6th Workshop on CW and High Average Power RF

Tuesday 4 May 2010 - Friday 7 May 2010

ALBA, Barcelona, Spain

Book of Abstracts

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Operation of a 10kW@1.3 GHz Solid State Amplifier at the Superconducting Linac ELBE

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The prototype of a "tunk key" 10kW@1.3GHz solid state power amplifier, designed and built by Bruker BioSpin Wissembourg/France has been tested at the superconducting linac ELBE in the Research Center Dresden-Rossendorf.
The talk gives an overview on the design, its RF-parameters and the first 8-week period of test and operation at the superconducting CW-linac ELBE.

Cavities and related / 5

Design of the CESR-B cavity for Q external of 65000

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The superconducting cavity designed for the Cornell Electron Storage Ring B-Factory (CESR-B) has been successfully adapted for use in synchrotron light sources and are in use at Canadian Light Source, Taiwan LS, Diamond LS, Shanghai LS. The coupling for these systems results in external Q's of ˜250,000 to 150,000. For application in new large diameter high brightness light sources such as NSLS-II and Taiwan Photon Source with very large ratios of beam power to cavity power the external Q must be reduced by increasing the coupling significantly. We present a coupler design which meets the NSLS-II Q external requirements of 65,000.

RF General / 6

Operational experience with the SOLEIL 352 MHz RF systems

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OPERATIONAL EXPERIENCE WITH THE SOLEIL 352 MHZ RF SYSTEMS

Patrick Marchand, on behalf of the SOLEIL RF group

The 352 MHz RF accelerating systems for the SOLEIL Booster (BO) and Storage Ring (SR) are in operation since mid 2006. In the BO, a 5-cell copper cavity of the CERN-LEP type is powered with a 35 kW solid state amplifier. In the SR, the required RF accelerating voltage (up to 4.4 MV) and power (560 kW at full beam current of 500 mA) is provided with two cryomodules, each containing a pair of superconducting cavities, specifically designed for SOLEIL. Both cryomodules are cooled down to 4.2 K with liquid helium from a single 350 W liquefier and each cavity is powered by a 180 kW solid state amplifier. The operational experience with these systems is reported.

Solid State Amplifiers / **7**

High RF power solid state amplifier developments at SOLEIL

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The required RF power for the SOLEIL Booster and Storage ring is provided using 352 MHz solid state amplifiers (1 x 35 kW and 4 x 190 kW). They consist in a combination of a large number of 330 W amplifier modules (1 x 147 and 4 x 726), based on a design developed in house, with LDMOS transistors, integrated circulators and individual power supplies. After about four years of running, the operational experience proved to be fully satisfactory. In the meantime, developments were carried out, which leads to a new generation of modules. The operational experience and development results are reported.

Tubes & HVPS / **8**

Correlated Measurments of HV power supply ripple and RF jitter: techniques and results

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Various methods of measuring RF amplitude and phase jitter and time correlated DC power supply variations are presented. A simple setup using a 4 channel scope as a digitizer is described. Measurements of the DC power supply variations and correlated RF amplitude and phase jitter of the klystron amplifier and SRF cavity fields for the Canadian Light Source are presented and the results summarized.

RF General / **9**

CW RF systems at Cornell University: status and operational experiens

Author: Sergey Belomestnykh[1]

[1] *Cornell University*

Two accelerator facilities at Cornell University use CW superconducting RF systems: Cornell Electron Storage Ring (CESR) and ERL injector prototype. The CESR RF operates at 500 MHz and employs two high power klystrons and four single-cell superconducting cavities. The 1300 MHz ERL injector system has six klystron transmitters and one IOT-based transmitter feeding five superconducting 2-cell cavities and normal conducting deflector and buncher cavities. In this presentation we discuss the status of the two systems and recent operational experience.

RF General / **10**

Analysis of Booster and Storage Ring RF System Reliability at the Advanced Photon Source

Author: Doug Horan[1]

[1] *Argonne National Laboratory*

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Performance of the Advanced Photon Source 352-MHz rf systems will be described, with emphasis on system reliability and related hardware issues. Recent failures involving high-voltage capacitors and cavity input couplers will be discussed. Methods employed to minimize klystron-related downtime will be described.

Solid State Amplifiers / **11**

352-MHz Solid State RF Power System Development at the Advanced Photon Source

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An investigation into the feasibility of utilizing solid-state rf power systems to replace the existing 352-MHz klystron-based rf power systems for the Advanced Photon Source booster and storage ring rf systems was started. Data from tests conducted on a dual-transistor/single-package LDMOS device capable of 1kW CW rf output at 352MHz will be discussed. Design details and test data for a four-port combiner will be presented.

Cavities and related / **12**

High Power RF Processing of Couplers, Windows, and Cavities for the SNS Linac

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High power RF processing of RF components has been performed at the Spallation Neutron Source (SNS) for installation, commissioning, and operations support of its linac accelerating cavity structures. SNS linac employs various types of accelerating structures: the normal conducting RFQ, drift tube linac (DTL), and coupled cavity linac (CCL) cavities and the superconducting RF linac (SCL) 6-cell cavities. The DTL and the CCL use the rectangular waveguide coupler windows and the RFQ and the SCL use the coaxial window couplers. At the beginning of the construction of the SNS, some couplers were processed at the partner laboratories of the SNS project; since then all types of couplers including new developments are routinely RF conditioned efficiently in the SNS test facility. The RF systems, components, and results of the RF processing in the SNS will be presented.

SSA (cont.) & Transmission lines & New projects / **13**

Status of High Power Solid State Amplifiers for the ESRF

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As presented in detail at the CWRF'2008 workshop, the ESRF RF system will undergo a major upgrade, klystrons being replaced with high power solid state amplifiers (SSA) and existing five-cell cavities of the storage ring with strongly HOM damped single cell cavities. The company ELTA, who has a technology transfer contract with SOLEIL, was selected to produce the first batch of seven 150 kW SSA for the ESRF. The first four SSA will be installed end of 2011 and then be operated in pulsed mode on the booster cavities. The following three SSA will be commissioned mid 2012 to power the first three HOM damped cavities on the storage ring. The progress of the SSA design and manufacture will be presented at the workshop.

Tubes & HVPS / **14**

MODIFICATION OF SEPARATOR AMPLIFIER AS A TEST STAND

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In TRIUMF, the Eimac power tetrode vacuum tube 4CW100,000 (or 4CW150,000) is used in 3 amplifier systems. It is also used in Nordion, a medical isotope production company with collaboration with TRIUMF, in its TR-30 phase II amplifier system. In addition, the power tetrode 4CW50,000, which uses the same socket as 4CW100,000, is used in Nordion TR-30 phase I amplifier system. A test stand is needed for conditioning and testing the spare vacuum tubes so that they can be ready for these systems in case the replacement of the tubes is needed.
There was originally an amplifier served for separator, which is no longer used in the beam line. It has been de-commissioned and has been standing idolly for more than 10 years. There is also a 25KV 10 amp PEI (Power Energy Industry) high voltage supply with missing soft start (ramping up voltage) control cards standing idolly for more than 15 years. It is decided that these two units will be modified to form the test stand amplifier system.
Compared with other amplifiers, the particular modification requirements for this one are as follows:
1): To modify the construction of the output cavity centre conductor to make the removal and installation of the vacuum tubes to be easier.

2): To design an adjustable output coupling loop to reflect the different load impedance requirement for 4CW100,000 (or 4CW150,000) and 4CW 50,000.
3): To provide the filament voltage selection with 15.5 volts for 4CW100,000 (and 4CW150,000), and 12 volts for 4CW 50,000;
4): To ensure the solid state driver be able to provide enough drive power at frequencies caused by the different plate output capacitance between 4CW100,000 (or 4CW150,000) and 4CW50,000.
As for the high voltage supply, the method of soft start for our RFQ high voltage supply is used. The special feature of the method is using single phase ramping for one phase first and subsequently for another to avoid the complicated logic for ramping three phases simultaneously.
The details of the modifications will be described in the post following.

SSA (cont.) & Transmission lines & New projects / **15**

WAVEGUIDE DISTRIBUTION SYSTEM FOR FLASH

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The linear accelerator for the Free Electron Laser in Hamburg (FLASH) contains fifty six superconducting cavities grouped into seven cryogenic modules and one normal conducting RF gun. The five RF stations using 5MW single beam and a 10MW multibeam klystrons supply the cryogenic modules and the gun through the distribution system based on WR650 waveguides. Since FLASH is based on the Tesla Test Facility, TTF, a number of different RF distribution layouts for the different modules and the gun have been developed and used over the years. Several waveguide components and distribution layouts have been developed, installed, operated at FLASH and checked for further usability at the European Free Electron Laser (XFEL). This presentation describes waveguide components and the distribution layout and summarizes the experience with the waveguide distribution system.

Tubes & HVPS / **16**

Upgrades to the SNS MEBT RF Power Amplifiers

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The original SNS baseline installation included six 20kWpk vacuum tube power amplifiers (four online amplifiers and two ready spares, manually interchangeable) to drive the four rebuncher cavities that are part of the Medium Energy Beam Transport (MEBT) structure. We are in the process of replacing the six vacuum tube amplifiers with five commercially-available 25kWpk solid-state amplifiers that will connect to the rebuncher cavities through a remotely-operated 4+1 switching matrix. An interim effort to replace the original linear high voltage anode power supplies with switching supplies, designed specifically for pulsed power applications, has significantly reduced the downtime associated with the MEBT rebuncher amplifiers. We report progress to date.

Tubes & HVPS / **17**

High voltage tetrode replacement in the LHC klystron modulator

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The 400MHz/300kW LHC klystrons are powered by 58kV DC supply. The klystron cathode current is controlled by a means of "modulation anode (MA)". Variation of the MA potential between 5kV and 35kV provide klystron current regulation from zero up to the nominal 9A.
A high voltage tetrode (Thomson TH5186) used in the klystron modulator allows to control the MA voltage. Many of the currently used tubes were recuperated from the LEP machine and they are reaching end of their life time. Very high price of the new replacement tubes triggered development of a new "tubeless" MA voltage source. A novel, step-controlled high voltage resistive divider based on reed switches is presented.

SSA (cont.) & Transmission lines & New projects / **18**

Hot S22 Measurement of LHC Circulators

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The LHC accelerating RF system merely consists of a 300 kW klystron, a 3-port circulator, a superconducting cavity and an RF load. The resonance of the superconducting structure is strongly influenced by the external RF system. The loaded Q, i.e. the external quality factor of the cavity, therefore also depends on the reflection of the circulator.
The circulators are equipped with a temperature control unit (TCU) compensating the thermal drift of the used ferrites for different power levels and phases. The response of the TCU is slow (as expected) and fast variations in power result in impedance changes in the circulator and therefore in a change of the loaded Q.

A study is being conducted on the RF behavior of the LHC circulators. The objectives are to understand the the relationship between the different reflection coefficients (S11 and S22) and their dependence on the applied RF power, compensation current and operating temperature. At high output power levels the S22 evades direct measurements, i.e. it has to be derived from transmission measurements.

We present the two different measurement setups for low and high power, respectively, and show first results. We discuss problems and limitations of the approach.

Solid State Amplifiers / **19**

150 kW Solid State Amplifier for Booster and Storage Ring

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ELTA is an AREVA subsidiary specialized in Radiofrequency Equipments and High Power Supplies for Aeronautics, Nuclear and Scientific applications.
In the frame of the upgrade of RF Power Amplifiers currently in operation at ESRF Booster (BO) and Storage Ring (SR), ELTA is in charge of the design and manufacturing of seven 150 kW SSA operating at 352 MHz .
This 150kW SSA is based on the pioneering work carried out by SOLEIL team on RF Amplifier Modules and their combination. A strong heritage on this technology is now recognized thanks to the SSA in operation at SOLEIL since several years.
A tight partnership between ELTA and SOLEIL has been set up for the design and the industrialization of this new 150kW SSA in order to achieve significant size saving. This 150 kW SSA features a new generation of modular High Power SSA with improved reliability, availability and maintenability. A new Instrumentation & Control Unit has been designed for achieving an accurate monitoring at LRU level and for performing safe interlocking functions.

RF General (cont.) & New Projects / **20**

The SPring-8 RF system and the experience of more than ten years of operation

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The RF system of the booster synchrotorn and of the storage ring at SPring-8 is equipped with 1MW CW klystrons. For the booster two klystrons are used and the phase between the two klystrons are changed accorging to the ramping up of the electron energy from 1 GeV to 8 GeV in order to form the accelerating voltage by the vector sum of the two outputs. The power produced by the 2 klystrons are fed to the 8 five-cell cavities to form the accelerating voltage.
For the storage ring, 32 single cell cavities in total are used to compensate the ca. 12-MeV radiation loss. The power consumed as a radiation loss is 1.2 MW, since the stored current is 100 mA. Four RF power stations are distributed evenly around the storage ring. Each station has 8 single cell cavities. Three stasions out of four are equipped with one klystron and remaining one station has two klystrons. The cavities for the storage ring has bell shaped and the radii of outer boundaries are slightly varied from cavity to cavity for them to have different HOM frequency while maintining the accelerating frequency unchanged to avoid strong instabilities induced by the HOM summing up. Furthre, HOM tuners are attached on all the cavities to obtain the flexible countermeasure against the instabilities.
The configuretions of the RF system will be introduced with the experience of the over 10-year period of operation.

RF General (cont.) & New Projects / **21**

Status of the Oak Ridge Spallation Neutron Source (SNS) and the RF Systems

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The SNS has been delivering production neutrons for four years. First beam was delivered to the neutron target at the end of April 2006. On September 18, 2009 SNS officially reached 1 megawatt of beam on target marking the achievement of a decades-old dream of delivering a mega-watt class pulsed spallation source in the U.S. The present effort is aimed at routinely delivering 1 megawatt of beam and gradually increasing the intensity to the 1.4 megawatt design level. This presentation provides a review of the SNS design, an overview of the performance and weaknesses of the various systems and a detailed review of the performance of the RF systems.

Cavities and related / **22**

The APS 350-MHz CW RF Test Stand

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In operation since 2002, the APS 350-MHz cw rf test stand is used primarily for testing and conditioning of storage ring rf cavity components. Successes, failures, and conditioning techniques will be discussed, as well as recent improvements including the implementation of an automated conditioning script, input coupler design modifications, and future plans.

Tubes & HVPS contd. / **23**

Klystron Amplifier for Short X-ray Pulse Prototype and Test Set*

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The proposed baseline design for the addition of short X-ray pulses at a sector of the Advanced Photon Source (APS) storage ring called for 20 superconducting deflecting cavities, each excited with 5 kW cw at 2815.5 MHz, which is the 8th harmonic of the storage ring frequency. A klystron amplifier has been designed based on a best effort, reduced power, engineering sample tube. The initial use of the first amplifier is to support developmental cavity testing. However, the amplifier was designed as an advance prototype for final power amplifiers, using a version of the same klystron that includes an upgrade to meet the full power requirement needed to support operation in the APS storage ring. Power supply-induced residual phase modulation could easily prevent meeting the severe phase tracking requirements. Therefore, a state-of-the-art, extra-low-ripple, high-voltage power supply is incorporated into the amplifier design. The requirements, design, construction, and results from initial turn-on are discussed.

- Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357

SSA (cont.) & Transmission lines & New projects / **24**

Cavity combiners for high power solid state RF amplifiers

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Cavity combiners have been used before: at ALBA, for instance, 2 IOTs add their output power in such a device to drive one storage ring accelerating cavity. Their main advantages lie in the minor footprint when compared to hybrid couplers and their capability to accept a large number of feeders. This makes them ideally suited for high power transistor amplifiers, where many pallets have to be combined to power one accelerating cavity. The presentation will show the design of a 75 kW CW solid state amplifier at 352.2 MHz using such a cavity combiner.

RF General (cont.) & New Projects / **25**

Status of the RF Power Systems for the SPIRAL2 Linac

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The high current driver accelerator of the SPIRAL 2 project uses independently phased resonators working at 88 MHz. One RFQ, three normal conducting rebunchers and twelve and fourteen SC cavities of two different families have to be driven with amplifiers ranging from few to tens of kW, for a total installed RF power up to 750 kW.

Solid state power amplifiers equipped with circulators are foreseen to drive the single cavities while 4 tube amplifiers are foreseen for the RFQ. The paper describes the present status of these devices.

Cavities and related / **26**

CERN SPL proposed RF power couplers

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Description of the new CERN-SPL, ESRF and SOLEIL RF power couplers.

Summary:

Comparison of the proposed designs, using the CERN LHC power window for the CERN SPL, ESRf and SOLEIL couplers and an SPS power window for the SPL coupler.

RF General (cont.) & New Projects / 27

Operation experience with the LHC RF system

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Operation experience with the LHC RF system

RF General (cont.) & New Projects / 29

JLAMP Proposed 4th Generation VUV/Soft X-ray Light Source

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Jefferson Lab (JLab) is proposing JLAMP (JLab AMPlifier), a 4th generation light source covering the range 10–100 eV in the fundamental mode with harmonics stretching towards the oxygen k-edge. The scientific purpose is to study ultrafast dynamics in complex systems as a pathway to the understanding and creation of novel materials and devices. The machine will be based on an energy upgrade to an existing energy-recovering linear accelerator at JLab, made possible by advances in superconducting accelerator technology. Specifically, accelerating gradients of 20 MV/m and electron-beam recirculation will allow electron-beam energies of >600 MeV to be achieved at repetition rates up to 4.68 MHz with continuous wave RF. The RF systems for the machine will operate at 1497 MHz, 748.5 MHz and 187.125 MHz. The average brightness will substantially exceed existing light sources in this device's photon energy range, and in addition, multiple photon sources will be made available for pump-probe dynamical studies. The system will be capable of operating as a seeded amplifier for precise pulse length and bandwidth control or as an oscillator at higher average brightness. An overview of the accelerator with specific details relating to the RF systems will be presented.

Tubes & HVPS contd. / 30

New RF Power Amplifier Unit for Berkeley 88"Cyclotron.

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The 88-Inch Cyclotron is operated as a national facility in support of U.S. Department of Energy programs in basic nuclear science. The RF system of the cyclotron is based on the quarter-wave cantilever type resonating structure powered by 500kW 4648 RCA RF tetrode operating in grounded

cathode configuration. The resonance frequency range of the RF system is 5.5MHz to 16.5MHz. Prohibitive cost of 4648 RCA tetrode, permanent problems with anode blocking capacitors and the fact that cyclotron operation has been founded for next several years generated decision to build the new PA unit based on lower cost CPI 4CW150000E tetrode. New PA unit has been designed, build and is scheduled to be installed during next shut-down (May 24-28 2010). Presentation will cover the PA design process and the preliminary low power test results.

RF General (cont.) & New Projects / **31**

The Current Status and Upgrade of the ALS Storage Ring RF System

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The Advanced Light Source (ALS) is a 3rd generation light source operating in her 17th year and is in the midst of a vigorous series of upgrades including Top-Off, Magnet PS's, SRRF, Insertion Devices, Control System & Diagnostics that will keep ALS near the forefront in its specific synchrotron radiation regime. The Storage Ring RF is being upgraded over the next three years to meet a modest increase in electron beam power and to modernize several sub-systems to increase their maintainability and reliability. Currently the SRRF consists of a single 500 MHz 330kW klystron that powers two normal conducting single-cell RF cavities, an analog based LLRF system, a HVDC Power Supply with Ignitron based crowbar system and a functional yet inflexible diagnostic and control system. The upgrade plan is to replace the single klystron with two that will enable independent control of each cavity, to install a new FPGA based LLRF system, to modify the HVDC PS, to replace the crowbar system with an IGBT based HV dis-connect switch, to replace the controls with PLCs and to upgrade the diagnostic systems. Details of the SRRF Upgrade will be presented in this talk.

Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Tubes & HVPS contd. / **32**

New prototype modulator for the European XFEL Project in Pulse Step Modulator (PSM) Technology

Author: Marcel FREI[None]

The European XFEL project at DESY in Germany requires 27 RF stations capable of 10 MW RF power each. Each RF station needs one high voltage modulator that generates pulses up to 12 kV and 2 kA with a duration of 1.7 ms and a nominal repetition rate of 10 Hz.
DESY decided to investigate new modulator prototypes and Thomson has been awarded to design and build one of these prototype modulators.
The Thomson modulator is based on the pulse step modulator (PSM) principle. This technology allows the regulation of the pulse voltage during the pulses, thus achieving a good flatness.
The modulator was delivered to DESY in July 2008 and is under test at the modulator test facility in Zeuthen.
In the mean time an additional Thomson modulator of the same kind has been ordered and will be delivered to LAL Orsay in October 2010. This Thomson modulator will be integrated in a RF test bench required to condition and test the power couplers for the XFEL superconducting cavities.

The presentation gives an overview about the system design and enhanced PSM technology, the gained advantages and the test results as taken during testing at the modulator test facility at the DESY Zeuthen site.

RF General / **33**

ALBA RF system

Author: Francis Perez[1]

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ALBA RF system

Hot Talk: Low-Level RF for High Power systems / **34**

Discussion session on Low-Level RF for High Power systems

SSA (cont.) & Transmission lines & New projects / **36**

Developments in Accelerator High Power RF Distribution.

Author: Yoon Kang[None]

Developments in Accelerator High Power RF Distribution.

SSA (cont.) & Transmission lines & New projects / **37**

Project X and its RF systems.

Author: M. Champion[None]

Project X and its RF systems.

Hot talk: IOT vs. Klystrons vs. Solid state / **38**

Hot talk: IOT vs. Klystrons vs. Solid state

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