**

Commissioning of the Linear IFMIF Prototype Accelerator High-power CW RF system

Wednesday 11 September 2024 14:25 (20 minutes)

The Linear IFMIF Prototype Accelerator (LIPAc) is a validation and test facility for the injector and the initial low-energy part of the IFMIF accelerator, designed to study a 125 mA-CW deuteron beam driver of the neutron source for the fusion materials examination. The RF section of the accelerator comprises three elements: a 9.8 m-long RFQ designed to extract a 5 MeV bunched beam accelerated from a 100 keV coasting beam, two re-buncher cavities, and eight superconducting half-wave resonators, which accelerate the beam up to 9 MeV. The beam commissioning has been conducted by incrementally increasing the duty cycle from the chopped to the raw extracted pulses. To date, in the intermediate construction phase of the design model, where the superconducting cryomodule has been replaced with a quadrupole beam transport line, we reached a duty cycle of 8.75 % for the 116 mA deuteron beam. This work presents an overview of the RF system, including a discussion of the challenges encountered during the commissioning periods. In particular, it will address the following points: the stability of the tetrode amplifier system, the impact of dissipation in the circulators, and the impact of beam cavity interaction in the RFQ as a resonator driven by eight RF stations.

Author: HIROSAWA, Kouki (QST)

Co-authors: Dr DE FRANCO, Andrea (QST); SCANTAMBURLO, Francesco (F4E); MOYA MARTINEZ, Ivan (F4E); ADAM, Jean-Pierre (CEA); Dr GONZÁLEZ-GALLEGO SÁNCHEZ-CAMACHO, Luis (IFMIF-DONES España, EUROfusion); Mr KUBO, Naoya (QST); INTEGRATED PROJECT TEAM, the IFMIF/EVEDA (QST, F4E, IFMIF-DONES España, EUROfusion, CEA, INFN, CIEMAT, the IFMIF/EVEDA project team)

Presenter: HIROSAWA, Kouki (QST)

Session Classification: Session 6a

Track Classification: Project reports, new projects

Contribution ID: **36** Type: **Talk**

Direct Cavity Combiner

Tuesday 10 September 2024 15:15 (25 minutes)

Ion Cyclotron Range of Frequencies (ICRF) have been demonstrated in reactor-grade plasmas to be effective at plasma heating and central current drive, which are necessary to initiate and maintain controlled fusion reactions. For high magnetic field fusion devices 60-240 MHz systems are envisioned, which are ideal for solid state devices.
Diversified Technologies, Inc. (DTI) is building a novel, patented, Direct Cavity Combiner (DCC) VHF Transmitter in a single high power (megawatt-class), compact (2 meter diameter), and efficient (>65%) amplifier under a Department of Energy Small Business Innovative Research (DOE SBIR) grant . The DCC directly combines the RF output of each solid state transistor into a resonant cavity. The low impedance of each transistor output is directly connected to a magnetic coupling loop inside the large cavity. There are no impedance transformers, circulators, cables or connectors in the RF combining stage. DTI has demonstrated this modular DCC solid state transmitter technology previously at L-band and UHF and will develop and produce a low-cost, steady state, solid state megawatt VHF transmitter for RF applications. This technology is an alternative to conventional megawatt-class Vacuum Electron Devices (VED) RF sources and overcomes the limited frequency range, reliability, and supply chain issues associated with tetrodes and similar VEDs. The DCC transmitter can reduce the cost of high-power RF for fusion and similar applications. The basic transmitter technology can be readily tailored over a wide range of frequencies which makes it applicable in a wide range of applications, including high power microwaves, high energy physics, radar, and broadcasting. Of course, other VHF transmitter applications are also possible.
The RF cavity and transistor modules have been fabricated and are presently undergoing testing and evaluation to compare the amplifier performance to that predicted by the design simulations and calculations at 120 MHz operation. In this paper, DTI will report on the design and test results of the RF cavity and modules (>1.3 kW per module) at 120 MHz (approximately the center of the ICRF band).

Authors: POTHIER, Brad (Diversified Technologies, Inc.); Dr COPE, David (Diversified Technologies, Inc.); QUINLAN, Kathleen (Diversified Technologies, Inc.); Dr GAUDREAU, Marcel (Diversified Technologies, Inc.); KEMPKES, Michael (Diversified Technologies, Inc.); LEWIS, Slade (Diversified Technologies, Inc.)

Presenter: QUINLAN, Kathleen (Diversified Technologies, Inc.)

Session Classification: Session 4a

Track Classification: Power transmission and distribution

Contribution ID: **37** Type: **Talk**

Overview of Tetrode-Based RF System for High-Power Plasma Heating Operation in the 4-9 MHz Range for the MPEX Project at ORNL

Monday 9 September 2024 11:05 (25 minutes)

The MPEX (Material Plasma Exposure Experiment) project at ORNL requires a high-power RF system to operate in the challenging frequency range of 4-9 MHz, essential for sustaining plasma needed in material testing. A tetrode-based RF system has been chosen for this application due to its superior performance in generating high power RF across these frequencies. Unlike solid-state RF systems, which face significant challenges in combining to a power level of 500kW within this frequency range, tetrode-based systems excel due to their inherent ability to handle large power loads. The tetrode's vacuum tube technology allows for greater tolerance to impedance mismatches and load variations, which are common in plasma environments. Additionally, tube-based systems can deliver the necessary high peak and average power without the thermal management complexities that solid-state systems encounter at similar power levels. The robustness, reliability, and long operational life of tube-based RF systems make them not only still competitive but sometimes the only viable technical solution for demanding applications like MPEX, where consistent high power across a broad frequency range is critical. These advantages ensure that tube-based RF technology remains a cornerstone in high-power RF applications.

Author: FRITSCHE, Bodo

Presenter: FRITSCHE, Bodo

Session Classification: Session 1b

Track Classification: Gridded tubes

Contribution ID: **38** Type: **Talk**

LANSCE CCL klystron reliability, evaluation, and path forward

Wednesday 11 September 2024 11:40 (25 minutes)

The reliability of Los Alamos Neutron Science Center (LANSCE) 805MHz klystrons used for powering the CCL will be examined and data presented on service hours, post re-build performance and failure points. Reliability and performance of today's klystrons will be compared with historical data and our current evaluation process will be discussed. Foreseeable problems with current capabilities will be discussed and possible solutions for improving LANSCE CCL will be examined.

Author: WAGHMARE, Aditya (los alamos national laboratory)

Co-authors: LYLES, John; BRADLEY, III, Joseph (Los Alamos National Laboratory)

Presenters: WAGHMARE, Aditya (los alamos national laboratory); LYLES, John; BRADLEY, III, Joseph (Los Alamos National Laboratory)

Session Classification: Session 5b

Track Classification: Klystrons

Contribution ID: **39** Type: **Talk**

Design and Testing of Solid State Amplifier for the FRIB RFQ

Wednesday 11 September 2024 14:45 (25 minutes)

FRIB is commissioning a 120 kW, 80.5 MHz solid-state RF amplifier for the RFQ cavity to increase overall system availability. Although reliability of the tetrode amplifier was greatly improved during commissioning and early operations, some potential failures may have long repair times. In contrast, solid-state amplifiers have shorter repair time due to the modular design and no high voltage. The RFQ solid state amplifier will use the same technology as FRIB linear segment 1, which reduces the effort for development of new controls and maintenance procedures, and allows sharing of spares. Each of the eight racks includes six amplifier modules for a total of 15 kW per rack; and the system uses 3 dB hybrid couplers in a 3-stage corporate power combining scheme to achieve 120 kW. The paper will describe the RFQ solid-state amplifier design and commissioning; as well as other 2-way and 3-way combined amplifier systems at FRIB.

Author: GUTIERREZ, Eleazar T (Radio Frequency Engineer)

Co-authors: Mr MORRIS, Dan; Mr BERNAL-RUIZ, Enrique; Mr ZHAO, Shen

Presenter: GUTIERREZ, Eleazar T (Radio Frequency Engineer)

Session Classification: Session 6a

Track Classification: Solid state systems

Contribution ID: **40** Type: **Talk**

Status of the HIPA Injector 2 upgrade at PSI

Wednesday 11 September 2024 09:05 (25 minutes)

The Paul Scherrer Institute (PSI) is upgrading its High Intensity Proton Accelerator (HIPA) facility to enhance beam power and improve reliability. As part of this effort, the upgrade of the RF system for the Injector 2 cyclotron began several years ago. To increase the energy gain per turn, the two 150 MHz flattop cavities were replaced by higher-voltage 50 MHz aluminum cavities. New frequency tuners resolved initial mechanical issues, ensuring optimal operation of the setup. The upgrade program also includes replacing the old LLRF and amplifier system for all four resonators. Measurements with Resonator 2 in 2023 confirmed the desired higher beam acceleration characteristics, and since June 2024, the new Resonator 2 has been used for regular beam operation.
After an unrepairable failure of the very old 150 MHz amplifier for Resonator 4, two 10 kW SSAs were combined in 2023 to enable a setup for 2 mA beam current using three resonators. Following the successful tests with the new Resonator 2 in 2023, the new Resonator 4 was installed in the cyclotron this year. The installations for the LLRF and amplifiers are currently in progress and will undergo testing during 2024.
This talk summarizes the latest progress in the PSI Injector 2 upgrade project, emphasizing the technical and operational challenges.

Author: SCHNEIDER, Markus

Presenter: SCHNEIDER, Markus

Session Classification: Session 5a

Track Classification: Project reports, new projects

Contribution ID: **41** Type: **Talk**

Overview of the SNS Ring RF Systems and Recent Work

Monday 9 September 2024 09:35 (25 minutes)

The Spallation Neutron Source (SNS) facility at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN, USA completed the proton power upgrade (PPU) project in 2024 and is operating with 1.7 MW of beam power on target (August 2024). A ˜1 ms long H- beam pulse produced by the RF-driven SNS Front-End Ion Source is accelerated to 1.3 GeV in the SNS linear accelerator (linac) and transported to the injection region of the SNS accumulator ring. The SNS operates with a 60 Hz beam pulse repetition rate (60 Hz x ˜ 1 ms = ˜ 6% duty cycle).
Beam is injected into the accumulator ring via the charge exchange process which uses stripping foils to remove the electrons from the H- beam (proton plus two electrons), thereby converting the H- beam into a proton beam. It takes ˜ 900 ns for 1.3 GeV protons to travel once around the ˜ 248 m circumference SNS proton accumulator ring, the "turn time" is then ˜ 900 ns and the ring revolution frequency is then 1 / turn time = ˜ 1.1 MHz. Four dual-gap ferrite loaded RF cavities in the RF section of the SNS accumulator ring are operated at either the fundamental ring revolution frequency (˜1.1 MHz) or the second harmonic frequency (˜2.2 MHz) to maintain a ˜ 250 ns gap in the accumulated proton beam which is required for clean extraction of beam from the ring and also to suppress the peak current in the center of the proton beam bunch. This presentation will provide an overview of the SNS Ring RF systems and some recent work which includes impedance matching improvements to the second harmonic Ring RF power amplifier input circuits, replacement of the cavity tuning power supplies, and a look at cavity tuning vs. beam loading effects.

Authors: NARAYAN, Amith (ORNL); VESTAL, Carter (ORNL); PILLER, Chip (ORNL); HEIDENREICH, Dale (ORNL); MOSS, John (Oak Ridge National Laboratory); RUPP, Louis (ORNL)

Presenter: PILLER, Chip (ORNL)

Session Classification: Session 1a

Track Classification: Project reports, new projects

Contribution ID: **42** Type: **Talk**

Recent Experience with the SNS Ion Source 2 MHz Tube and Solid State RF Systems

Wednesday 11 September 2024 09:30 (25 minutes)

The Spallation Neutron Source (SNS) facility at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN, USA completed the proton power upgrade (PPU) project in 2024 and is operating with 1.7 MW of beam power on target (August 2024). The RF-driven SNS Ion Source produces a ˜ 1 ms long H- beam pulse at a 60 Hz pulse repetition rate. The SNS Ion Source utilizes a dual RF system to ignite and maintain a low intensity CW 13.56 MHz plasma (˜ 300 W) and to generate a high intensity pulsed 2 MHz plasma (˜ 50 kW, 1 ms, 60 Hz). The SNS Ion Source provides a challenging environment for the 2 and 13.56 MHz RF systems which includes HV power supplies (up to 65 kV) and stored energy. Three separate H- Ion Sources are used at the SNS facility; the Front-End production system, the Ion Source Test Stand system, and the Beam Test Facility system. Two different types of pulsed 2 MHz 80 kW RF power amplifiers have been used with the SNS H- Ion Sources; an older tetrode tube unit and a more recent solid state design. This presentation will discuss recent operational experience and lessons learned with the SNS Ion Source tube and solid state 2 MHz RF systems.

Authors: NARAYAN, Amith Hulikal (ORNL); VESTAL, Carter (ORNL); PILLER, Chip (ORNL); STINSON, Chris (Oak Ridge National Laboratory); HEIDENREICH, Dale (ORNL); MOSS, John (Oak Ridge National Laboratory); RUPP, Louis (ORNL)

Presenter: PILLER, Chip (ORNL)

Session Classification: Session 5a

Track Classification: Gridded tubes

Contribution ID: **43** Type: **Talk**

NSLS-II Klystron Transmitters

Monday 9 September 2024 09:10 (25 minutes)

Brookhaven National Lab's NSLS-II storage ring currently utilizes two 310kW Klystron Transmitters and one 310kW Solid State Amplifier (SSA) to support its operations. Each Klystron Transmitter is comprised of a 310kW klystron, a 50 kV cathode power supply, several commercially available power supplies along with controls and interlock systems. These Klystron Transmitters have been in operation since 2012 (operational statistics will be presented) and are now facing end of life issues including klystron failures and control system obsolescence/ unavailable spares. An upgrade involving new klystron spares and an updated controls system was investigated- it was determined the complete replacement of one klystron transmitter with a new solid-state amplifier was a more cost effective and reliable approach. This approach also yields a full complement of spare components (klystrons, power modules, etc.) for the remaining Klystron Transmitter.

Author: MONTELEONE, Michael

Co-authors: HOLUB, Brian (Brookhaven National Laboratory); ROSE, James; BORGER, Roger

Presenter: MONTELEONE, Michael

Session Classification: Session 1a

Track Classification: Klystrons

Contribution ID: **44** Type: **Talk**

CWRF Workshop BNL Abstract –Solid State Amplifier Two Design and Implementation

Wednesday 11 September 2024 15:10 (25 minutes)

The NSLS-II particle accelerator at Brookhaven National Laboratory currently incorporates three transmitters, with two 310 kW klystron transmitters and one 310 kW solid state amplifier (SSA) each powering a single superconducting RF cavity. A second solid-state amplifier is being fabricated in industry to replace one of the klystron transmitters, within the next year. Based on lessons learned from the first SSA, a new architecture for the transmitter is being developed, which will incorporate a waveguide combiner and other improvements. The new design will interface with the previous transmitter's infrastructure such as AC power, utilities/waveguide systems, etc. The new design will interface with the previous transmitters infrastructure such as AC power, utilities/waveguide systems, etc.

Author: BORGER, Roger

Co-authors: HOLUB, Brian (Brookhaven National Laboratory); MARQUES, Carlos (Brookhaven National Laboratory); ROSE, James; MONTELEONE, Michael

Presenter: BORGER, Roger

Session Classification: Session 6a

Track Classification: Solid state systems

Contribution ID: **45** Type: **Talk**

NSLS-II Operations Experiences with our 310 kW Solid State Amplifier

Tuesday 10 September 2024 09:30 (25 minutes)

In the spring of 2021 NSLS-II commissioned the project's first SSA high power transmitter (310 kW CW) to complement the two existing 310 kW klystron-based transmitters which had been in use since 2012. This presentation will present the technical performance of the system as well as detail the hardware and software failures that occurred and the resulting downtime accumulated over the past three years. A comparison of the reliability of the SSA vs the Klystron units will also be shown over this time period. Finally, there will be a discussion on the lessons learned including things we would do differently in the next generation design (See R. Borger et al, these proceedings).

Author: HOLUB, Brian (Brookhaven National Laboratory)

Co-authors: Mr MARQUES, Carlos (BNL); Mr GAO, Feng (BNL); ROSE, James; MONTELEONE, Michael; BORGER, Roger

Presenter: HOLUB, Brian (Brookhaven National Laboratory)

Session Classification: Session 3a

Track Classification: Solid state systems

Contribution ID: **46** Type: **Talk**

Testing and Improvements on the 27 MHz RF System for plasma generation at the Spallation Neutron Source

Monday 9 September 2024 16:40 (25 minutes)

The Spallation Neutron Source at Oak Ridge National Laboratory utilizes a dual RF system for H^- beam generation, where a continuous wave (CW) 300-450 W 13 MHz RF initiates a low-density plasma that is subsequently enhanced by a pulsed 60 kW 2 MHz RF to achieve high-density plasma. Recently, we have tested a new pulsed 50-150 W 27 MHz RF on the Ion Source Test Stand to replace the CW 13 MHz RF, offering benefits such as lower peak and average power and reduced gas flow requirements for plasma generation. To enhance the performance and reliability of the pulsed 27 MHz RF system, we are testing power amplifiers that can better handle reflected power, building a new isolation transformer with a better match and lower insertion loss, designing a matching network specifically for impedance matching at 27 MHz, and implementing a high-pass filter chassis to prevent impedance mismatch issues. These advancements and their implications for production runs will be discussed in this workshop.

Authors: NARAYAN, Amith Hulikal (Oak Ridge National Laboratory); PILLER, Chip (ORNL); RUPP, Louis (ORNL); CARTER, Vestal; HEIDENREICH, Dale (ORNL); Mr STINSON, Chris (Oak Ridge National Laboratory); WELTON, Rob; HAN, Baoxi; ANDZULIS, Vic; TERSZAKOWEC, Greg

Presenter: NARAYAN, Amith Hulikal (Oak Ridge National Laboratory)

Session Classification: Session 2b

Track Classification: Project reports, new projects

Contribution ID: **47** Type: **Talk**

Modifications of the Storage Ring RF systems to support APS-U

Monday 9 September 2024 16:15 (25 minutes)

The klystron based RF systems for the APS storage ring were recently modified to support the MBA based lattice of APS-U. This involved both the high and low power components of the RF systems. Discussed are the some technical details, challenges faced, and the lessons learnt.

Author: GOEL, Aditya (Argonne National Lab)

Presenter: GOEL, Aditya (Argonne National Lab)

Session Classification: Session 2b

Track Classification: Project reports, new projects

Contribution ID: **48** Type: **Talk**

Ten Years of RF Operation with the TH628L Diacrode at LANSCE

Monday 9 September 2024 14:25 (25 minutes)

Los Alamos Neutron Science Center started developing a replacement RF powerplant for the 100 MeV drift tube linac over twenty years ago, as there were lifetime issues with high duty factor (12% DF) operation using the RCA/Burle/Photonis 7835 power triode at 200 MHz. Cathode emission failures were predominantly happening at LANSCE at high average power, as 200 MHz injector linacs at BNL and FNAL run at much lower DF. In 2006, LANSCE reduced beam power to half DF, going from 120 Hz to 60 Hz repetition rate, and remained in that mode to survive until the replacement system was tested, commercialized and installed 8 years later. Prototyping began with test stand construction in 2009, with a LANL-built cavity amplifier working in 2011. This was followed by commercial production of 7 power amplifiers built-to-print with installation in three outages in 2014-2016. The linac returned to full DF in 2014. As the only linac using this tube from Thales, we took a risk with a new tube development at the time. In the subsequent decade of operation, the choice of the Thales TH628L has proven to be a wise decision as four tubes have exceeded 55K hours in operation, with two more with slightly less. Reliability of the amplifiers and supporting infrastructure has exceeded expectations. This talk will discuss details of this work, and share insights on using modern tetrode technology for an old linac.

Work was performed under the auspices of the US Department of Energy by Triad National Security, LLC, under contract 89233218CNA000001.

Authors: ROYBAL, G. (LANL); SANDOVAL, G. (LANL); LYLES, John; SANCHEZ BARRUETA, Maria (Los Alamos National Laboratory); BRATTON, R. (LANL); W. HALL, Thomas (Los Alamos National Laboratory)

Presenter: LYLES, John

Session Classification: Session 2a

Track Classification: Gridded tubes

Contribution ID: **49** Type: **Talk**

High Power RF Test Facilities at FNAL

Wednesday 11 September 2024 17:00 (25 minutes)

Fermilab's PIP-II project seeks to enhance its proton beam capabilities for scientific research by modifying the existing synchrotrons and replacing the linear accelerator with a superconducting linear accelerator. To mitigate risks in technology readiness and prepare for operational maintenance, test stands of various complexities were built. Many of the RF components, subsystems, and systems have been tested further reducing risk. The conversion of the former Tevatron RF gallery into a test area has allowed for 162.5MHz and 650MHz circulator, SSA, and amplifier module testing. In the RF test cave for warm cavities, both the prototype dual-tetrode 52-53MHz and prototype 30-53MHz ferrite loaded cavities were fully characterized. At the single cavity SRF test cave, individual SRF cavities continue to be tested individually before string assembly. The PIP-II Injector Test (PIP2IT) facility was used to successfully test the Linac components with beam up to 10MeV. These tests included the 162.5MHz RFQ, buncher cavities, eight-cavity half wave resonator cryomodule (HWR), and the 325MHz eight-cavity prototype single spoke resonator cryomodule (pSSR1). After its beam run, this facility was converted into the test bed for all future 325MHz and 650MHz cryomodules. All of these test facilities will be utilized for quality control testing and the advancement in the TRL of key high-risk technologies.

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