Ninth CW and High Average Power RF Workshop

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Book of Abstracts

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Klystrons / 0

LANSCE Klystron Replacement

Author: Daniel Rees[1]

Co-authors: Jon Bergemann [1]; Lenci Steve [2]; William Haynes [1]

[1] *Los Alamos National Laboratory*

[2] *Communication and Power Industries*

Corresponding Authors: drees@lanl.gov, steve.lenci@cpii.com, jbergemann@lanl.gov, wbhaynes@lanl.gov

The Los Alamos Neutron Science Center (LANSCE) recently completed major upgrades to its RF systems. The focus of the project was to return LANSCE to its historical operating capability and sustain facility operations for the next several decades. The LANSCE accelerator provides pulsed protons and spallation neutrons for defense and civilian applications. This project involved replacing all the existing 201 MHz RF stations, the low level RF controls, selected electronics chassis and all 805 MHz klystrons. The paper will focus on the klystron replacement. LANSCE was historically supported by two types of 1.25 MW peak power klystrons operating at 805 MHz. Designed and delivered in the early 70s, the reliability of the LANSCE klystrons has been amazing. We are still operating some of the klystrons that were purchased over 40 years ago. This paper will discuss how the basis for our new purchases preserved the demonstrated reliability of the existing design. It will share the measured performance and consistency of the 45 new klystrons and present the current experience with these new klystrons.

Summary:

Solid state amplifiers 1 / 1

Ten years of operation with the SOLEIL RF systems : experience, upgrades, R&D's

Author: Patrick Marchand[1]

[1] *Synchrotron SOLEIL*

Corresponding Author: patrick.marchand@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 ten-year operational experience with these systems, their main upgrades and more generally about R&D's, carried out at SOLEIL in the SSA field.

Summary:

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 ten-year operational experience with these systems, their main upgrades and more generally about R&D's, carried out at SOLEIL in the SSA field.

Solid state amplifiers 1 / 3

The PSI Compact 500MHz 65kW High Power Solid-State Amplifier

Author: Marcos Gaspar[1]

[1] *Paul Scherrer Institut*

Corresponding Author: marcos.gaspar@psi.ch

The Paul Scherrer Institut currently operates a klystron amplifier on the booster ring of the Swiss Light Source (SLS). In order to have an optional RF source for the booster cavity, we have been developing a compact 500MHz –65 kW solid state RF amplifier. An important goal in this development is the optimization of efficiency at any given operating point. With this technique it is possible to maximize the overall efficiency at any given RF output power. Considerable effort has been made in order to obtain extensive measurements from each individual module with the aim of investigating the behavior of such a large number of combined arrays. We will discuss the amplifier design and present the results of measurements.

Summary:

We describe the present solid-state amplifier design developments in the Swiss Light Source. The main performance results of the present installation are also described giving emphasis to efficiency optimization.

Status and projects 1 / 4

Status and Operation of the ALBA RF System

Author: Jesús Ocampo[1]

Co-authors: Angela Salom Sarasqueta [2]; Beatriz Bravo [3]; Francis Perez [4]; Pol Solans [5]; Roger Fos [1]

[1] *CELLS - ALBA*

[2] *Synchrotron ALBA*

[3] *CELLS*

[4] *ALBA Synchrotron - CELLS*

[5] *CELLS- ALBA*

Corresponding Authors: bbravo@cells.es, rfos@cells.es, psolans@cells.es, jocampo@cells.es, asalom@cells.es, francis@cells.es

ALBA is a 3 GeV, 400 mA, 3rd generation Synchrotron Light Source in Barcelona, Spain. The RF System provides up to 3.6 MV of accelerating voltage and restore up to 540 kW of power to the electron beam. For that, six RF plants, working at 500 MHz are in operation. A RF plant includes a Dampy cavity (HOM damped) which is feed by two 80 kW IOT amplifiers combined via CaCo; a cavity combiner. This presentation describes the performance of the RF systems, including reliability statistics during 2015 and 2016. Also, the installation of five L3 4444C IOT's will be presented, comparing their performance and reliability to the Thales TH-794 IOT's that are also in use at ALBA.

Summary:

Solid state amplifiers 2 / 5

Development of a cavity-type power combiner for 509 MHz solid state amplifier

Author: Takahiro Inagaki[1]

Co-authors: Akira Terada [2]; Hiroyasu ego [3]; Kazutaka Harumatsu [2]; Kazutaka Hayashi [2]; Satoshi Miyagawa [2]; Tatsuyuki Sakurai [3]; Yasunori Yamamoto [2]; Yuji Otake [1]

[1] *RIKEN SPring-8 center*

[2] *Mitsubishi Electric Tokki Systems Corporation*

[3] *SPring-8/JASRI*

Corresponding Authors: ya-yamamoto@west.melos.co.jp, harumatsu@west.melos.co.jp, otake@spring8.or.jp, ego@spring8.or.jp, kazu-hayashi@west.melos.co.jp, ak-terada@west.melos.co.jp, inagaki@spring8.or.jp, sa-miyagawa@west.melos.co.jp, t-sakura@spring8.or.jp

Development of a solid state amplifier (SSA) is planned for a 509 MHz accelerator cavity at the SPring-8 storage ring, as an optional plan of the upgrade project. Instead of the present power distribution system using a 1.2 MW klystron, a 100 kW SSA drives each of acceleration cavities. This system enables us to control the power and phase of the cavity, which gives us the redundancy, better stability, and maintainability. In order to obtain a 100 kW rf power, we should combine rf power from 160 LDMOS transistor modules. Therefore a power combiner with low loss is important for better power efficiency and cost reduction. We designed an 80-way power combiner using a TM010 mode cavity with 80 input loop couplers attached on the cylinder inner surface of the cavity. The design simulation shows the power loss of the combiner is less than 2% in the ideal case. We made a prototype combiner and measured its rf characteristics. 4-way power combining with 6% loss, which was consistent with our designed value, was confirmed. In addition, we demonstrated the power combining from 4 LDMOS transistor modules with 10% loss. This presentation reports the design and obtained characteristics of the prototype.

Summary:

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Innovative High Power, High Efficient Amplifier Design for Accelerator-Applications

Author: Uwe Dalisda[1]

[1] *Rohde & Schwarz GmbH & Co. KG*

Corresponding Author: uwe.dalisda@rohde-schwarz.com

Amplifiers for Broadcast applications with RF output power in the range of 100kW was a domain of tube (IOT) amplifiers.
Since innovative and powerful LDMOS transistors are available, IOT amplifiers are being replaced by solid state.
Efficiency and size of modern LDMOS-amplifiers are very competitive and not worse than tube based amplifiers anymore.
The big advantage to use LDMOS technology is the overall handling: low supply voltages, redundant RF power, high efficiency, serviceability, MTTR, etc.
All advantages "out of the broadcast world", i.e. high efficiency and broadband design, high redundancy, hot pluggable amplifier design, high availability
and serviceability during operation can be applied to the design and requirements of broad- and narrowband amplifiers for accelerator applications.

This presentation shows how the technologies and design principles used in field proven and reliable broadcast transmitters, which are produced in high volumes

and designed for 24/7 operation, can be adapted to fulfill the requirements of amplifiers for accelerator applications.

Summary:

This presentation shows how the technologies and design principles used in field proven and reliable broadcast transmitters, which are produced in high volumes
and designed for 24/7 operation, can be adapted to fulfill the requirements of amplifiers for accelerator applications.

Solid state amplifiers 3 / **10**

Solid State RF Amplifier Development at the Advanced Photon Source

Author: Douglas Horan[1]

Co-authors: A. Goel [1]; A. Nassiri [1]; D. Bromberek [1]; G. Waldschmidt [1]; K. Suthar [1]

[1] *Argonne National Laboratory*

Corresponding Authors: suthar@aps.anl.gov, djbromb@aps.anl.gov, waldschm@aps.anl.gov, nassiri@aps.anl.gov, horan@aps.anl.gov, agoel@aps.anl.gov

Solid state rf amplifier development is underway at the Advanced Photon Source at two operating frequencies. A new 9.77-MHz solid state driver amplifier was designed and built to replace existing obsolete driver amplifiers presently used in the Advanced Photon Source accumulator ring rf systems. The amplifier design uses a single 1.25kW LDMOS push-pull transistor output device operating at 30 volts. It achieved very high efficiency, which provided the option of forced-air cooling. "Cut and try"techniques were used in the design phase of the amplifier due to the lack of accurate device models at low frequencies. The design and construction of a compact 352-MHz, 12kW cw solid state demonstration amplifier system is also underway. The system consists of six 2kW power amplifier modules supplying rf power to a resonant combining rf cavity. The 2kW amplifier design utilizes a single push-pull LDMOS output device operating at 60 volts, and an efficient cooling system is used to maintain safe transistor die temperature while operating at power levels exceeding normal device specifications. The combining rf cavity consists of a compact rf structure utilizing water cooling, a single resonance-control tuner, six input ports, and one WR2300 waveguide output port. The design process, performance data, and implementation of the new amplifiers will be discussed.

Summary:

Poster session / **11**

Upgrade of the 1.3 GHz Resonant Ring for High Power RF Test of Accelerator Components

Author: Hartmut Büttig[1]

Co-authors: Andre' Arnold [1]; Gerald Staats [1]

[1] *Helmholtz Zentrum Dresden Rossendorf*

Corresponding Authors: h.buettig@hzdr.de, a.arnold@hzdr.de, g.staats@hzdr.de

Since 2009 the ELBE center for high power radiation sources is using a 1.3 GHz resonant ring for RF conditioning of power couplers and to test different waveguide components. The poster describes

the ring and two new features that are improving the ring significantly. First, a PLL system is used to stabilize the RF-power in the ring which normally drops with increasing temperature because the frequency of the structure shifts. And second, an adjustable test waveguide was designed that allows perfect matching of a pair of RF-couplers with different antenna tip lengths. All measurements are in good agreement with simulations and the ring is now routinely in use for travelling wave measurements of RF components up to 50 kW CW.

Summary:

Poster session / **12**

Remarks on 3 years SSPA Operation at the Superconducting Linac ELBE

Author: Hartmut Büttig[1]

Co-authors: Andre' Arnold [1]; Michael Kuntzsch [2]; Rico Schurig [1]

[1] *Helmholtz Zentrum Dresden Rossendorf*

[2] *Helmholtz Zentrum dresden Rossendorf*

Corresponding Authors: r.schurig@hzdr.de, h.buettig@hzdr.de, a.arnold@hzdr.de, m.kuntzsch@hzdr.de

Since January 2012 the superconducting Linac ELBE is in operation with 1.3 GHz Solid State Power Amplifiers (SSPA). One system can deliver up to 20 kW per cavity.
The presentation revues the experiences gained within 3 years of operation and problems that have been solved.

Summary:

Status and projects 2 / **13**

HPRF Systems of Electron Linac at TRIUMF

Author: Zhengting ANG[1]

[1] *TRIUMF*

Corresponding Author: zang@triumf.ca

A new facility, ARIEL at Triumf is employed 9 cell superconducting cavity at 1300 MHz cw model to produce radioactive isotope beams. The five superconducting cavities are installed in three cryo modules to accelerate electron beams to energy of 500 KW. This paper will present the high power rf system design, tests, commissions and first operation.

Summary:

Zheng Ting ANG and RF group, Triumf, Vancouver, Canada

Solid state amplifiers 1 / **14**

LCLS-II High Power RF Systems Overview and Progress

Author: Anahid Yermeian[1]

Co-authors: Andrew Haase [2]; Chris Adolphsen [3]; Christopher Nantista [1]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC National Accelerator Laboaratory*

[3] *SLAC*

Corresponding Authors: nantista@slac.stanford.edu, aah@slac.stanford.edu, anahid@slac.stanford.edu, star@slac.stanford.edu

A second X-ray free electron laser facility, LCLS-II, is being constructed at SLAC. LCLS-II is based on a 1.3 GHz, 4 GeV, continuous-wave (CW) superconducting linear accelerator, to be installed in the first kilometer of the SLAC tunnel. Multiple types of high power RF (HPRF) sources will be used to power different systems. The main 1.3 GHz linac will be powered by 280 1.3 GHz, 3.8 kW solid state amplifier (SSA) sources. The normal conducting buncher in the injector will use four such SSAs. Two 185.7 MHz, 60 kW sources will power the photocathode dual-feed RF gun. A third harmonic linac section, included for linearizing the bunch energy spread before the first bunch compressor, will require sixteen 3.9 GHz sources at about 1 kW CW. A description and an update on all the HPRF sources of LCLS-II and their implementation is the subject of this paper.

*Work supported by DoE, Contract No. DE-AC02-76SF00515

corresponding author: anahid@slac.stanford.edu

Summary:

A second X-ray free electron laser facility, LCLS-II, is being constructed at SLAC. LCLS-II is based on a 1.3 GHz, 4 GeV, continuous-wave (CW) superconducting linear accelerator, to be installed in the first kilometer of the SLAC tunnel. Multiple types of high power RF (HPRF) sources will be used to power different systems. The main 1.3 GHz linac will be powered by 280 1.3 GHz, 3.8 kW solid state amplifier (SSA) sources. The normal conducting buncher in the injector will use four such SSAs. Two 185.7 MHz, 60 kW sources will power the photocathode dual-feed RF gun. A third harmonic linac section, included for linearizing the bunch energy spread before the first bunch compressor, will require sixteen 3.9 GHz sources at about 1 kW CW. A description and an update on all the HPRF sources of LCLS-II and their implementation is the subject of this paper.

*Work supported by DoE, Contract No. DE-AC02-76SF00515

corresponding author: anahid@slac.stanford.edu

emphasized text

Poster session / 15

First experience using a MicroTCA.4-based LLRF-controller driving the SSPA-based high power RF system at ELBE

Author: Michael Kuntzsch[1]

Co-authors: Christian Schmidt [2]; Hartmut Büttig [3]; Igor Rutkowski [4]; Maciej Grzegrzółka [4]; Martin Hierholzer [2]; Matthias Hoffmann [2]; Radosław Rybaniec [4]; Rico Schurig [5]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

[2] *DESY*

[3] *Helmholtz Zentrum Dresden-Rossendorf*

[4] *Warsaw University of Technology, ISE*

[5] *FZD*

Corresponding Authors: m.hoffmann@desy.de, m.kuntzsch@hzdr.de, schurig@fzd.de, maciej.grzegrzolka@desy.de, martin.hierholzer@desy.de, igor.rutkowski@desy.de, buettig@hzdr.de, christian.schmidt@desy.de, radoslaw.rybaniec@desy.de

The ELBE center for high power radiation sources is operating a superconducting RF accelerator in CW mode. Since 2012 solid state amplifiers are used to drive the accelerating structures at ELBE. New experiments which are in preparation need a better temporal resolution and therefore a higher beam stability. Since 2013 a test series has been performed to evaluate a MicroTCA.4-based digital LLRF (low level RF) system foreseen to replace the analogue controllers. The contribution gives an overview of the setup, reports first performance results and discusses challenges and experience gained during commissioning.

Summary:

Spallation sources / **16**

Status and Performance of RF Linac in Oak Ridge Spallation Neutron Source

Author: Yoon Kang[1]

[1] *Oak Ridge National Laboratory*

Corresponding Author: kangyw@ornl.gov

*emphasized text*The RF linac in SNS has been performing progressively since the commissioning in 2006 for production and delivery of neutrons to beamlines. The RF systems in the front-end, the normal conducting section, and the superconducting section, have been operating as initially designed but with some limitations. Various problems that hampered achieving the design beam power and reduced availability of the SNS accelerator systems have been identified and eliminated through repairs, upgrades, and developments. The 1.4 MW design beam power is now routinely achieved during 24/7 operation while the beam energy is slightly lowered from the design goal of 1 GeV to about 950 MeV. Efforts are put on developments and investigations for system improvements for enhanced availability and performance. In this report, developments, and operation experiences on the accelerator systems will be presented along with the efforts for future upgrades of the SNS accelerator systems.

Summary:

Miscellanea / **18**

Observation of Failure Modes of RF Amplifiers at ATLAS

Authors: Sergey Sharamentov[1]; Yong Luo[None]

Co-authors: Gary Zinkann [2]; Matt Hendricks [2]; Peter Ostroumov [2]

[1] *A*

[2] *Argonne National Laboratory*

Corresponding Authors: hendricks@anl.gov, zinkann@anl.gov, yluo@anl.gov, ostroumov@anl.gov, sharamentov@phy.anl.gov

Corresponding author:Y. Luo, yluo@anl.gov

Summary:

About four years ago, at Argonne Tandem Linac Accelerator System (ATLAS), a 4-meter long 60.625 MHz CW radio-frequency quadrupole (RFQ) had been developed and has been used in operation since then. Two 60 kW vacuum tube type amplifiers are used to provide the power for the RFQ. A new cryomodule consisting of seven 72.75 MHz superconducting (SC) quarter-wave resonators (QWR) has also been developed and put into operation more than two years ago. Seven 4 kW solid state amplifiers are used to provide RF powers to the QWRs. Over the years, we have seen numerous failure modes on both types of amplifiers especially on 60 kW amplifiers. In this paper, we would like to share our observation on failure modes and the measures we have taken to substantially improve the reliability of CW RF amplifiers. Our experience could be beneficial for similar facilities worldwide. This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357. This research used resources of ATLAS facility at ANL, which is a DOE Office of Science User Facility.

Poster session / **19**

The operation experience of TLS&TPS RF transmitter and the development solid-state amplifier in NSRRC

Author: Tsung-Chi Yu[1]

Co-authors: Chaoen Wang [1]; Chih-Hung Lo [1]; Fu-Tsai Chung [1]; Ling-Jhen Chen [1]; Lung-Hai Chang [1]; Mei-Hsia Chang [1]; Ming-Chyuan Lin [1]; Ming-Hsun Tsai [1]; Yeh Meng-Shu [1]; Zong-Kai Liu [1]

[1] *National Synchrotron Radiation Research Center*

Corresponding Authors: yu.tc@nsrrc.org.tw, mhchang@nsrrc.org.tw, mhtsai@nsrrc.org.tw, rfwang@nsrrc.org.tw, lhchang@nsrrc.org.tw, liu.zk@nsrrc.or, chen.lj@nsrrc.org.tw, msyeh@nsrrc.org.tw, chyuan@nsrrc.org.tw, lo.ch@nsrrc.org.tw, gofor@nsrrc.org.tw

At present, two synchrotron radiation facilities – Taiwan Light Source (TLS) & Taiwan Photon Source (TPS) are in operation simultaneously in NSRRC. Both RF systems of these facilities use superconducting cavities as electron accelerating components in storage ring. The RF power for the cavity and electron beam is provided by klystrons with high voltage (HV) power supplies. For TLS, the klystron is supplied by a crowbar type HV power supply, while in TPS, the klystron is supplied by a PSM crowbar-less HV supply unit. The operation experience in daily operation and commission will be presented. Besides, to satisfy the coming RF requirement in Phase-II beam-line construction in TPS, solid-state amplifier is also developed in NSRRC. The latest progress will also be described here.

Summary:

Spallation sources / **20**

ESS-BILBAO CONTRIBUTION TO THE ESS WARM LINAC HIGH POWER RF SYSTEMS

Author: Arash Kaftoosian[1]

[1] *ESS Bilbao*

Corresponding Author: akaftoosian@essbilbao.org

ESS Bilbao, an international center for neutron science and technologies in Spain, is in charge of Spanish in-kind contribution to the European Spallation Source (ESS) project. That includes all high power RF sources for the normal-conducting section of ESS LINAC consists of three 30kW solid-state

amplifiers for buncher cavities in the MEBT section and six 3MW 352MHz klystron amplifiers for RFQ and DTLs including modulators, LLRF, interlocks and RF distribution system. These RF sources will operate in pulse regime with 3.5ms pulse-width and 5% duty cycle.
In line with this project, a 2kW solid-state amplifier module based on novel compact balanced architecture has been developed and tested in-house as an R&D activity and also characterization and tendering of 30kW solid-state RF transmitters with high reliability to feed the buncher cavities and high average power klystrons are in process.
This paper will address status of the project including conceptual design, test results, ongoing activities and challenges.

Summary:

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Solid state amplifier using a cavity combiner

Author: Michel Langlois[1]

Co-authors: Jörn Jacob [1]; Pierre Barbier [1]

[1] *ESRF*

Corresponding Authors: barbier@esrf.fr, michel.langlois@esrf.fr, jacob@esrf.fr

Further to our communication at last CWRF, a 85kW solid state amplifier has been designed, assembled and tested at ESRF up to 90kW. Its operation frequency is 352.2MHz. It features a cylindrical cavity to combine the RF power coming from its 132 modules. Details will be given on its construction, and test results both for CW and pulse modes.

Summary:

RF Power Amplifier Technology –New Developments and Performance

Solid state amplifiers 3 / 22

Commissioning of high-power RF at Solaris Light Source

Author: Pawel Borowiec[1]

[1] *Jagiellonian University (PL)*

Corresponding Author: pawel.borowiec@uj.edu.pl

This presentation will give a view on an installation, a commissioning process and first operational experience related to injector's acceleration components and cavities in storage ring with their RF power sources and transmission lines at Solaris synchrotron. Solaris injector's RF stations uses one K1-type solid state pulsed modulator with S-band 10MW Thales klystron for RF thermionic gun and 3 pieces of K2-type solid state pulsed modulators with S-band 37MW Toshiba klystrons. Modulators are operational since November of 2014, first as standalone RF units for test themselves and now in connection with linear accelerator. Injector consists S-band thermionic RF gun, 6 pieces of room temperature S-band accelerating structures organized in 3 units. 3 SLED cavities are working in one unit. Storage ring includes 2 pieces of 100MHz active main cavities and 2 pieces of 3rd order passive cavities. 2 pieces of solid state 100MHz 60kW transmitters are used for operation in storage ring since May 2015. They are modified CW Band II broadcasting transmitters. Two 30kW racks are combined in one 60kW system and modification in internal control system have been implemented light source application.

Summary:

Operation reports & Closure / 23

Operation of Diamond Light Source RF Cavities

Author: Pengda Gu[None]

Corresponding Author: gupengda@gmail.com

In past two years, we have experienced two serious failures of our SRF cavities. Cavity 2 developed a leak from the helium can into cavity UHV and the RF window assembly of cavity 4 failed after just 10 months' operation. The UHV leak repair is on-going but the RF window was swapped with a spare in a clean room on site and cavity 4 has been subsequently tested to over 2 MV. The impact of cavity failure on machine operation and the long repair time of the UHV leak has led to the proposal for a combined configuration of normal conducting cavities and SRF cavities for the storage ring. We are also working to upgrade our LLRF system from analogue to digital. This will enable us to address issues such as probe blips, cavity conditioning and fault diagnosis. This system will be deployed for both storage ring and booster cavities.

Summary:

IOTs / 24

Improvements to Diamond Light Source RF Amplifiers

Author: Peter Marten[1]

[1] *Diamond Light Source*

Corresponding Author: peter.marten@diamond.ac.uk

Reliability of Diamond Light Source has improved enormously since operation for users began in 2007, with overall machine MTBF for the 12 months to May 2016 over 120 hours. Details are presented of reliability-related management and improvements to both storage ring and booster amplifiers. Beam quality is also an issue for users and so work has been carried out to minimise and remove high frequency noise on the beam arising from the IOT high voltage power supply. Plans to introduce normal conducting cavities into the storage ring to support superconducting cavity operation also introduce challenges and opportunities for amplifier operation and so an overview of amplifier work in relation to this project is discussed.

Summary:

Tetrodes and miscellanea / 26

Optimisation of SLED Cavities and Waveguide Network to Drive the Linac at the Australian Synchrotron

Author: Thomas Geoffrey Lucas[1]

Co-authors: Karl Ludwig Zingre [1]; Mark Boland [2]; Roger Paul Rassool [1]

[1] *Australian Synchrotron (AU)*

[2] *Australian Synchrotron*

Corresponding Authors: thomas.geoffrey.lucas@cern.ch, mark.boland@synchrotron.org.au, roger.paul.rassool@cern.ch, karl.zingre@synchrotron.org.au

With the ageing of equipment in user facilities, the risk of downtime due to hardware malfunctions becomes a more likely scenario. At the Australian Synchrotron, two klystrons running at 15 MW each are required for injection into the booster ring. Consequently, failure of a single klystron could lead to the loss of weeks of beam time. A forthcoming upgrade to the current system includes a SLED system for pulse compression to increase output power, and allows for the use of a single klystron for full energy injection from the linac. This paper describes the optimisation of the SLED cavities and waveguide system to deliver electrons at nominal energies in single bunch mode. Following is an analysis on maximising the possible bunch train length multi-bunch mode and a brief look at the feasibility of generating electrons at greater energies.

Summary:

Miscellanea / **27**

The High Power RF Systems of MAMI and MESA

Author: Robert Heine[1]

Co-author: Frank Fichtner [1]

[1] *Johannes Gutenberg-Universität Mainz*

Corresponding Authors: fichtner@kph.uni-mainz.de, rheine@uni-mainz.de

The Institute for Nuclear Physics (KPH) of Mainz University is operating the CW mictrotron cascade MAMI (Mainzer Mikrotron) for more than 30 years. Since 2012 KPH is also planning a CW multi-turn energy recovery linac MESA (Mainz Energy-recovering Superconducting Accelerator).

In this contribution we will sum up our experience with the klystron based RF-system of MAMI (2.45 GHz and 4.9 GHz) and will also discuss our plannings for the solid-state based RF-system of MESA.

Summary:

Poster session / **28**

RF systems testing solutions for scientific facilities

Author: Francisco Sierra[1]

Co-authors: Juan Lluch [1]; Moises Weber [2]

[1] *BTESA*

[2] *CIEMAT*

Corresponding Authors: moises.weber@ciemat.es, f.sierra@btesa.com, j.lluch@btesa.com

Radiofrequency systems of scientific installations are composed of several independent sub-systems, which should be tested both independent and jointly. These tests may become an issue since normally each system is manufactured by a different company, especially at joint international installations where contributions come from different countries.

This presentation will introduce the different solutions implemented by BTESA to solve some problems such as how to test an independent SSPA module extracted out of a SSPA amplifier (thus without the main SSPA control, circulator, loads and liquid cooling), how to condition a coupler without the main liquid cooling system of the facility, how to test a 200-entries cavity combiner with a single amplifier, how to test the stability of power supplies for superconducting magnets without the magnet load···Details about the test benches and installations with all the control system, probes, diagnosis and self-refrigeration systems will be described in this poster

Summary:

Poster session / **29**

Advanced Low Level RF system for IFMIF and LIPAc particle accelerators

Author: MOISES WEBER[1]

Co-authors: Benoit Ratt [2]; Cristina de la Morena [3]; David Regidor [3]; Igor Kirpitchev [1]; J. Gabriel Ramirez [2]; Javier Díaz [2]; Joaquin Molla [1]; Miguel Méndez [2]; Purificacion Mendez [3]; Ángel Ibarra [1]

[1] *CIEMAT*

[2] *SEVEN SOLUTIONS*

[3] *Ciemat*

Corresponding Authors: mmendez@sevensols.com, moises.weber@ciemat.es, bratt@sevensols.com, gramirez@sevensols.com, joaquin.molla@ciemat.es, p.mendez@ciemat.es, cristina.delamorena@ciemat.es, igor.kirpitchev@ciemat.es, jdiaz@sevensols.com, david.regidor@ciemat.es, angel.ibarra@ciemat.es

The International Fusion Materials Irradiation Facility (IFMIF) aims to develop a structural materials database for future nuclear fusion reactors. In order to validate its final accelerators concept and technologies, the IFMIF Linear Prototype Accelerator (LIPAc) is commissioned at Rokkasho (Japan) in the framework of the IFMIF-EVEDA project.
CIEMAT (Spain) leads the Engineering Design of the IFMIF RF Power System as well as integrates and provides the RF Power System for LIPAc, including the Low-Level Radio Frequency system (LLRF).
LIPAc is an innovative accelerator (125mA, 9 MeV D+beam, C.W.). Its challenging requirements lead to a high level of uncertainty and thus a flexible and reconfigurable high performance LLRF is required.
LLRF systems use to be analog or digital-analog, since they use, at least, analog front-ends for intermediate frequency (IF) conversion before or after digitalization. However, the LIPAc LLRF, developed by CIEMAT and SEVEN SOLUTIONS, is an innovative fully digital system. No analog frequency conversion is performed, which increases the measurement bandwidth and simplify the analog front-end design. This LLRF also integrates White Rabbit (WR) protocol for timing synchronization (sub-nanosecond) and Master Oscillator distribution. The first units have been tested with full power LIPAc RF amplifier chains performing better than expected.

Summary:

On the IFMIF/LIPAc innovative fully digital advanced LLRF developed by CIEMAT and SEVEN SOLUTIONS

Miscellanea / **30**

Circulator Tracking at 80.5 MHz

Author: Janez Klanjsek[1]

Co-authors: Fabian Schütt [1]; Martin Beyer [1]; Matthias Ehret [2]; Thomas Weber [3]; Wilhelm Tewes [4]

[1] *HBH Microwave GmbH*

[2] *HBH Microwave Gmbh*

[3] *Elamakato GmbH*

[4] *HBH Microwave*

Corresponding Authors: m.beyer@hbhmw.de, jansek@gmail.com, w.tewes@hbhmw.de, m.ehret@hbhmw.de, f.schuett@hbhmw.de, thomas.weber@elamakato.de

A high power amplifier at 80.5 MHz was developed for a linear accelerator system. This amplifier has to hold 100% reflection at all phases and therefore a circulator has to be integrated to protect the transistor of the amplifier pallet from overvoltage breakdown.
At this low frequency isolation and reflections are changing with RF power and temperature. To hold the necessary input return loss of the circulator, voltage controlled tuning coils give the ability to adjust the magnetic field and tune the circulator in such way that is keeps minimum reflection.
Software defined tracking algorithm was developed to control the circulator. Input parameters of the tracking algorithm are forward and reflected RF power applied to the input port of the circulator and heat sink temperature. Output of the control module is an analog voltage that keeps circulator return loss at input port at minimum and therefore isolation at maximum.
Three circulators are part of one 2 kW Solid-State Power Amplifier unit and are controlled simultaneously. Software controlled circulator tracking works for any reflection phase, CW or modulated signal and requires no ramp up or inhibition time to reach full power.
Circulator characterization, tracking algorithm and implementation results will be presented.

Summary:

Software regulation of a 80.5 MHz circulator in a high power solid-state power amplifier for a linear accelerator system.

Poster session / 31

RAON RF Systems

Author: Jae Eun Han[1]

Co-authors: Doyoon Lee [1]; In-Il Jung [1]; Kitaek Son [1]; Myungook Hyun [1]; Ohryong Choi [1]

[1] *Institute for Basic Science*

Corresponding Authors: skt1385@ibs.re.kr, dylee@ibs.re.kr, atikus43@ibs.re.kr, analogcmos@ibs.re.kr, cor@ibs.re.kr, jehan@ibs.re.kr

The RAON accelerator planned SC linac in Korea will use solid state power amplifiers to provide superconducting cavities with rf power. The RAON main accelerator is composed of a normal conducting injector and a superconducting linac. SC linac uses 3 types of SC cavities which are QWR, HWR and SSR. SSR is composed of two families at low and high beta. Each cavity is driven by a SSPA. SSPA which is developed by in house is based on the 2 kW module. An LLRF systems to control the amplitude and phase of RF fields, which was built for normal conducting cavities for mock-up cavities has been modified to control a superconducting cavity. RF reference line will be planned to test the power distribution systems.

Summary:

Operation reports & Closure / 32

A new concept of High Voltage Power Supply System for the RF Amplifier of the CR Debuncher at FAIR

Author: Cristiano Morri[1]

Co-authors: Girolamo OCERA [1]; Giuseppe Taddia [1]; Miguel PRETELLI [1]; Stefano LISSANDRON [1]; Thomas WINNEFELD [2]; Ulrich LAIER [2]

[1] *OCEM Energy Technology*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

Corresponding Authors: cristiano.morri@ocem.com, u.laier@gsi.de, stefano.lissandron@ocem.com, miguel.pretelli@ocem.com, t.winnefeld@gsi.de, giuseppe.taddia@ocem.com, girolamo.ocera@ocem.com

A sophisticated power supply was developed, built and commissioned to operate the RF system of the Collector Ring, a storage ring of the future FAIR (Facility for Antiproton and Ion Research) complex. It supplies the power amplifier of RF: a total of 5 power supplies (anode, control grid, two screen grids, two filaments) and a controlled load.

The RF system will be operated in continuous wave (CW), with RF voltages of up to 2kV, and pulsed, with RF voltages up to 40kV. The power supply performs a fast switching between them (<200 µs) of the control grid voltage (700V versus 200V) and the anode voltage (6kV - 10A versus 25kV - 100A). Also the requirements for voltage stability, to be assured in every condition, are challenge: down to ±0.1% of set point.

The realized anode PS uses a modular design: many smart units precisely control their output voltage; PSM modulation fixes the overall output through IGBTs. A mix of centralized and distributed control strategy applies. The final PS is a high voltage - high energy switching converter, with reduced ripple, wide dynamic and integrated arc protection.

This paper presents the solution designed and the results obtained on the first prototype.

Summary:

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This paper presents the solution designed and the results obtained on the first prototype.

Status and projects 1 / 35

Towards Elettra-II

Author: Cristina Pasotti[1]

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

Corresponding Author: cristina.pasotti@elettra.eu

Elettra is a user dedicated third generation light source operating at 2.0 GeV (310 mA) and 2.4 GeV (160 mA). The performances and the operating features of the 500 MHz storage ring RF stations and the single RF booster plant are presented. The revamp plan of the RF power sources that takes into account the requirement for the Elettra II project is presented. The first step of this plan is the 18 kW SSPA for the Booster.

Summary:

Status and projects 1 / **36**

RF System Upgrade for the New Extremely Brilliant Light Source at the ESRF, Operation Experience with Klystrons and Solid State Amplifiers

Author: Jorn Jacob[1]

Co-authors: Alessandro D'Elia [1]; Georges Gautier [1]; Jean-Maurice Mercier [1]; Michel Langlois [1]; Vincent Serrière [1]

[1] *ESRF*

Corresponding Authors: serriere@esrf.fr, gautier@esrf.fr, delia@esrf.fr, mercier@esrf.fr, jacob@esrf.fr, michel.langlois@esrf.fr

Since April 2012, the ESRF booster synchrotron is powered with four 150 kW - 352.2 MHz solid state amplifiers (SSA). In 2013 another three 150 kW SSAs were taken into operation on the 6 GeV storage ring, powering new strongly HOM damped cavities, which are run in parallel with the existing five-cell cavities fed from 1.1 MW klystron transmitters. Operation experience and RF system developments partly linked with the recent implementation of top up operation will be reported.

A new ultra low emittance storage ring is under construction at the ESRF and will be installed in the existing tunnel in 2019. All the five-cell cavities will be replaced with single cell HOM damped cavities. Four of them will be powered with SSAs and ten with an existing klystron transmitter.

Summary:

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Tetrodes and miscellanea / **37**

INNOVATIVE KLYSTRON MODULATION ANODE VOLTAGE CONTROL SYSTEM AND VOLTAGE & CURRENT MEASUREMENT SYSTEM

Authors: Gianfranco Ravida[1]; Ruben Lorenzo Ortega[1]

[1] *CERN*

Corresponding Authors: ruben.lorenzo.ortega@cern.ch, gianfranco.ravida@cern.ch

The counter-rotating proton beams in the Large Hadron Collider (LHC) are captured and then accelerated to their final energies by two identical 400 MHz RF systems. The RF power source required for each beam comprises eight 300 kW klystrons powered by two 100 kV, 40 Amp, AC/DC power converters. The klystron currents (and DC power) can be individually controlled by means of a klystron modulator. A solid state crowbar system protects the four klystrons of each unit. The performance of the high-voltage elements of this system are discussed, with emphasis on the new features of the klystron modulator system: the new Voltage and Current Measurement System, which uses sensitive electronics such as current transducers, Complex Programmable Logic Device (CPLD) and Analog-to-Digital Converter (ADC), that have to cope with huge current spikes in case of faults, is described. Ongoing developments for an innovative Klystron Mod Anode Voltage Control System, which will be used to regulate the klystron current, replacing the existing tetrodes, are also discussed.

Summary:

Tetrodes and miscellanea / **38**

Various RF systems within the Collider-Accelerator complex at Brookhaven National Laboratory

Author: Darryl Goldberg[1]

[1] *Brookhaven National Laboratory*

Corresponding Author: dgoldber@bnl.gov

Various High power RF cavities are utilized within the C-AD complex, including ferrite loaded, pill-box, folded transmission line, and tapped transmission line. High power amplifiers range from solid state solutions to vacuum electron devices, at power ranges of 1 kW to 5 MW pulsed. The RF frequency spectrum of systems varies drastically, from 300 kHz to 201 MHz for operational systems, and up to 2.1GHz for developmental systems.

Summary:

There are many types of RF systems used at Brookhaven National Laboratory (BNL). This will discuss a general overview of operational systems within the Collider-Accelerator Department (C-AD), from pre-injector to final storage rings. Concentration will focus on the Alternating Gradient Synchrotron (AGS) Booster, AGS, and the Relativistic Heavy Ion Collider (RHIC). Included will be a discussion on the current operational status of the 200MeV LINAC and upgrades needed to extend the lifetime of the accelerator.

Welcome / **39**

Status of the ALS and APEX RF Systems at LBNL

Author: Kenneth Baptiste[1]

Co-authors: Greg Harris [1]; James Julian [1]; John (Pat) McKean [1]; Massimiliano Vinco [1]; Qiang Du [1]; Slawomir Kwiatkowski [1]

[1] *LBNL*

Corresponding Authors: kmbaptiste@lbl.gov, mvinco@lbl.gov, jpmckean@lbl.gov, alsjulian@comcast.net, skwiatkowski@lbl.gov, glharris@lbl.gov, qdu@lbl.gov

I will present the status of the RF systems at the Advanced Light Source (ALS), the progress made in upgrading the Storage Ring RF system and the remaining work to complete the upgrade. Additionally, I will report on the design and early operation of the Advanced Photon Experiment (APeX) RF systems.

Summary:

I will present the status of the RF systems at the Advanced Light Source (ALS), the progress made in upgrading the Storage Ring RF system and the remaining work to complete the upgrade. Additionally, I will report on the design and early operation of the Advanced Photon Experiment (APeX) RF systems.

Solid state amplifiers 2 / **40**

Preliminary measurements of eight solid-state modules of the 10 kW pulsed power amplifier at 352 MHz under development at FREIA

Author: Dragos Dancila[1]

Co-authors: Anders Rydberg [1]; Jorgen Olsson [1]; Long Hoang Duc [1]; Magnus Jobs [1]; Roger Ruber [2]; Vitaliy Goryashko [1]

[1] *Uppsala University*

[2] *Uppsala University (SE)*

Corresponding Authors: magnus.jobs@physics.uu.se, roger.ruber@cern.ch, vitaliy.goryashko@physics.uu.se, long.hoang@angstrom.uu.se, anders.rydberg@angstrom.uu.se, jorgen.olsson@angstrom.uu.se, dragos.dancila@angstrom.uu.se

Solid-state high power amplifiers are increasingly used in particle accelerators as drivers and as high power stages themselves. In this context, at FREIA, we are developing a 10 kW pulsed power amplifier at 352 MHz. The frequency and pulsed operation (3.5 ms pulse at 14 Hz repetition) correspond to the specifications of the European Spallation Source (ESS), which we assist in its development and testing. The 10 kW amplifier is composed of eight modules, each module is built around a single package including two Si LDMOS transistors, operated in class B. The r.f. design implements matching networks in a single-ended architecture and avoids the use of baluns, required for a push-pull configuration. The operation in pulsed mode allows using a capacitor bank (eight 68 mF capacitors) releasing the extent of the DC power supply. Preliminary measurements demonstrate an output pulsed power around 1250 W per module, a power-added efficiency of 70% and a gain of 20 dB. A small variation (< 5^0) within the phase and gain (< 0.5 dB) distribution among the modules is obtained. Analogue circuits monitoring the operational currents, voltages and temperature for each module are also under development in addition of high power combiners.

Summary:

Solid state amplifiers 3 / **41**

Time domain characterization of high power RF pulsed solid state amplifiers for linear accelerators

Author: Long Hoang[1]

Co-authors: Anders Rydberg [1]; Dragos Dancila [1]; Jorgen Olsson [1]; Roger Ruber [2]; Vitaliy Goryashko [1]

[1] *Uppsala University*

[2] *Uppsala University (SE)*

Corresponding Authors: anders.rydberg@angstrom.uu.se, roger.ruber@cern.ch, dragos.dancila@angstrom.uu.se, vitaliy.goryashko@physics.uu.se, jorgen.olsson@angstrom.uu.se, long.hoang@angstrom.uu.se

At the FREIA laboratory, we develop and test high power RF equipment for the linear accelerator of the European Spallation Source (ESS). In this respect, we develop high power RF amplifiers based on the Laterally Diffused Metal Oxide (LDMOS) semiconductor technology. The purpose of this paper is to present a time domain characterization methodology for high-power pulsed amplifiers. A measurement setup composed of an embedded monitoring circuit is built-up in order to perform the pulse profile measurements, as well as to investigate the pulse-to-pulse amplitude and phase stability. The monitoring circuit consists of several analogue sensors and an Arduino microcontroller. The analogue circuits are used to measure the critical parameters of the amplifiers such as: the pulsed current, drain voltage, and operating temperature of the transistor. The measured results enable the evaluation of the amplifiers' performance and stability i.e. the time domain average and variation of the amplitude and phase. Initial tests performed at about 1.25 kW RF power, with 70% drain efficiency at 352 MHz demonstrate a high stability of the tested amplifiers. A standard deviation of around -85 dB in amplitude and -30 dB in phase is obtained after 10 hours of operation.

Summary:

IOTs / **42**

The Multi-Beam IOT developments for ESS

Author: Morten Jensen[1]

[1] *European Spallation Source*

Corresponding Author: morten.jensen@esss.se

The high beta section of the ESS linac requires 84 RF sources which each have to deliver 1.1 MW to the beam plus a power overhead capability for losses and regulation requirements. This talk will summarise the main reasons for funding the IOT developments for this part of the linac, present the outline IOT design and simulation results. Additionally, a selection of key results from the first prototype will be presented.

Summary:

The high beta section of the ESS linac requires 84 RF sources which each have to deliver 1.1 MW to the beam plus a power overhead capability for losses and regulation requirements. This talk will summarise the main reasons for funding the IOT developments for this part of the linac, present the outline IOT design and simulation results. Additionally, a selection of key results from the first prototype will be presented.

Spallation sources / **43**

Upgrades to the Spallation Neutron Source Radio Frequency Systems to Support the Second Target Station.

Author: Mark Middendorf[1]

[1] *SNS, ORNL*

Corresponding Author: middendorfme@ornl.gov

To support the requirements for the Spallation Neutron Source (SNS) Second Target Station (STS), the accelerator systems will be upgraded to support an average proton beam power on target of 2.8MW. To accomplish this requires an increase in both beam energy and average current. We describe the upgrades to the SNS Radio Frequency (RF) systems to support these requirements.

Summary:

To support the requirements for the Spallation Neutron Source (SNS) Second Target Station (STS), the accelerator systems will be upgraded to support an average proton beam power on target of 2.8MW. To accomplish this requires an increase in both beam energy and average current. We describe the upgrades to the SNS Radio Frequency (RF) systems to support these requirements.

Status and projects 1 / **44**

Some Thoughts on the Advanced Photon Source Upgrade (APS-U) 352MHz RF System

Author: Alireza Nassiri[1]

[1] *Argonne National Laboratory*

Corresponding Author: nassiri@aps.anl.gov

A hybrid seven-bend achromat lattice is designed for the APS-U multi-bend achromat (MBA) which will require a bunch-lengthening cavity to mitigate the effects of Touschek scattering on the beam lifetime. Accommodating MBA lattice in the existing APS storage ring tunnel will require reconfiguration of the present storage ring rf system. We will describe various potential RF system configurations.

Summary:

A hybrid seven-bend achromat lattice is designed for the APS-U multi-bend achromat (MBA) which will require a bunch-lengthening cavity to mitigate the effects of Touschek scattering on the beam lifetime. Accommodating MBA lattice in the existing APS storage ring tunnel will require reconfiguration of the present storage ring rf system. We will describe various potential RF system configurations.

Klystrons / **45**

Overview of the 704 MHz high power amplifiers at ESS including progress and first results

Author: chiara marrelli[1]

Co-authors: Morten Jensen [2]; Stevo Calic [1]

[1] *ESS*

[2] *European Spallation Source*

Corresponding Authors: stevo.calic@esss.se, chiara.marrelli@esss.se, morten.jensen@esss.se

The talk will give an overview of the ESS RF system, with focus of the medium beta part of the linac. This section will contain 36 superconducting cavities, each foreseen to be supplied by a single

klystron, able to provide 1.5 MW peak output power at 704.42 MHz. ESS is currently procuring three medium beta klystron prototypes: The main design features will be presented in the talk, together with results from the first tests.

Summary:

Welcome / **46**

Operation Status of the RF Systems in Taiwan Light Source and Taiwan Photon Source

Author: Ming-Chyuan Lin[1]

Co-authors: Chaoen Wang [2]; Chi-Lin Tsai [2]; Chih-Hung Lo [2]; Fu-Tsai Chung [2]; Ling-Jhen Chen [2]; Lung-Hai Chang [2]; Mei-Hsia Chang [2]; Meng-Shu Yeh [2]; Ming-Hsun Tsai [2]; Tsung-Chi Yu [2]; Zong-Kai Liu [2]

[1] *National Synchrotron Radiation Research Center*

[2] *NSRRC*

Corresponding Authors: tsai.cl@nsrrc.org.tw, rfwang@nsrrc.org.tw, mhchang@nsrrc.org.tw, lo.ch@nsrrc.org.tw, chen.lj@nsrrc.org.tw, chyuan@nsrrc.org.tw, liu.zk@nsrrc.org.tw, mhtsai@nsrrc.org.tw, yu.tc@nsrrc.org.tw, lhchang@nsrrc.org.tw, msyeh@nsrrc.org.tw, gofor@nsrrc.org.tw

Two synchrotron light sources are operated in the National Synchrotron Radiation Center (NSRRC), Taiwan: the Taiwan Photon Source (TPS) is newly built with a circumference of 518.6 meters and stored beam energy of 3.0 GeV, whereas the Taiwan Light Source (TLS) is operated over two decades with a circumference of 120 meters and stored beam energy of 1.5 GeV. Both light sources are equipped with high power superconducting radio-frequency (SRF) modules to accelerate the electron beam. The continuous wave 100-kW RF system for electron storage ring of the TLS has great reliability; its mean time between failure (MTBF) has a record of 862.8 hours in 2013 and lately 665.9 hours in 2015. Two 300-kW CW RF systems serves for electron storage ring of the TPS, higher and higher operation power are requested for greater stored beam current and more insertion devices and thus the operation parameters are still optimized from time to time. Moreover, a 60-kW RF system dedicates to the booster ring of the TLS to satisfy the top-up operation of the TLS storage ring, whereas a 100-kW RF system serves for TPS booster ring. An energy-saving operation scheme is successfully realized on the booster RF system of TLS which requests of beam injection of 2 seconds each minute. Herein not only the operation status and activity but also the foreseen challenges of the CW RF systems of both the TLS and TPS are presented.

Summary:

IOTs / **47**

Initial Factory Test of the L6200 Multi-Beam IOT for ESS

Author: Mark Kirshner[1]

Co-authors: Andrew Zubyk [2]; Ann Sy [2]; Brandon Weatherford [2]; Holger Schult [2]; Ladislav Turek [2]; Michael Boyle [2]; Richard Kowalczyk [2]; Richard True [2]

[1] *L-3 Communications*

[2] *L-3 Communications Electron Devices*

Corresponding Authors: ann.sy@l-3com.com, richard.kowalczyk@l-3com.com, andrew.zubyk@l-3com.com, michael.boyle@l-3com.com, richard.true@l-3com.com, brandon.weatherford@l-3com.com, ladislav.turek@l-3com.com, holger.schult@l-3com.com, mark.kirshner@l-3com.com

L-3 Communications Electron Devices is developing a 1.2 MW Multi-Beam Inductive Output Tube (MBIOT) for the European Spallation Source. Construction of the MBIOT has been completed, an in-house test facility is operational, and factory testing is in process. In this talk, the MBIOT design and supporting simulation work will be summarized, as will important aspects of the fabrication process and test configuration. MBIOT performance data will also be presented.

Summary:

L-3 Communications Electron Devices is developing a 1.2 MW Multi-Beam Inductive Output Tube (MBIOT) for the European Spallation Source. Construction of the MBIOT has been completed, an in-house test facility is operational, and factory testing is in process. In this talk, the MBIOT design and supporting simulation work will be summarized, as will important aspects of the fabrication process and test configuration. MBIOT performance data will also be presented.

Spallation sources / **48**

High power model of Isolator

Author: Rutambhara Yogi[1]

Co-author: Morten Jensen [2]

[1] *ESS*

[2] *European Spallation Source*

Corresponding Authors: morten.jensen@esss.se, 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. The ESS linac will accelerate a proton beam current of 62.5 mA to 2 GeV. The beam pulse width is 2.86 ms long and the pulse repetition frequency is 14 Hz, producing a proton beam with 5 MW average power and 125 MW peak power. The acceleration will be provided by 155 cavities. According to the base line design for ESS, there will be one RF system per cavity. Hence there will be 155 RF systems.

According to energy recovery plans, klystron and IOT collectors as well as anodes of the tetrodes will be cooled by hot water (minimum inlet temperature ≥ 50oC). The loads are also put on high temperature cooling circuit to simplify the energy recovery. To understand the effect of hot water cooling of load on the operation of amplifier, high power model of isolator is developed. The high power model also takes into consideration the effect of finite load return loss and the finite directivity of the circulator.

The paper discusses the possible effect of load technology and load return loss on the operation of high power amplifiers.

Summary:

Poster session / **49**

High Power Gysel Combiner Circuit design of Parallel plate structure

Author: Ki taek Son[1]

Co-authors: IN-IL JUNG [2]; Jae Eun Han [1]

[1] *Institute for Basic Science*

[2] *Rare Isotope Science Project/Institute for Basic Science*

Corresponding Authors: skt1385@ibs.re.kr, analogcmos@ibs.re.kr, jehan@ibs.re.kr

The Parallel Plate RF Power Combiner consists of 2 copper palate and has a gap between 2 Plate

Summary:

The recent development of semiconductor technology has proved that solid-state RF amplifier is a quite effective alternative high power RF source for numerous accelerator applications.
when high Power RF source supply cavity, high power combiner is required to combine a lot of solid-state RF amplifier
The parallel plate RF power combiner, Which was designed to combine various high power module is under Development for Rare Isotope Science Project(RISP)

Tetrodes and miscellanea / **51**

Status of the High Intensity Cyclotron RF-System at PSI

Author: Markus Schneider[1]

[1] *Paul Scherrer Institut*

Corresponding Author: markus.schneider@psi.ch

In the High Intensity Proton Accelerator (HIPA) facility at PSI, protons are accelerated in the injector cyclotron to 72MeV and afterwards in the Ring cyclotron to 590 MeV. The routine operation of the facility is at a current of 2.2 mA with tests regularly up to 2.4 mA. In both separated sector cyclotrons, the main acceleration is done by 50 MHz cavities. For flat-topping, an additional 3rd harmonic cavity is installed.

This talk will report on the operational experience of the rf-system with an emphasis on the amplifiers. Those are 20 to 30 years old tetrode based amplifier chains and feed up to 600kW CW into each main cavity.

Summary:

Poster session / **52**

HPRF 162.5MHz SSPA(5 kW) Power Test using parallel Plate Gysel Combiner

Author: Oh Ryong Choi[1]

Co-authors: IN-IL JUNG [2]; Jae Eun Han [1]; Ki taek Son [1]

[1] *Institute for Basic Science*

[2] *Rare Isotope Science Project/Institute for Basic Science*

Corresponding Authors: cor@ibs.re.kr, analogcmos@ibs.re.kr, jehan@ibs.re.kr, skt1385@ibs.re.kr

In rare isotope accelerator facilities, the 162.5MHz high power RF combiner is used to combine many RF power modules.
Recentry HPRF combiner has developed to combine high power RF source up to 10 kW for Rare Isotope Science Project(RISP)

162.5 MHz RF power test to the high power combiner has been performed 5 kW before the full power operation

Summary:

Solid state amplifiers 2 / 53

High Power Solid State Power Amplifiers for the CERN LHC Injector Upgrade for SPS programme

Author: Eric Montesinos[1]

[1] *CERN*

Corresponding Author: eric.montesinos@cern.ch

The talk will explain the reasons why CERN signed a contract for the procurement of two 2 MW peak power amplifiers based on SSPA technology.

Comparison that has been made with other technologies (tetrodes, IOT, Diacrodes, Klystrons) will be explained.

Basic principles of the chosen solution will be given.

Summary:

Klystrons / 54

Recent developments towards very high efficiency klystrons

Author: Erk Jensen[1]

[1] *CERN*

Corresponding Author: erk.jensen@cern.ch

Even though the klystron concept is more than 50 years old, recent innovative ideas concerning the bunching mechanism promise a significant increase of electronic efficiency and indicate the possibility to reach 90%. These ideas include “bunch core oscillations”, “concregated bunches” and the BAC method (for “bunch - align - collect”). We will present the status of this work including the recent first experimental verification of the principle.

E. Jensen reporting for the collaboration (I. Syratchev, A. Baikov, I. Guzilov, J. Neilson, A. Jensen, G. Burt, D. Constable, C. Lingwood, A. Mollard, R. Marchesin, Q. Vuillemin, C. Marrelli, R. Kowalczyk, T. Grant)

Summary:

Status and projects 2 / 55

Construction of the RF System for the European XFEL

Authors: Stefan Choroba[1]; Valery Katalev[1]

[1] *DESY*

Corresponding Authors: stefan.choroba@desy.de, valery.katalev@desy.de

The European XFEL is based on a superconducting linear accelerator with an energy of 17.5GeV. The nine-cell superconducting cavities are operated at 1.3GHz at a nominal gradient of 23.6MV/m. In order to supply RF power to the 808 superconducting cavities and to the normal conducting RF gun 27 RF stations are required. Each RF station generates up to 10MW of RF power at a pulse duration up to 1.4ms and a repetition rate of 10Hz. It consists of several subsystems and components e.g. klystrons, modulators or waveguides. A reliable, compact and inexpensive RF power distribution has been developed. During production of the cavities and the accelerating modules for the XFEL it turned out that cavities are only capable of different maximum gradients. Since the original layout was aimed for equal power of 120kW for each cavity it was necessary to modify the distribution allowing for individual RF power supply for each cavity, between 50kW and 240kW. This paper describes the final layout of the RF power distributions and reports on the present status of the construction of the RF system.

Summary:

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Welcome address by Jörn Jacob and Pantaleo Raimondi

Author: Jorn Jacob[1]

[1] *ESRF*

Corresponding Author: jacob@esrf.fr

Summary:

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Workshop summary and closing remarks

Author: Daniel Valuch[None]

Corresponding Author: balu@balu.sk

Workshop summary and closing remarks

Summary:

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Availability of PETRA III from the RF point of view

Author: Ruediger Onken[1]

[1] *DESY*

Corresponding Author: ruediger.onken@desy.de

PETRA has not the availability as expected and stated to the MAC in November 2015.
It is, with 95 %, not “state of the art”for 3rd generation synchrotrons.
That is why a ”PETRA III Availability Review”takes place in May 26-27, 2016.
We want to present the result of this review from the rf point of view.

Summary: