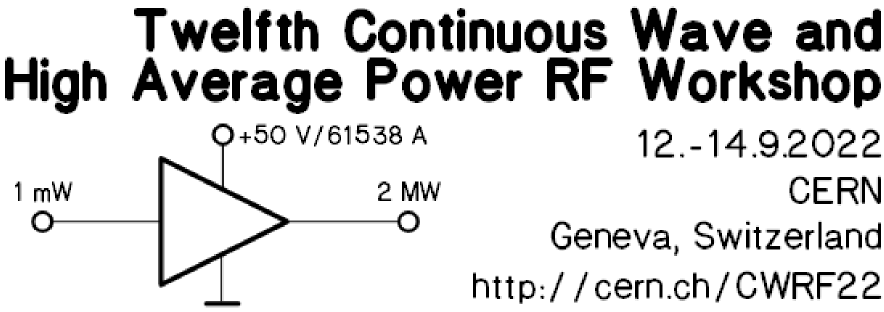
Twelfth CW and High Average Power RF Workshop

Sunday, 11 September 2022 - Thursday, 15 September 2022

CERN



Book of Abstracts

Contents

Miscellanea / 3

Is it possible to simplify the RF system of a multi-port cavity? The case of the NEWGAIN RFQ.

Author: Marco Di Giacomo[1]

[1] *CEA-GANIL*

Corresponding Author: marco.digiacomo@ganil.fr

Multiport RFQ of several projects are powered by complex systems with several LLRF in master-slave configuration. No body seems promoting the architecture of parallel chains simply combined into the cavity, though this is commonly used in RF commercial amplifiers. The presentation aims at rising a discussion on the reasons of these complex architectures.

Industrial presentations / 4

High Stability Klystron Modulator for Commercial Accelerator Application

Authors: Marcel Gaudreau[1]; Michael Kempkes[None]

[1] *Diversified Technologies, Inc.*

Corresponding Authors: kempkes@divtecs.com, gaudreau@divtecs.com

Diversified Technologies, Inc. (DTI) designed and developed a high stability modulator system for a commercial linear accelerator application. The DTI modulator delivers significant advantages in klystron performance through highly reliable functionality as well as flicker- and droop-free operation from 50-500 μs up to 400 Hz (duty limited). The main assemblies on the DTI system consist of a controls rack, high voltage power supply
(HVPS), modulator, and cooling manifolds for the modulator, high voltage power supply and klystron tube.
Two HVPS (upgradeable to four) provide stable and accurate DC voltage which is used to drive a CPI VKP - 8352C UHF-band pulsed klystron for the linear
accelerator. A solid state series switch, based on DTI's patented design, provides both pulse control and arc protection to the klystron. Operating with four HVPS, the DTI modulator is able to operate at a maximum average power of ~750 kW at 105 kV, 47 A nominal.

High Power RF systems Status and Operating Experience #2 / 5

Addition of a 3rd 500MHz system to NSLS-II

Author: James Rose[None]

Corresponding Author: rose@bnl.gov

The NSLS-II light source has been operating since 2015 with two 500 MHz Superconducting cavities fed by Klystron based amplifiers providing in up to 1.8 MV of accelerating gradient and up to 310kW of RF power per system. A third 500 MHz system project was completed and installed in 2021 consisting of a superconducting cavity assembled in-house and a 320 kW cavity combined Solid State amplifier designed and built in industry.The project included a significant upgrade of the cryogenic helium distribution system to bring LHe to the new cavity location in a second RF straight. The details of the new system will be described along with our experience in commissioning and with user operations over the past 16 months with the new systems.

Solid state amplifiers #2 / 8

310 kW Solid State CW RF Amplifier for the NSLS-II Third RF System

Author: Brian Holub[1]

[1] *Brookhaven National Laboratory*

Corresponding Author: bholub@bnl.gov

The National Synchrotron Light Source II (NSLS-II) Storage Ring was originally commissioned in 2014 with two 310 kW CW Klystron transmitters supplying their respective cavities with RF power. Late in 2017 the process of procuring a third RF 310 kW CW transmitter for the Storage Ring was started. Proposals from multiple vendors offering both Klystron and Solid-State Amplifier (SSA) solutions were all considered with the contract being awarded to purchase a Solid-State Amplifier. There were many bumps in the road along the way to a successful Site Acceptance Test and completion of commissioning which were both accomplished in April of 2021. This paper will detail some of the pitfalls which were encountered along the way as well as demonstrating some of the superior technical performance specifications that can be achieved with this technology.

New projects / 9

High Power RF for the EIC

Author: Alex Zaltsman[None]

Corresponding Author: zaltsman@bnl.gov

Brookhaven National Laboratory's future Electron Ion Collider (EIC) will be a complex system of accelerators providing high-luminosity, high-polarization, variable center-of-mass energy collisions between electrons, and protons or ions. The EIC requires over 70 RF cavities requiring more than 90 high-power RF amplifiers, with 34 of them of 400 kW CW. We will describe the EIC's high-level system parameters, needs and how we are addressing them in this presentation.

Solid state amplifiers #1 / 10

CERN SPS RF SSPA, from design to operation

Author: Eric Montesinos[1]

[1] *CERN*

Corresponding Author: eric.montesinos@cern.ch

Within the frame of our LHC Injector Upgrade program, CERN decided to build two new amplifiers of 2 MW cw operating at 200 MHz. These amplifiers are based on Solid State technology, and use Cavity Combiner systems to reach the required power levels. Availability being the key word with respect to beam operation, the amplifier architecture choices will be explained. After a review of the challenges we had to face during the design phase of this new amplifiers, the difficulties of such a large production, as well as the commissioning and the performances obtained during the first years will be presented. With respect to global efficiency, hints to improve the wall-plug efficiency with a large RF amplifier will also be proposed.

Facility status reports #1 / 11

Status and Operation of the ALBA RF System and developments for ALBA-II

Author: Jesús Ocampo[None]

Co-authors: Agustín Gómez [1]; Francis Perez ; Ignasi Bellafont [1]; Joan Revoltós [1]; Pol Solans

[1] *CELLS - ALBA Synchrotron*

Corresponding Author: jocampo@cells.es

ALBA is a 3rd generation 3 GeV synchrotron light source located in Barcelona, Spain. The RF system of the Storage Ring provides 3 MV of accelerating voltage with six 500 MHz HOM-damped cavities fed by two 80 kW IOTs each. The Booster RF system comprises a 50 kW SSPA and a 5 cell PETRA cavity. This presentation describes the performance of these systems and the upgrades performed in the last years. The future plans for the ALBA-II accelerator upgrade towards 4th generation are also presented, including the test results on the normal conducting active 3rd harmonic cavity prototype as well as the performance of the 1.5 GHz Digital LLRF and a 5 kW 1.5 GHz GaN SSPA prototype.

Facility status reports #1 / 12

ESRF RF system for the new ultra low emittance machine EBS: performance and upgrade projects

Author: Jorn Jacob[None]

Co-authors: Alessandro D'Elia [1]; Georges Gautier [1]; Pawel Borowiec [1]; Vincent Serrière [1]

[1] *ESRF*

Corresponding Author: jacob@esrf.fr

After 25 years of service to users, the world's first 3rd generation storage ring light source at the ESRF was shut down in December 2018 to leave the space for the first high energy 4th generation ultra low emittance ring, the Extremely Brilliant Source EBS. The new machine was started as scheduled in December 2019 and fully commissioned by the end of February 2020. Service to users was resumed as planned end of August 2020 after beam line commissioning. For the new machine the five-cell LEP type cavities were replaced with 13 in house developed strongly HOM damped cavities. Thanks to reduced dipole radiation, only one of the two remaining klystron transmitters and the three existing Solid State Amplifiers (SSA) are required to power the new ring and still provide operational redundancy. The upgraded 352 MHz RF system was fully operational and very reliable from day zero, and nominal beam current of 200 mA could be stored in record time. Yet a number of projects are underway to further improve the EBS RF system.
In 2021 a call for tender for the procurement of ten 110 kW SSA was launched and, after selection among six received offers, a contract was signed with JEMA France. The now already 30 years old klystron transmitters will definitely be shut down after the connection of the last cavity to its SSA end of 2026. Furthermore an active 4th harmonic RF system at 1.41 GHz is under study for bunch lengthening in order to increase the Touschek lifetime, minimize intrabeam scattering and reduce impedance heating mainly when the ring is operated with high currents per bunch. Normal conducting harmonic cavities are being developed at the ESRF.

Industrial presentations / 13

Solid State amplifiers up to 350kW

Authors: Carlos Rosa[None]; Eduardo Ugarte[None]

Corresponding Author: c.rosa@btesa.com

In 2015 BTESA manufactured its first Solid State CW RF Amplifier (SSA) for Scientific applications, applying all the good practices learnt during 20 years of designing and manufacturing amplifiers for other applications, that is, industrialized design, careful thermal management, water cooling, high redundancy, hot pluggable modules, high availability and serviceability during operation.
After that 20kWcw SSA, many other SSA projects for Scientific institutions have been implemented, in different frequencies (from 40MHz to 750MHz) and in power levels (from 200W or 600W klystron drivers, until the most recent high-power SSA of 350kW at 101MHz just delivered on July 2022 for CERN).
This presentation will highlight the technology improvements, in efficiency (from 50 to 60% wall-plug efficiency), in compacity (50kWcw in one single rack for ALBA), in LDMOS technology (from 50V to 65V) in combination techniques (from gysel or hybrid combiner to cavity combiners), etc.

High Power RF systems Status and Operating Experience #1 / 14

The Advanced Photon Source 350MHz RF Systems – 27 Years of Operation and Future Plans

Author: Doug Horan[None]

Corresponding Author: horan@aps.anl.gov

The challenges faced in keeping the Advanced Photon Source 350MHz rf systems reliable will be discussed. This includes klystron performance and problems, troublesome intermittent fault conditions, HVPS system failures, and the effects ac power outages have on 27-year-old equipment.

High Power RF systems Status and Operating Experience #1 / 16

Dual Klystron Driven Storage Ring RF System at Advanced Light Source

Authors: Qiang Du[1]; Kenneth Baptiste[1]; Benjamin Flugstad[1]; Angel Jurado[1]

Co-authors: Gilbert Palafox [1]; Betz Michael [1]; Massimiliano Vinco [1]

[1] *LBNL*

Corresponding Authors: kmbaptiste@lbl.gov, ajurado@lbl.gov

The Advanced Light Source (ALS) has completed an upgrade on its storage ring RF system, which enabled various RF drive modes that can deliver up to 320kW power into two RF cavities through a motorized waveguide matrix. The system incorporates two 300kW klystrons, both are powered by -52.5 kV DC voltage via a fast-disconnect switch network, and are driven by a digital low-level RF control system that actively stabilizes the cavity voltages and phases through 4 feedback loops in an FPGA.
Two RF cavities can be driven by a single klystron, or by one of each klystron, depending on the high voltage and waveguide configuration modes. There are 42 RF power sensors and 16 Arc detectors along the RF distribution path, where a subset is included in the fast interlock system with $< 3\mu$s latency for real-time machine protection. A PLC network is developed to configure high voltage system and waveguide matrix, control klystron operations, monitor water cooling system and circulator tuning, interface with various interlock systems, and manage overall RF system operations. Control systems are developed to enable FPGA-PLC-EPICS communication to support daily operation and parameter optimization. The system is commissioned with full 1.9 GeV, 500mA electron beam, and is in operation since October 2021.

Solid state amplifiers #3 / 17

Design and Fabrication of the 20kW RF SSPA for the RAON SSR2

Author: Kyungtae Seol[1]

Co-authors: Doyoon Lee [1]; Hojae Jang [1]; Hyunik Kim [1]; Kitaek Son [1]; Ohryoung Choi [1]

[1] *IBS (Institue for Basic Science)*

Corresponding Author: ktseol74@gmail.com

The heavy-ion accelerator of the Rare Isotope Science Project (RISP) in Korea has been developed. There are three types of SRF cavity, which are 81.25MHz quarter-wave resonator (QWR), 162.5MHz half-wave resonator (HWR), 325MHz single-spoke resonator (SSR). There are 22 QWRs and 102 HWRs in the superconducting linac#3 (SCL3), and 69 SSR1s and 144 SSR2s in the superconducting linac#2 (SCL2). The required RF power is 4kW for each QWR, 4kW for each HWR, 8kW for each SSR1, and 20kW for each SSR2. The high power RF SSPAs for the SRF cavities have been developed and fabricated with domestic companies. The SSPA systems for the SCL3 were installed and have been operated for RF system integration. The SSPAs for the SSR1 were fabricated and installed in the SCL2 gallery. 325MHz 20kW SSPAs have been designed and fabicated to test the prototype of the SSR2 SRF module including six SSR2 cavities. They were designed to enable full-reflection operation at all times. It consists of four 6kW power-units, four 6kW circulator units, 4-way combiner, a control unit, a power distribution unit, and cooling water inlet/outlet manifolds in each 19" rack. The power-unit has six 1.2kW pallets and circulators, and three power packs. This paper describes the design and fabrication of the 20kW SSPA systems for the RAON SSR2.

Passive devices / 18

Overview of high power ferrite devices and key considerations for the design, operation and high-power testing of ferrite circulators

Author: Carsten Weil[1]

[1] *AFT microwave GmbH*

Corresponding Author: carsten.weil@aft-microwave.com

With a heritage of more than 50 years AFT is a leading designer and manufacturer of high-performance ferrite-based microwave components and subsystems. The high-power product range includes microwave ferrites, circulators, isolators, loads, fast ferrite tuners and power variators for scientific particle accelerators, medical and industrial LINACs as well as for radar systems.

Isolators provide key contributions in high-power RF systems such as reliable protection and stable operation of RF tubes and SSPAs, improvement of the life time of tubes, high efficiency by low insertion loss, continuous and failure-free system operation, high system availability and long system operating life.

This workshop contribution introduces basic design aspects for circulators operated under high peak and cw power. It specifies important power handling requirements regarding capabilities to cope with the max. possible power dissipation (heating) as well as to withstand electrical break down under worst case conditions. Key topics are low insertion loss by careful selection of ferrite materials and proper setting of the magnetic bias for the ferrite, sophisticated thermal management by cooling, thermal drift compensation (TCU) and an elaborated design of the ferrite section with regard to electrical breakdown.

The considerations of circulator power capability cover worst case conditions as given by operation into a 100% reflective load at the circulator output, including all phase conditions. In a high-power test these conditions are usually represented by a sliding short circuit or multiple discrete short circuits of different electrical offset length, forming a moveable standing wave between the short circuit and the circulator. Focus is on two critical phase conditions of the standing wave: (1) Max.

magnetic field strength (min. electrical field) in the circulator: criterion for max. power dissipation and heating in the circulator. (2) Max. electrical field strength (min. magnetic field) in the circulator: criterion for high peak power capability. Based on calculations of the standing wave pattern, a method is presented for finding a minimum number of phase positions or offset lengths, in order to adequately cover the above critical phases in a high power test.
The presentation provides technical comments on the expression "isolation" and introduces basic calculations for the effective port 1 input return loss of a circulator, operated into a short circuit at port 2 and terminated with a dummy load at port 3, by taking into account all possible signal contributions.
Attention is also dedicated to the requirements on directional couplers and harmonic filters to accurately measure forward and reverse power. An analysis investigates the coupler directivity and its sensitive impact on reverse power measurements.
The presentation discusses an essential high-power test set-up, test equipment, measurement categories (such as forward and reverse power, return loss, insertion loss, calorimetric power loss, body temperature…), test procedures, high-power circulator-TCU calibration, arc protection, safety interlocks and common safety rules for hot testing.
High-power test results for recent state-of-the-art circulators illustrate the above topics and complete the workshop contribution.

New projects / 19

PETRA III Upgrade to PETRA IV

Authors: Ruediger Onken[None]; Peter Huelsmann[None]; Michael Ebert[None]

Corresponding Author: peter.huelsmann@desy.de

Rough overview of how PETRA-IV will look like
What are the plans for the HF systems
*Fundamental-system: SSA-HOM-damped cavity*Harmonic system: SSA- HOM-damped cavity
Alternative ideas for a 3rd harmonic cavity

Facility Status Reports #2 / 20

ESS-Bilbao new developments in RFQ coupler and a novel SSPA power source for our ECR ION source

Author: Arash Kaftoosian[None]

Co-authors: Ibon Bustinduy ; Nagore Garmendia [1]; Pedro González [1]; Sergio Masa [1]

[1] *ESS-Bilbao*

Corresponding Author: akaftoosian@essbilbao.org

ESS-Bilbao is a leading proton science research center in Spain that carries out different projects in particle accelerator field. One of the recently accomplished projects is a novel solid-state based RF power source as a replacement for an old klystron of the ECR ION Source (ISHP) that will feed an RFQ, also designed and developed at ESS-Bilbao, to accelerate proton beam up to 3MeV at its output. The new SSPA RF power source is equipped with a cRIO controller and a pre-distortion technique is used to remove overshoot and compensate pulse droop thus generating a very flat 1kW RF pulse at 2.7GHz.
Another ongoing project is design and fabrication of two power couplers for the RFQ. The couplers are based on 4-1/2" coaxial ending in DN40 ports. They handle 300kW peak power at 352MHz.
Design, implementation and test results of the above projects will be presented, plus briefly mentioning of other ongoing projects at ESS-Bilbao.

Solid state amplifiers #3 / 21

The ESS RF Systems: An overview and progress summary

Author: morten jensen[1]

[1] *European Spallation Source ERIC*

Corresponding Author: morten.jensen@ess.eu

ESS will ultimately need 155 high power RF systems to deliver 5 MW of power to the proton beam. The first phase will consist of 91 systems which are currently being installed and tested, with the first systems already in operation to support cavity conditioning and beam operation. This talk will introduce the high level RF system design, key technologies, our strategy for installation, test and support, and will summarise the progress and main challenges to date.

Tube amplifiers and power supplies / 22

ESS Klystrons: Installation, test and early experience

Author: chiara marrelli[1]

Co-author: morten jensen [2]

[1] *ESS*

[2] *European Spallation Source ERIC*

Corresponding Author: chiara.marrelli@esss.se

In order to reach 5 MW proton beam power, the ESS linac will be powered by 155 RF transmitters using different technologies. Most of these transmitters will use klystrons as amplifiers, and more precisely six 3 MW, 352 MHz klystrons in the normal conducting linac, and 120 1.5 MW, 704 MHz klystrons in the superconducting linac.
The talk will give an overview of the ESS klystron-based systems, with focus on the experience gained during installation, testing and initial operation; some of the issues faced during the commissioning of the power stations will be discussed.
Possible solutions to increase the operational efficiency of the systems will be presented, with results from initial tests."

Passive devices / 23

ESS arc detector systems, development and experience

Author: Tomas Olsson[1]

Co-author: morten jensen [1]

[1] *European Spallation Source ERIC*

Corresponding Author: tomas.olsson@ess.eu

ESS is deploying a number of different arc detector systems to protect the RF and distribution systems. ESS are currently installing and testing three different systems. The initial installation and early batches were based on commercial systems but we will also present the test results, motivation and performance parameters of the more recent arc detectors constructed at ESS. Early high power operation highlighted a need for additional protection due to blind spots. We will present the results of a sound based arc detection system used to identify the location of arcing in longer waveguide runs and our thoughts on how to improve the protection in a cost effective way.

Passive devices / 24

RF distribution systems at ESS

Author: Walther Borg[1]

Co-author: morten jensen [1]

[1] *European Spallation Source ERIC*

Corresponding Author: walther.borg@ess.eu

ESS is installing and testing the RF distribution systems including waveguide and coaxial components, circulators, RF loads for up to 155 high power RF systems; > 5000 RFDS components. This talk will present the early quality issues, waveguide tuning and how they were resolved. RFDS components are often considered trivial however, the initial high power operation revealed a number of serious issues with many components. We introduce some of the main issues and summarise the design changes carried out by us and our partners.

High Power RF systems Status and Operating Experience #2 / 25

The ESS MEBT 30 kW solid state amplifiers

Author: Bruno Lagoguez[1]

Co-author: morten jensen [1]

[1] *European Spallation Source ERIC*

Corresponding Author: bruno.lagoguez@ess.eu

A solid state amplifier family has been developed to provide 30kW pulsed at 352 MHz for each of the three buncher cavities of the ESS proton linac. The presentation will give an overview of the amplifiers, with a focus on the installation and tests carried out. The amplifiers are now in operation having been used initially for cavity conditioning and recently for early operation with beam. This presentation reviews the experience gained, improvements and problems solved.

Passive devices / 26

Overview of the ITER high power CW Ion Cyclotron Range of Frequencies system and latest developments for its antennas

Authors: A. Bustos[1]; A. Mukherjee[1]; B. Beaumont[1]; D. Guillermain[1]; D. Milanesio[2]; F. Calarco[1]; F. Durodié[3]; F. Kazarian[1]; M. Graham[1]; N. Ferrigno[1]; P. Lamalle[1]; T. Blackman[1]; T. Gassmann[1]; V. Bobkov[4]; V. Polli[5]; Walid Helou[1]

[1] *ITER Organization*

[2] *Department of Electronics*

[3] *LPP-ERM/KMS*

[4] *Max-Planck-Institut für Plasmaphysik*

[5] *Capgemini Engineering | France*

Corresponding Author: walid.helou@iter.org

In a steady-state nuclear fusion reactor of the tokamak type, high-power CW RF systems are envisaged, among other systems, to heat the plasma up to the required temperatures of 10-20 keV and to drive a non-inductive plasma-current which is required for the plasma confinement. This paper overviews the so-called Ion Cyclotron Range of Frequencies (ICRF) system of the International Thermonuclear Experimental Reactor (ITER).
The ITER ICRF system is a 20 MW CW RF system operating at 40-55 MHz. It is designed to be upgradable to 40 MW CW. The system is based on two identical antennas or couplers. Each coupler is a 24-element phased array antenna. The radiating elements are grouped in 8 triplets and are oriented, spaced and phased such as to couple to the plasma with the right polarization and radiating plane wave spectrum while reducing parasitic interactions at the plasma edge. The triplets of an antenna are fed through a specific internal circuit with embedded, compact and robust service-stubs providing cooling to the internal conductors of the coaxes and broad-banding the antennas' response. The stubs also provide the necessary mechanical support for the antennas' internal components and allow positionning the vacuum RF feedthroughs at a location that is favorable from mechanical and neutronic points of view. Each antenna is fed by eight transmission lines that are connected to the RF sources through a specific decoupling & matching network. The RF sources are based on RF tubes as end-stage amplifier chain.
After overviewing the ITER ICRF system, the paper develops the RF design of the ITER ICRF antennas and details the strategy that has been adopted to optimize the antennas' power coupling within the operation frequency range (40-55 MHz) while ensuring compliance with the requirements on the maximum voltages (45 kV peak), and maximum electric fields (2-3 kV/mm depending on the location and orientation w.r.t. the tokamak magnetic field). The paper also develops the ongoing R&D and prototyping works for the antennas components (such as RF feedthroughs and their dedicated testbed, the 3D-printed radiating elements, etc.).

High Power RF systems Status and Operating Experience #1 / 27

FLASH HPRF System Upgrade

Author: Stefan Choroba[None]

Corresponding Author: stefan.choroba@desy.de

FLASH is a free electron laser driven by a superconducting linear accelerator. During the last shutdown for the FLASH2020+ upgrade several modifications have been made to the HPRF system. Two European XFEL type superconducting accelerator cryomodules with tailored RF power waveguide distribution have replaced two old lower performance modules. Another two old accelerator modules have been equipped with tailored RF power waveguide distributions allowing to make use of the maximum achievable accelerating gradient of each cavity. One new RF station with a multibeam klystron has been installed and another RF station has been equipped with a new pulse modulator. In addition to these major changes several other modifications have been made to the RF power waveguide distributions and the RF power stations. The measures will result in an increase of the electron beam energy from 1.25 to 1.35 GeV.
This presentation will report on the modifications of the HPRF system during the shutdown for the FLASH2020+ upgrade.

Industrial presentations / 28

Highly Reliable Industrial Solid-State RF Amplifier for Synchrotron Light Sources

Authors: Mirco Nedos[1]; Nico Pupeter[1]

[1] *Cryoelectra GmbH*

Corresponding Author: mne@cryoelectra.de

Cryoelectras 3rd generation of solid-state RF amplifiers (SSA) for synchrotron applications is presented in the frame of a poster. The SSA delivers up to 160 kW cw RF output power at 500 MHz. The amplifier is of industrial design regarding space and maintenance requirements. Together with its redundant architecture this allows for a 24/7 operation.
The output power of the amplifier is produced by 15 RF power modules of our patented "tower" design with 16 RF transistors each. With its advanced water cooling scheme, cable-free 16-way high power combiner, and, reliability optimized RF transistor path, the "tower" module enables industry leading run-times. A newly designed compact 15-way wave guide combiner collects the output power of each RF module for a practically lossless combination. For a smooth operation of the solid-state amplifier and reliable machine and personell protection, all components are continuously monitored by a sophisticated control system.

High Power RF systems Status and Operating Experience #1 / 30

SSA Developments at SOLEIL

Author: Massamba DIOP[None]

Co-authors: Fernand RIBEIRO [1]; Patrick Marchand [2]; Robert Lopes [2]

[1] *Synchrotron-Soleil*

[2] *Synchrotron SOLEIL*

Corresponding Author: massamba.diop@synchrotron-soleil.fr

In the SOLEIL storage ring, two cryomodules provide to the electron beam an accelerating voltage of 3-4 MV and a power of 575 kW at 352 MHz. Each cryomodule contains a pair of "HOM free" superconducting cavities, cooled with liquid Helium at 4.5 K, which is supplied by a single 350 W cryogenic plant. The RF power is provided by four solid state amplifiers (SSA), each delivering up to 180 kW. In the Booster ring one 5-cell copper cavity, powered with a 35 kW SSA, provides an accelerating voltage of about 1 MV at 352 MHz. We report here about the operational experience with these systems, their main upgrades and more generally about R&D's, carried out at SOLEIL in the SSA field, leading to the power sources that will be used for the SOLEIL machine upgrade.

Miscellanea / 31

Operation Status and Upgrade Activities of TPS RF System

Authors: Chih-Hung Lo[1]; Fu-Tsai Chung[1]; Hu-Yu Chang[1]; Ling-Jhen Chen[1]; Mei-Hsia Chang[1]; Ming-Chyuan Lin[None]; Zong-Kai Liu[1]; Meng-Shu Yeh[1]; Yi-Ta Li[1]; Shian-Wen Chang[1]; Chaoen Wang[1]

[1] *National Synchrotron Radiation Research Center*

Corresponding Author: chyuan@nsrrc.org.tw

The TPS RF system consists of two RF plants. each at a power level of 300-kW, for the electron storage ring operation. The system performance and statistics on trip events in the recent years are presented. To improve the RF performance, some activities such as digital low level RF system and solid state amplifier are developed and implemented, whereas a spare 500-MHz superconducting RF module is established and successfully tested with high power. Another upgrade activity on going is to develop a third-harmonic SRF module to lengthen the electron bunch. Current status of this third harmonic SRF module is also reported.

Facility status reports #1 / 32

Status of the HIPA rf-system at PSI

Author: Markus Schneider[None]

Corresponding Author: markus.schneider@psi.ch

The High Intensity Proton Accelerator (HIPA) facility at PSI delivers a proton beam of 2 mA during routine operation and was tested up to 2.4 mA. The acceleration includes three stages: a Cockcroft-Walton, the Injector 2 cyclotron and the Ring cyclotron.
The injector 2, commissioned in 1984, is a separated sector cyclotron with 4 sector magnets and 4 sections cavities. Two 50 MHz cavities provide the main acceleration voltage, assisted by two 150 MHz Flattop cavities today routinely operated in accelerating mode. To increase the energy gain per turn, we are currently replacing these two systems with 50 MHz cavities. This ongoing upgrade program includes the replacement of the old LLRF and amplifier system. This talk will give an overview on the present state of this project.
The Ring cyclotron is a separated sector cyclotron with a fixed beam energy of 590 MeV, built by PSI and commissioned in 1974. The last major upgrade was the replacement of the four main aluminum cavities by copper cavities from 2004 to 2008. The IMPACT project, under planning at PSI, foresees a major upgrade on the Muon-Targets side of the facility. With this new project, the HIPA facility should be operated for additional 15 years. To compensate for the beam intensity losses caused by IMPACT on the target of the spallation source SINQ, the delivered beam intensity of the cyclotron should be increased by about 15%. Today the old 150 MHz flattop cavity system is the main limitation factor toward an increase of the beam current in the Ring cyclotron, and a power upgrade of the 50 MHz amplifiers also seems necessary. Therefore the pre studies for two rf-projects have been started. The first one will replace the existing flattop cavity by a new one, including a new LLRF, amplifiers and transmission line. The second one is to renew the LLRF and amplifiers for the four 50 MHz copper cavities. First concepts will be presented during this talk.

Industrial presentations / 33

New Solid State Power Amplifier will be soon merge both Broadband & Large-power performance

Author: riichiro kobana[1]

[1] *R&K Company Limited*

Corresponding Author: reichiro-kobana@rkco.jp

R&K Company Limited has achieved technological success in the fields of accelerators, mobile communications, plasma, EMC, and NMR/MRI. R&K's most differential feature is that it is a group of craftsmen and a manufacturing organization that values results obtained through actual trial and error.
By carefully adjusting the latest technology based on these experiences and achievements, R&K has been able to realize a newly designed solid-state power amplifier with both wide bandwidth and high output power, which will be released in the near future.
The control system, basic amplifier module, and power combiners, which are all the key components of these products, will be introduced.

Solid state amplifiers #1 / 34

Operational and design aspects of solid state amplifiers

Author: riichiro kobana[1]

[1] *R&K Company Limited*

Corresponding Author: reichiro-kobana@rkco.jp

Operational and design aspects of solid state amplifiers, covering, but not limited to e.g. the bandwidth, linearity vs. efficiency, sensitivity to reflected power, paralleling and combination, heat extraction, life time vs. working point.

* place holder by D. Valuch *

Solid state amplifiers #2 / 35

Planning, requirements, features, vendor design and development status of 60kW 500 MHz AR RF HPA for ALSU project

Authors: D. Nett[1]; K Hirano[2]; Kenneth Baptiste[3]; S Hihara[2]; Shree Subhasish Basak[1]; T. Sueishi[2]; W Lewis[1]; riichiro kobana[4]

[1] *LBL*

[2] *R&K Company Ltd*

[3] *LBNL*

[4] *R&K Company Limited*

Corresponding Author: ssbasak@lbl.gov

A solid state LDMOS FET based RF High Power Amplifier (HPA) with 60 kW CW RF output power , operating at 500 MHz, with a power gain ~ 80 dB is being designed and manufactured for the Accumulator Ring (AR) RF cavity in the ALS-U project at LBNL, through a joint effort with a commercial company, R&K. This paper presents the highlights of the important initial planning, installation site space constraints, technical specifications, features, modular construction & numerology, build standards requirements, safety standards etc., of the various diverse subsystems viz., AC power distribution, parallel DC power distribution system and DC bus bar, modular RF amplifiers used for preamplifiers & final amplifiers, high power combiners, control system using PLC & FPGA for slow/ fast response of various interlocks & local/ remote operation, LCW & heat exchanger, cabinet structure etc., in this HPA. This paper will also present the HPA important design requirements like high reliability, redundancy with failed RF amplifier and/or DC power modules, fault tolerance of control system to failed modules etc., that are incorporated in HPA design by R&K. The important thermal management of power dissipation in this HPA is also presented. The design by the vendor is well matured and manufacturing of HPA by vendor shall begin shortly.

High Power RF systems Status and Operating Experience #2 / 36

Operational experience with CW klystrons at CERN (LHC and Linac4)

Author: Nuria Catalan Lasheras[1]

[1] *CERN*

Corresponding Author: nuria.catalan.lasheras@cern.ch

14 years of LHC operation 300kW/400MHz klystrons
5 years of Linac4 operation a mix od recuperated LEP klystrons and new klystrons 1MW/352MHz

——– placeholder by D. Valuch ——–

Tube amplifiers and power supplies / 37

High voltage power supplies for RF amplifiers -

Author: Davide Aguglia[1]

[1] *CERN*

Corresponding Author: davide.aguglia@cern.ch

An overview of high voltage power supplies for tetrode, IOT and klystron amplifiers (DC and pulsed power), with an introduction of basic concepts in power electronics, design specificities for RF applications, and illustrations of CERN-designed RF power converters.
Invited talk offered to Dr. Davide Aguglia, Electrical Power Converter Deputy group leader, and Fast Pulsed Converter section leader.

Facility status reports #1 / 38

The Plans and Status of the ALS-U RF Systems

Authors: David Nett[1]; Kenneth Baptiste[1]; Kevin Bender[1]; Mark Galt[1]; Shree Subhasish Basak[2]

Co-authors: Benjamin Flugstad [1]; Qiang Du

[1] *LBNL*

[2] *LBL*

Corresponding Author: kmbaptiste@lbl.gov

The Advanced Light Source (ALS) is in the midst of and upgrade, ALS-U, an upgrade which will replace the existing triple-bend achromat storage ring with a stronger focusing nine-bend achromat storage ring. The new storage ring's small emittance and reduced dynamic aperture requires a new injection scheme. ALS-U has chosen an on-axis swap-out injection to exchange bunch trains between the storage ring and new low-emittance, full-energy accumulator ring. To meet the requirements for these two new rings, the 500 MHz storage ring RF system will be upgraded with a new cavity power coupler to meet the new beam loading conditions and will receive new passive 3rd harmonic cavity systems while a completely new 500 MHz accumulator ring RF system, will be designed and installed using solid state amplifiers (SSA) and HOM damped commercially available normal conducting cavities. In this presentation, the details of the new systems will be described and the installation and commissioning plans given.

Facility Status Reports #2 / 39

Commissioning of 400 kW 352 MHz Amplifiers for ESS ERIC

Author: Cristina Pasotti[1]

[1] *Elettra-Sincrotrone Trieste S.C.p.A.*

Corresponding Author: cristina.pasotti@elettra.eu

Elettra has delivered 27 Radio Frequency Power Station (RFPS) - 400 kW 352 MHz Amplifiers - to the European Spallation Source ERIC (ESS ERIC) in an In-Kind (IK) collaboration frame. These RFPSs, 26 equivalent units plus 1 spare unit, will feed the Spoke cavity section of the proton Linac. The RFPS is a custom made machine. Its manufacturing has been awarded to European Science Solutions Srl as a result of the Italian Public procurement procedure tender and Elettra has been in charge to manage

the contract compliance.
The RFPS design and production started with a first unit, so called pre-serie, that has been extensively optimized and tested. Then the mass production of the next units has followed.
This talk will cover the RFPS's achieved performances and the RFPS Factory Acceptance Test (FAT) main outcomes togheter with the remote FAT protocol that has been deployed to cope with the restrictions on travels imposed by the COVID-19 pandemic period.

High Power RF systems Status and Operating Experience #2 / 40

Radio Frequency RF Power Stations (RFPS) at ESS: Installation and Initial operating experience

Authors: Carlos Martins[1]; Carlos Martins[2]; Manish Kumar[None]; Matthew Bergstrom[3]; Mohammadhadi Sadeghzadeh[None]; Rutambhara Yogi[None]

[1] *European Spallation Source ERIC*

[2] *European Spallation Source*

[3] *ESS*

Corresponding Author: rutambhara.yogi@esss.se

The European Spallation Source (ESS) will be the world's most powerful pulsed neutron source by the end of the decade, which will accelerate a beam of protons with a beam current 62.5 mA to 2 GeV. The beam pulse width is 2.86 ms long and pulse repetition frequency is 14 Hz. The acceleration will be provided by 155 cavities, out of which 97 % of the cavities are superconducting.
The first section of the ESS superconducting linac is the Spoke linac. The spoke linac increases the beam energy from 90 MeV to 216 MeV using the 26 superconducting Spoke cavities resonant at 352 MHz, situated in 13 cryomodules. The maximum power requirement for the spoke RF power station is 400kW. Outputs of two tetrode TH595A based amplifiers are combined to achieve 400kW output. The two tetrodes are powered by a single anode power supply to increase the system reliability and to achieve the cost reduction. In the event of arc in the tetrode, a single series switch will be used to protect the two tetrodes.
The present paper discusses the choice of the tetrode technology and high level design of the tetrode based RF Power Station (RFPS)[1]. The RFPS are delivered by Elettra as a part of Italian in-kind contribution towards the construction of ESS. The detailed design of RFPS is done by ESS and Elettra[2]. At present, 24 RFPS are delivered to ESS. Out of these, 8 RFPS are installed and 6 RFPS are commissioned at ESS. Four RFPS are under soak testing in order to understand the possible issues regarding life-time and operation. The present paper also discusses the initial operational experience of RFPS, some issues and their mitigation.

References:
1. R.A.Yogi et. al.,'352 MHz Source and Plans for Full Power Testing of Prototype Spoke Cryomodule', presented during SLHiPP-2012 meeting, 3-4 May 2012, Katania, Italy.
2. Cristina Pasotti, '400 kW - 352 MHz Radio Frequency Power Station Technical Specification', E-ST ESS RF TSD 002, 2017 (confidential document).

New projects / 41

RF SSAs for MINERVA, general architecture and main challenges

Author: Victor Martinez Illamola[1]

[1] *SCK CEN*

Corresponding Author: victor.martinez.illamola@sckcen.be

SCK CEN (Studiecentrum voor kernenergie or Centre d'étude de l'énergie nucléaire) is building MINERVA on views of MYRRHA, an ADS (Accelerator Driving System) which will eventually enable transmutation of nuclear waste but also fundamental research.
MINERVA LINAC will accelerate a proton beam current of 4mA@100 MeV in CW. The front-end will be composed by an injector with 20 NCRF (Normal Conducting Radio Frequency) cavities operating at 176,1 MHz and a main LINAC with 60 SRF (Superconducting Radio Frequency) cavities operating at 352,2 MHz.
The NCRF and SRF cavities will be powered by using SSAs with RF power levels ranging from 6 kW up to 140 kW and from 6 to 25 kW respectively.
The extremely high reliability (MTBF > 250h) is one of the main requirements which would need to be achieved. It will be accomplished by implementing parallel redundancy in the NCRF section and an innovative fault tolerant scheme for the SRF section.
This talk presents the general RF SSAs system architecture for MINERVA as well as the main challenges for the RF SSAs due to the extremely high reliability requirements for both sections, NCRF and SRF, but also due to the fault tolerant scheme for the SRF section, which will strongly impact the operational point of the RF SSAs.

Solid state amplifiers #2 / 42

Construction and Installation of a 320kW Solid State Power Amplifier for Taiwan Photo Source.

Author: Fu-Tsai Chung[None]

Corresponding Author: gofor@nsrrc.org.tw

It took a decade to develop the 500-MHz module for the Solid State Power Amplifier (SSPA) in NSRRC. Performance of a single module was gradually improved to reach a steady output power of 960W by using the RF chip IC-BLF578XR. Heat dissipation unit and high-efficiency power supply are key issues in improving integral performance (49.5% RF power) of the single module. A 110-module SSPA tower was first constructed to generate 80 kW CW RF power. Next this 80-kW tower was successfully combined with a 100-kW klystron-type RF source to generate 160 kW RF power to finish the conditioning of power couplers (CPL) and off-line high-power test of a KEKB-type SRF module in the RF laboratory. Based on these operation experience, four towers of modified SSPA were then constructed and successfully combined to generate 320 kW RF power, in which the RF chip in each module is upgraded to IC-BLF578. This 320-kW SSPA station is applied to the on-line high-power test and CPL aging of a KEKB-type SRF module in 2021-2022. However, reduction on module damage rate during CPL aging, higher operation stability, greater energy efficiency, and suppression on acoustic noise are the challenges foreseen.

Miscellanea / 43

CLS improvements and future goals

Authors: Connor Boyle[1]; Denis Beauregard[1]; Jonathan Stampe[2]; Pol Solans[None]

[1] *CLS*

[2] *Canadian Light Source*

Corresponding Author: denis.beauregard@lightsource.ca

The Canadian Light Source (CLS) operates a single-cell CESR-B superconducting RF cavity system in the 2.9 GeV storage ring, powered by a 310 kW klystron.
In recent years CLS has been making changes to its RF systems with the aim to improve reliability. The booster klystron has been replaced with a solid state amplifier.

CLS has worked with ALBA to replace the LLRF system for the booster. CLS is waiting delivery of a 3rd cryomodule for the SR. In the future we aim to install an SSA for the SR and test the ALBA DLLRF on the superconducting cavity.

Tube amplifiers and power supplies / 44

The Proton Power Upgrade High-power Radiofrequency Systems

Author: John Moss[1]

[1] *Oak Ridge National Laboratory*

Corresponding Author: mossjs@ornl.gov

The Proton Power Upgrade (PPU) project at the Spallation Neutron Source (SNS) will double the available H- beam power from 1.4 to 2.8 MW by increasing the beam energy from 1.0 to 1.3 GeV and the beam current from 26 to 38 mA. The increase in beam current and energy drove the design decisions made for both the Normal Conducting Linac (NCL) and Superconducting Linac (SCL) Radio-frequency Systems which includes the upgrade of three Drift-Tube Linac (DTL) to 3MW peak power and the addition of 28 new 700kW peak SCL RF stations. This paper will detail both the history of the PPU RF Systems design, data that drove the decisions, and the status.

Facility Status Reports #2 / 45

Status and plans of the RF renewal in the framework of the Swiss Light Source upgrade (SLS2)

Authors: Lukas Stingelin[1]; Marco Pedrozzi[None]; Marcos Gaspar[1]; Riccardo Zennaro[None]; Wolfgang Tron[None]

[1] *Paul Scherrer Institut*

Corresponding Author: marcos.gaspar@psi.ch

We present the status of the RF upgrade of the SLS2.
We will describe the progress in different areas of the SLS2 accelerator complex concentrating on the RF infrastructure.
The chronology of the upgrade including the commissioning of components is also presented.

Solid state amplifiers #2 / 46

Design Study on the Booster RF System with SSPA for KOREA-4GSR

Authors: Myunghwan CHUN[1]; Sehwan park[2]; Younguk Sohn[2]; Yu Inha[2]

[1] *PAL(Pohang Accelerator Laboratory)/POSTECH*

[2] *Pohang Accelerator Laboratory*

Corresponding Author: mhchun@postech.ac.kr

The 4th Generation storage Ring (4GSR) as the second synchrotron light source in Korea was launched from 2021. The 4GSR is designed to be one of the world's best performance with a beam energy of 4 GeV / 400mA. Therefore the RF system is studied and designed with solid-state power amplifiers (SSPA) which are effective RF sources instead of tubes due to the broad studies and applications in the accelerator technics.
The 80kW SSPAs are needed for the booster ring, and 160kW SSPAs are estimated for the storage ring RF system to supply the high power RF to the NC cavities.
This poster describes the present design status and composition of the high power RF system of the booster and storage ring with mainly SSPA as the RF sources.

Solid state amplifiers #1 / 47

Special requirements for high power SSA for the ESRF high current storage ring

Authors: Jorn Jacob[None]; Pawel Borowiec[1]

[1] *ESRF*

Corresponding Author: jacob@esrf.fr

Details of the specification for the recent call for tender for 10 x 110 kW SSA at 352 MHz for the ESRF will be presented. They address a number of issues that were discovered in the course of the first procurement ever of 1 MW of SSA from industry, more than 10 years ago, and which we translated into special requirements for our 2021 specification. They are particular to a setup without high power circulators in isolator configuration, which was chosen for cost and space reasons.

CERN facility visit / 48

Group 1 BA3 visit

Group leaves by bus from behind the Globe at 15:30 sharp

CERN facility visit / 49

Group 1 SM18 visit

CERN facility visit / 50

Group 2 BA3 visit

CERN facility visit / 51

Group 2 SM18 visit

CERN facility visit / 52

Group 1 leaving SM18 to restaurant

CERN facility visit / 53

Group 2 leaving BA3 to restaurant

CERN facility visit / 54

Group 2 coffee in the Globe

CERN facility visit / 55

Group 1 apero in Andiamo