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RF SYSTEM DESIGN FOR ELETTRA 2.0

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Abstract

The Elettra 2.0 low emittance light source project aims to a substantial increase of the brilliance and coherence fraction of the source improving, at the same time, the storage ring stability and reliability. The Radio Frequency (RF) system plays a pivotal role in the beam quality, stability and reliability for the user operation.

This paper will cover the design and the implemented strategy to meet these features for the Elettra 2.0 RF system. Starting point of the new RF design is the final choice of the RF frequency, 500 MHz, and the available room, 1260 mm, to install the accelerating cavities.

Thanks to the 500 MHz frequency choice, some components of the new RF system for Elettra 2.0 are already installed and set into operation in the current Elettra storage ring. Their features and performance's optimization can therefore start well in advance with respect to the foreseen operation the new Elettra 2.0 storage ring.

INTRODUCTION

The preliminary design of the RF system for the Elettra 2.0 presented in [1] has continued to grow according to the following guidelines.

- The stated RF frequency is 500 MHz.
- Normal conducting accelerating cavities.
- RF power source based on solid state transistors.

The Elettra 2.0 RF system main parameters are listed in Table 1.

Table 1: Elettra 2.0 Main Specification

Storage Ring Parameters	
Energy (GeV)	2.4
Current (mA)	400
Momentum Compaction	1.2 10^{-4}
RF Frequency (MHz)	499.654
Harmonic Number	432
Energy Spread	1.0 10^{-3}
Energy Losses, maximum (keV)	670
Beam Power (kW)	268
Accelerating Voltage total (MV)	2.0

Considering the guidelines and the required beam power the number of cavities and RF power amplifiers has been set. Four independent and equivalent RF plants fulfil the Elettra 2.0 parameters that means four amplifiers and four cavities. The possibility to add a fifth RF plant to increase the total available RF power is kept ready. This backup plan foresees the re-use the one of the two Elettra IOT transmitters, the spare cavity and the spare RF passive components with a minimal impact on the planned budget but it is conditionally subordinated to identify a free room to host the fifth cavity into the crowded Elettra 2.0 storage ring. Therefore the four Elettra RF plant are under revamping to match the Elettra 2.0 parameters.

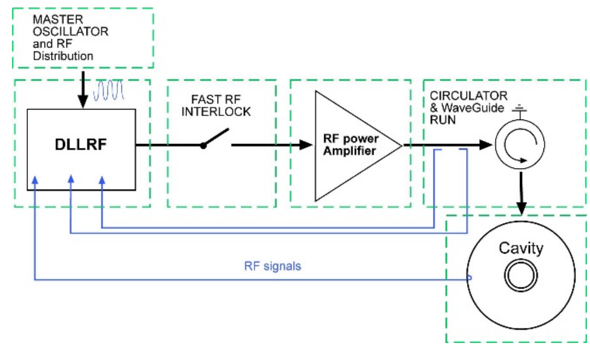

Figure 1: Schematic blocks of the RF plant.

Each RF plant can be subdivided in blocks as shown with green dashed squares in Fig. 1. All these blocks will be upgraded but the accelerating cavity. The existing "*Elettra type*" cavity that matches the available short straight section room is re-used achieving a good compromise between the cost saving and the attainable performances. The amplifier and the RF power run and passive high RF power components must be brand new due to the RF power increase. The Digital Low Lever RF and the dedicated local fast interlock are going to be designed according to the state of the art of the digital electronic.

The master oscillator and the low power RF signal distribution that have never suffered from any fault during more than 28 years of operations of Elettra will also be recycled contributing to the green economy.

The confirmation of the 500 MHz as a RF frequency has cleared the path for the procurement of the high RF power passive components such as high power circulators, loads, wave guides and, mainly, of the RF power amplifiers. The Elettra 2.0 project has given the chance to move towards the solid state technology using RF power transistors that now easily achieves more than 100 kW of output power at 500 MHz in a quite compact room. The contracts for the high RF power components are running now even if slowed down a little due to the raw materials shortage on the market and difficulty in obtaining new component. However this delay is not yet on the critical path.

The Booster RF plant, a 2.5 GeV ring used together with a 100 MeV Linac as the injector of the Elettra machine, is qualified also for the Elettra 2.0 project. A proposal to raise the available Booster RF power is under discussion. Today the RF power available for the Booster is 18 kW. The second 80 kW Inductive Output Tube (IOT) transmitter dismantled from the storage can be installed in the Booster RF plant allowing the Booster natural bunch length decreasing of 30% and thus predisposing the beam quality foreseen in the new Elettra 2.0 ring. This solution is almost free of

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charge but, very likely IOT production is going to be discontinued in the next years.

ELETTRA CAVITY

The "Elettra type" cavity has operated more than 28 years, its performances and reliability are well known. Table 2 shows the requested and attainable accelerating cavity parameters for the new Elettra 2. 0 storage ring.

Table 2: RF Cavity Parameters

Parameters for one cavity	needed	reachable
Accelerating Voltage (keV)	500	575
Losses (kW)	38	50
Power to the Beam (kW)	67	67
Total power (kW)	105	117
Coupling Factor	2.77	2.34
Overvoltage Factor	2.99	3.43
RF Acceptance (%)	3.5	4
Synchrotron Freq. (kHz)	2.94	3.18
Robinson limit current (mA)	460	490

Four cavities can score 2 MV of total accelerating voltage with the possibility to achieve 2.3 MV.

The RF cavities are the main source of the storage ring impedance that can spoil the high brilliance achieved by the emittance reduction of Elettra 2.0. The Elettra type cavity is not equipped with any dedicated High Order Modes (HOMs) dampers allowing high narrow band impedances along all the HOMs frequency spectrum. Transverse and longitudinal instabilities and beam losses can occur when the beam spectrum overlaps the HOMs frequencies. Currently the Elettra storage ring beam quality and stability is achieved by shifting the cavity's HOMs spectrum changing the cavity volume by means of a movable plunger and a cavity volume temperature control. This shift avoids any dangerous interaction between the beam and HOMs spectrum. The possibility to implement the very same strategy for Elettra 2.0 has been evaluated taking into account the 60% increase of the average current and the 2.4 GeV operating energy. Results are promising and the frequency shift required for Elettra 2.0 lies in the same range of the one needed for Elettra.

The Elettra 2.0 vacuum chamber transverse smaller sizes offer a new challenge: the HOMs trapped in the section between the cavity beam circular ports having 100 mm diameter and the rhombus-shaped vacuum chamber of 20 mm height and 30 mm wide. The cavity is connected to the vacuum chamber by means of two symmetrically displaced circular bellows, two vacuum valves and eventually, a really short and sharp tapers that accomplish the transverse size matching as shown in Fig. 2. A dedicated study of any beam port trapped modes field and associated impedances is mandatory and their characterization up to 5 GHz by means of the Ansys HFSS software tool and the bead-pull measurement method on the whole system composed by "cavity + bellows + tapers" is planned.

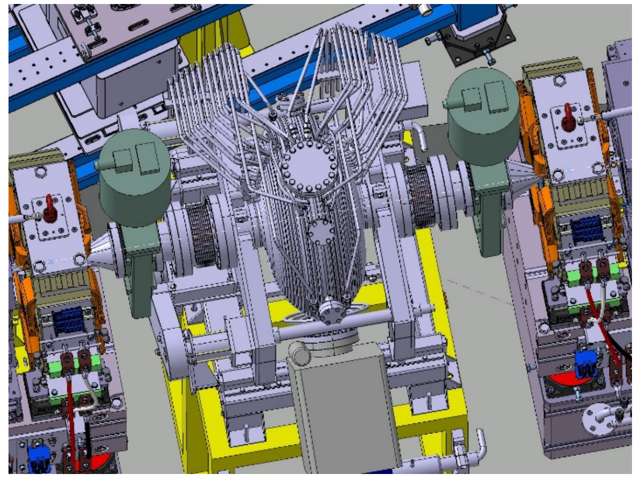

Figure 2: Elettra 2.0 cavity lay out.

The third harmonic passive superconducting cavity and the bunch by bunch longitudinal feedback system in operation today on the Elettra storage ring are nevertheless mandatory tools to suppress any residual coupled-bunch instability in the Elettra 2.0 storage ring.

Nevertheless the implementation of four 500 MHz cavities in the short straight sections of Elettra 2.0 seems feasible without major complications while the cost saving by using the same accelerating structures accompanied with all the operational experience and know-how gained during all those years of operation has made this choice very attractive.

130 kW AMPLIFIER

Following the Italian public procurement tender procedure, a contract was awarded to Cryoelectra for the procurement of four identical transmitters based on the Solid State Amplifier technology (SSA) running 130 kW in continuous wave (CW) at 500 MHz. The contract was signed in June 2019 and the installation and Site Acceptance Test (SAT) of the first SSA was initially planned within December 2020. The goal was to anticipate the installation of the SSA in the Elettra RF plants to cope with the klystron base amplifiers ageing. The SAT and installation of the first SSA on the Elettra occurred in October 2021, almost ten months later.

Main reason of this delay was the COVID-19 pandemic spread that has slowed down the production rate almost everywhere. But this delay gave also Cryoelectra the chance to develop a new modular design of the SSA to better combine the RF pallets on the intermediate high power module. Each RF pallet board, composed by a single transistor and its insulating circulator, seats directly on the λ/4 coaxial combiner reducing the need of flexible cables and improving thus the combining efficiency. The single high power module unit installed in the machine is shown in Fig. 3. Sixteen RF pallets are combined in a high power module unit. The module is tested up to more than 10 kW with a measured efficiency greater than 60%. The SSA achieves 130 kW by combining fifteen high RF power modules.

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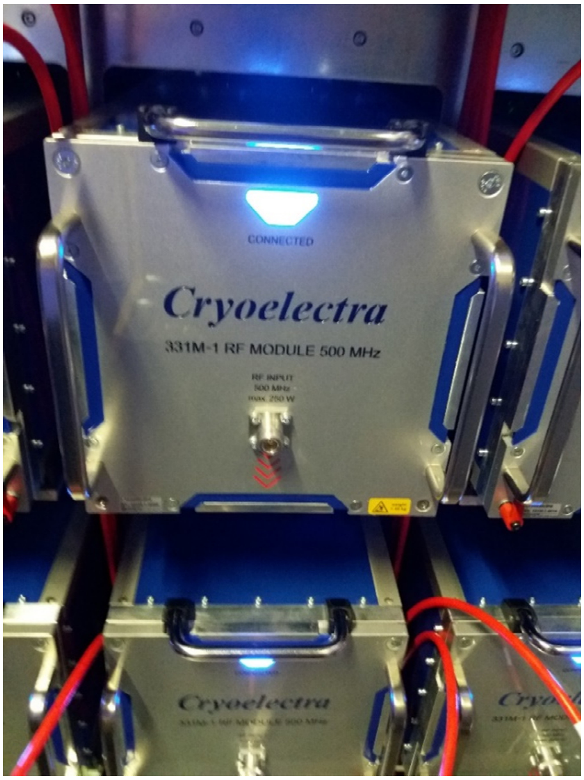

Figure 3: Single 10 kW RF power module.

The Factory Acceptance Test (FAT) of the first SSA was performed with several remote connection sessions and the SSA delivery was approved after a successful FAT.

The first SSA installed in the Elettra service area is shown in Fig 4. On the SSA back there is still the klystron based amplifier.

Figure 4: 130 kW 500 MHz amplifier.

The SSA was commissioned and set into operation on the accelerating cavity in the service gallery in three working weeks during the Elettra scheduled shut down. The first week was dedicated to the positioning, mechanical installation and alignment of the machine, the second to the SAT performed on a perfectly matched 50 ohm load at nominal RF power and the third to the integration of the SSA in the Elettra radioprotection and control systems and to the connection to the accelerating cavity. This installation was fully transparent to the Elettra's users and now the new SSA has already accumulated 3700 hours of operation at 50 kW CW with no failure at all but a short stop due to the wrong threshold interlock set for the mains phase detection. The 50 kW amount is the Elettra required power for this RF plant.

FAT and SAT have been fully compliance with the Tender specification. The SSA has overcome 66 hours nonstop duration test at 130 kW CW with no troubles, the measured wall-plug efficiency at nominal power is 52% but it drops at lower RF power level if the transistor drain voltage is kept constant. Gain stability is in the same range of the R&S NRP-Z81 power sensor measurement uncertainty. The redundancy test has been carried out with some power supplies and RF pallet boards in off state lasting four hours with no trouble at 130 kW thanks to the very good headroom of the design.

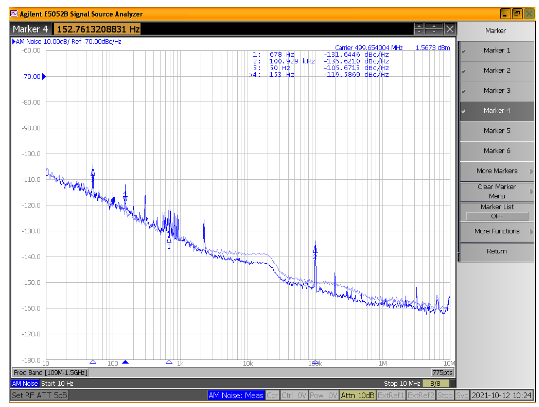

Figure 5: SSA phase noise at 130 kW.

In view of the Elettra 2.0 and the beam quality the low phase modulation (PM and amplitude modulation (AM) noise of the SSA is an asset. The measured PM is shown in Fig 5. The SSA PM and AM measured noise has spanked the klystron based of more than 30 dB. Unfortunately the second installation planned in April has been postponed to October 2022 due to the missed delivery of off-the-shelf components.

CONCLUSION

The RF system design for Elettra 2.0 is ongoing and the cavity and amplifier milestones choices are done. The set into work of the first SSA in Elettra has been a success even if it is running at RF power level well below its capability. The SSA installation has been the first step towards the Elettra 2.0 project for the RF system.

REFERENCES

[1] C. Pasotti *et al.*, "RF System Upgrade for Elettra 2.0", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 2849-2851.
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