ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF011

DESIGN AND STATUS OF SIRIUS LIGHT SOURCE RF SYSTMS

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Abstract

Sirius is the new synchrotron light source currently under construction at the site of the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas, Brazil. The facility comprises a 3 GeV electron storage ring, a full energy booster and a 150 MeV linac. This work provides a brief description of the RF system of the booster and storage ring, presenting their main characteristics and specification goals.

INTRODUCTION

Sirius is the new synchrotron light source being built at the site of the LNLS in Campinas, Brazil [1, 2]. The facility will comprise a 3 GeV 4th generation storage ring designed with a very low emittance 5-bend achromat (5BA) magnetic lattice. The circumference of the storage ring is 518 m and the design beam emittance is 0.25 nm.rad. The storage ring 5BA lattice has a 5-fold symmetric configuration, with 20 achromatic arcs, and was designed to provide straight sections with low beta functions in both vertical and horizontal planes. The straight sections are all low vertical beta and three in every four are also low horizontal beta. The lattice has 5 × 6.6 m (low β_y) and 15 × 5.8 m (low β_x, β_y) long straight sections (length between sector valves). In the design plan two short sections are destined to the RF cavities, including a future 3rd harmonic cavity.

In the magnetic lattice most of the orbit deflection is carried out by low field dipoles. In the centre of each achromatic arc a thin 3.2 T high field dipole is used to provide a hard x-ray source but they answer for just 6% of the total deflection. As a result, the energy loss per turn is relatively low and 3 MV total gap voltage will be sufficient to provide enough energy acceptance for an adequate beam lifetime at nominal current. The final setup of the storage ring RF system includes two CESR type SC cavities to produce the nominal gap voltage. For the commissioning of the machine, nonetheless, a different setup will be used. A single 7-cell PETRA cavity operating at 1.8 MV will be used to drive the storage ring. Both scenarios are described in this paper.

The nominal frequency of the RF reference signal is 499.658 MHz. A high stability signal generator is installed in the RF area and a distribution crate was designed to provide a sample of the signal for the linac, booster and storage ring low level systems, for the timing and BPM systems and for the beam lines. The low-level RF system is basically the same DLLRF developed for ALBA with firmware adapted to Sirius operation conditions and will be used for both booster and storage ring systems. Both systems use high power solid state amplifiers (SSA) to drive the RF cavities. The amplifiers were designed and assembled at the LNLS and uses components developed during more than a decade long collaboration with Synchrotron Soleil.

In the following sections we present an overview of each of these systems and their status.

BOOSTER RF SYSTEM

Sirius full energy injection booster will be positioned in the internal wall of the storage ring tunnel. With a circumference of 496 m, its lattice consists of 50 modified FODO cells with combined-function magnets. Besides providing a quite low emittance, the lattice also has low energy loss in the dipoles and low moment compaction, requiring relatively low total gap voltage at the extraction energy. A total gap voltage of 1.05 MV is required to provide enough beam lifetime at the extraction energy. The booster is designed to operate at 2 Hz, delivering up to 2 mA at 3 GeV to the storage ring in each cycle.

The main parameters for the booster RF system are listed in Table 1. A single 5-cell PETRA RF cavity will be able to supply the necessary RF power to drive the booster. Due to the FODO lattice the cavity is positioned in a dispersive section. A brand-new cavity was acquired and it was conditioned for power at the RF lab in the first semester of 2017.

A 50 kW SSA was designed and built to power the cavity. Except for the robust mechanical structure, the design of the booster SSA is very similar to those in operation in the UVX light source. It uses DC/DC power units to drive the amplifier modules. The final output power is achieved by combining the output power of 96×550 W amplifier modules. The amplifier was tested for nominal cycling condition at the RF lab. The test setup is shown in Fig. 1.

Table 1: Booster Main Parameters

Beam energy at extraction	3.0	GeV
Beam current	2.0	mA
Energy loss/turn	721.3	keV
Peak RF voltage	1.05	MV
Cavity shunt impedance	15	MΩ
Available RF power	50	kW
Harmonic number	828	
Energy spread	0.0874	%
Momentum compaction factor	7.19×10^{-4}	
Quantum lifetime	4600	s
Synchrotron frequency	2.67	kHz
RF acceptance	0.8	%

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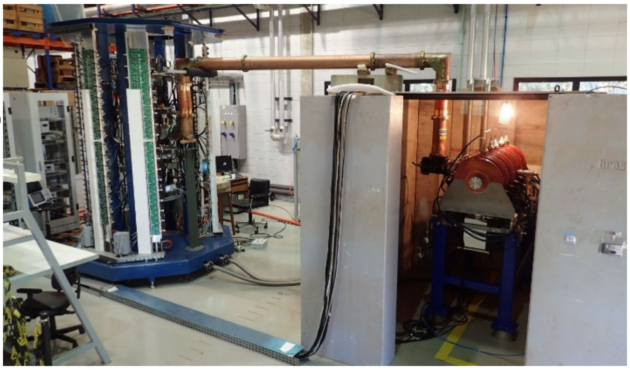

Figure 1: Setup for power conditioning of the 5-cell booster RF cavity showing the LLRF racks on the left, the high-power amplifier and the cavity bunker.

STORAGE RING RF SYSTEM

In its final configuration the storage ring RF system will include 2 SC cavities, each one driven by a set of four SSA delivering up to 240 kW CW at 500 MHz. With this configuration it would be possible to store up to 350 mA with up to 400 keV additional loss per turn due to insertion devices. Beyond that a third cavity would be necessary. The main storage ring parameters are listed in Table 2.

The option for using superconducting cavities was mostly based on beam dynamics issues driven by broad-band impedance and effectiveness of HOM damping. On the RF side the SC system requires only two RF plants and with only four 60 kW SSA it will be possible to run the storage ring up to 300 mA and half of the expected ID energy loss. Differently from conventional copper cavities the SC device is maintenance intensive and its performance must be closely monitored to avoid degradation of operating conditions. In contrast, for an equivalent operational scenario with normal conducting cavities, it would be necessary to have 5 RF plants, each one including a set of 2×120 kW SSA, in the first years of operation.

Table 2: Storage Ring Main Parameters

Beam energy	3.0	GeV
Beam current	350.0	mA
Energy loss/turn in dipoles	472.75	keV
Energy loss/turn in IDs	400	keV
Peak RF voltage	3	MV
RF Frequency	499.658	MHz
Harmonic Number	864	
Overvoltage	3.4	
RF Acceptance	5.13	%
Momentum compaction factor	1.6×10^{-4}	
Synchrotron Frequency	2.686	kHz
Natural Bunch Length	8.2	ps
RF acceptance	0.8	%

Two SC cavities have been contracted from a company and are in the initial production process. The cavities are the same CESR type model used at CLS, DLS, SSRF and PLS. They are expected to be installed in the machine in 2020. The external Q of the cavities is 1.6×10^5 and is specified for minimum reflection at the nominal current of 350 mA. The two cavities must fit in the tight 4.8 m clearance between the straight section girders. The cavities have RF shielded valves on both sides. A tapered section connects the cavity to the DN100 straight section gate valve and a DN250 valve connects it to the pumping station section in between the cavities. The cavities are positioned inverted to each other.

For commissioning and initial operation for beamlines a 7-cell PETRA cavity will be used, driven by a 120-kW solid state power amplifier. An old cavity from PETRA was acquired and conditioned for high power at DESY. With this setup it would be possible to store more than 50 mA operating with a gap voltage of 1.8 MV and chromaticity above 2.5 in both planes [3]. The cavity will be installed in the second straight section destined to RF components and will be removed after the installation of the SC cavities. Figure 2 illustrates the layout of the RF systems in the RF area.

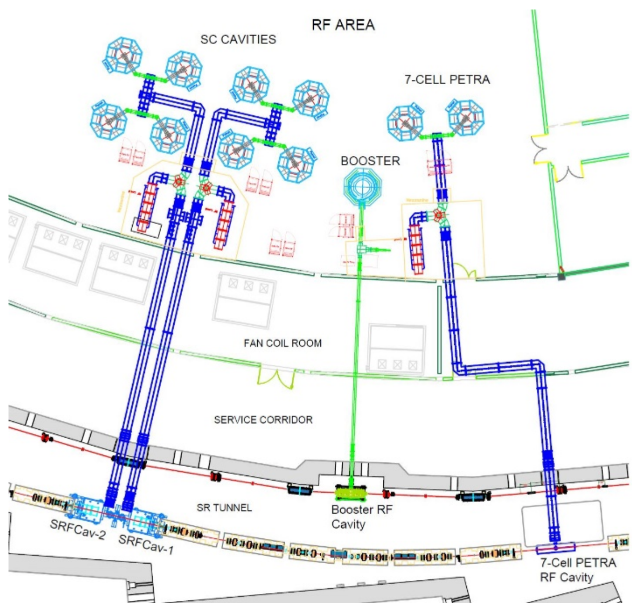

Figure 2: Layout of the RF plants of the booster (centre), 7-cell cavity (right) and SC cavities (left). The octagonal structures on the top are the SSA towers.

High Power Amplifiers

The overall RF design of the towers (Fig. 3) is very similar to the booster amplifier. The output power of a set of amplifier modules is combined using a tree of phase matched coaxial combiners. The 60-kW output power is obtained by combining 128×550 W modules. The main difference of the new design is that, for compactness, it uses AC/DC converters to feed the modules. The 140-kVA power supply was replaced by four sets of converters operating in hot-swap mode and positioned in small racks on the top of the tower. The SR towers are being assembled and the first one must be tested within a month.

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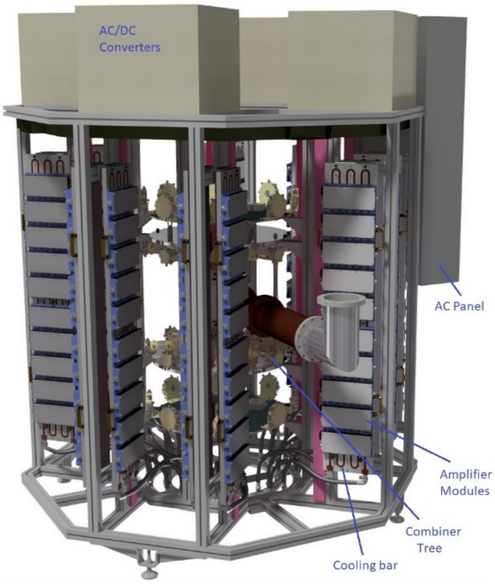

Figure 3: Design view of the 60 kW SR SSA.

Waveguide System

Each storage ring RF plant uses normal WR1800 waveguides and includes a high-power circulator and water load. The 2×60 KW combination uses a 2×EIA 6-1/8”-WR1800 originally designed by Soleil for SESAME. The lines for the SC cavities are not fully designed but the preliminary design includes a magic-T for the 2×120 kW combination and a 3-stub tuner for cavity matching when operating under non-optimum operation conditions.

LOW-LEVEL RF SYSTEM

The stability specification for the RF system is determined by the experiments that are being planned in the beamlines. For some critical experiments this can be very tight considering that the natural bunch length in the storage ring is smaller than 10 ps. The active feedback loops of the LLRF system control the amplitude of the accelerating voltage and relative phase of the RF signal in each cavity. Phase and amplitude jitter must be kept below certain limits otherwise the impact on beam characteristics may prevent the feasibility of important experiments. They may increase the vertical beam size and effective impedance and can be a problem for timing experiments. They can also reduce the brightness of the higher harmonics emitted by the undulators by increasing the vertical divergence of the photon beam. In the existing machines infrared experiments are particularly demanding and point to the need to achieve timing jitter of the order of only 5% of the RMS beam bunch length. The short bunches bring the tolerances for phase jitter to the level of 0.1° and the equivalent momentum jitter $\Delta p/p$ of 5×10^{-5}.

The stability of phase and amplitude is the main goal of the feedback control loops that are part of the LLRF systems, The LLRF adopted for the booster and SR RF plants is the digital system developed for ALBA light source and that is now in operation in facilities like MAX-4, SOLARIS and DLS [4]. The system is based on off-the-shelf commercial hardware. The up conversion and down conversion circuits are built from discrete components. A commercial picodigitizer is used as the core processor unit. It includes a Virtex-6 FPGA board and mezzanine cards for AD and DA conversion. The maximum sampling rate of the ADCs is 125 MSPS and 14-bit resolution. The maximum sampling frequency of the DACs is 1GSPS at 16-bit resolution. A digital patch panel provides the interface between the picodigitizer and the RF frontends (Fig. 4). The LLRF firmware is uploaded to the FPGA and an EPICS IOC provides the interface for the high-level control software. The goal for the LLRF is to achieve a phase stability of 0.1° rms. It was preliminary tested with the booster cavity and amplifier in the test area.

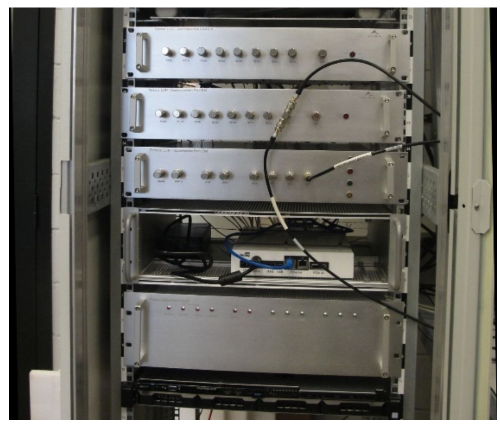

Figure 4: LLRF rack showing from top to bottom the down conversion and up conversion front ends, the picodigitizer, the digital patch panel and the CPU running the EPICS IOC.

CONCLUSION

The booster RF system is tested and ready for installation. The storage ring SSA are being assembled and will be tested and ready by the end of June. The low-level system is a new version of ALBA digital LLRF and was tested with the booster RF system. The cavities for the commissioning phase are conditioned and stored under vacuum.

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