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RF SYSTEM UPGRADE FOR ELETTRA 2.0

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Abstract

The Elettra 2.0 low emittance light source project has triggered the review of the installed RF system's performances and the analyses of the new machine requirement. This study includes the imperative revamp of the RF power sources. The trade-off between the best theoretical RF system design and the available room for installation and budget for Elettra 2.0 has been translated into the operational plan reported here. The first planned step is the installation of 100 kW 500 MHz solid state based transmitters.

INTRODUCTION

Elettra 2.0, a new generation light source is planned to replace the existing 3rd synchrotron radiation Elettra facility but with improved photon beam brilliance and coherence [1]. A feasibility study has been conducted with the following main constrains.

- Keep the very same Elettra ring, 260 m.
- Host the very same Elettra beam lines, many of them are now bending magnet beam lines.
- Use the Full Energy Injector, 2.5 GeV, set into operation in 2008, and off-axis injection.
- Multi-bunch beam current intensity ≥ 400 mA.
- Gain, at least, a natural emittance ε_N one order of magnitude less than the Elettra one, now ε_N =7 nm-rad.

At the same time, the Elettra facility shall work steadily up to the beginning of its dismantling and Elettra 2.0 facility assembly. The dismantling and assembling shall be fast and efficient and lasts only one year to minimize the impact on the beam user community. For this reason the installation and test on Elettra of any upgrade suitable for Elettra 2.0 is desirable [2].

The RF system feasibility study for Elettra 2.0 has involved the frequency choice first, the comparison between Normal Conducting (NC) accelerating cavities versus the Super Conducting (SC) ones and then the RF power source technology [3]. Essential milestone was to confirm the RF frequency even though preliminary investigations on the "ultimate storage rings" highlight the benefits gained in reducing the RF frequency value [4]. Keeping the operating 500 MHz has been a great asset for the overall cost of the new Elettra 2.0 project and for the current Elettra facility. Thanks to this choice the experienced gained running the Elettra facility and some of the most expensive hardware will be put to continued use. The "Elettra type" NC cavity will be re-used also for Elettra 2.0, at least in the first phase, and the RF transmitters that shall be purchased for the new facility will be installed to feed also the operating Elettra RF plants.

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RF SYSTEM

The Elettra 2.0 storage ring power requirement is evaluated at the highest foreseen energy, 2.4 GeV, maximum multi-bunch current intensity, 400 mA and at the preliminary estimate of the expected losses, around 600 keV/turn, as specified in Table 1. Total beam power is therefore 240 kW leading to the following possibilities:

- Four RF independent cavities, as they are already arranged in Elettra but fed by 100 kW each transmitter.
- Four RF independent cavities but with enhanced RF power amplification using the Additional Power Option (APO) to reach 125 kW for each transmitter.
- Five cavities, one fed by the 150 kW Inductive Output Tube (IOT) based amplifier and the remaining ones by the 100 kW transmitters.

Table 1: Elettra 2.0 RF System Options

Parameters	4 RF Plants	4 RF Plants APO	5 RF Plants
Accelerating Voltage (MeV)	1.8	2.4	2.4
Overvoltage	3	4	4
Requested Power (kW)	366	464	422
Available Power (kW)	400	500	550
Losses per Cavity (kW)	31.5	56.0	33- 49
β Coupling	2.9	2.1	2.3
RF Acceptance %	4	5	5
Synchronous Phase (deg.)	19.5	14.5	14.5

Five cavities option gives more operating margin in term of available power and losses per cavity even if adds another full RF plant that means increasing the total electrical energy consumption and the RF failure's probability.

Each plant of the RF system includes a RF signal conditioning section, the so-called Low Level RF (LLRF), the amplification stage, the run between amplifier and final load and the accelerating cavity (final load). On top of this, a RF line distribution at low level delivers the proper RF signal and interlock to all the RF plants.

Accelerating Cavity

The main issue of the "Elettra type" cavity is the High Order Modes (HOMs) interaction with beam since it does not host any HOM damper. Any coupled bunch mode (CBM) instability could spoil the high brilliance achieved by the emittance reduction. A preliminary investigation has

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been carried out for Elettra 2.0 storage ring running at 2.0 GeV, 400 mA. The threshold current for almost all the HOMs is below the rated one likely in Elettra. The frequency detuning needed to avoid any CBM is of the same amount for both the facilities. Therefore the HOMs frequency shift implemented so far for the beam user operation at Elettra with the cavity cooling and the cavity plunger position shall be as equally effective. Moreover the reuse of the third harmonic cavity that nowadays performs a very effective Landau damping is foreseen also in Elettra 2.0.

The implementation of the well-known "Elettra type" cavity will speed up also the commissioning phase of the Elettra 2.0 project in compliance with the required minimization of the facility shut down period. Meanwhile new idea and design about the HOMs damping will be investigated in case the final Elettra 2.0 CBMs instability will prove tough to damp. Last but not least, the cost reduction implementing the already owned cavities is substantial. The fifth cavity is already available and it has been RF conditioned in the laboratory. New idea and design about the HOMs damping will be investigated in case the final Elettra 2.0 CBMs instability will prove tough to damp. Last but not least, the cost reduction implementing the already owned cavities is substantial. The fifth cavity is already available and it has been RF conditioned in the laboratory.

RF Transmitter

Currently, at Elettra, three 60 kW klystron based amplifiers and one 150 kW Inductive Output Tube (IOT) based amplifier are installed in the four RF storage ring plants and their operation is really great [5]. The IOT transmitter has been working since 2008 but the klystron transmitters are in operation since 1994 and the machine obsolescence can't be ignored. Spare parts are not anymore available and the 60 kW klystron has been discontinued in 2012. Last spare one is still available at Elettra with an estimated lifetime around 40000 hours. Revamp of the RF transmitters is therefore mandatory for the reliability and full operation of the Elettra storage ring. This revamp is entirely in line with the 500 MHz milestone of the Elettra 2.0 project so that the initial Elettra 2.0 financial contribution is going to cover the RF plant revamp cost too.

Figure 1: Booster RF Transmitter in the service area.

SSA Booster A 500 MHz Solid State Amplifier (SSA) has been installed in the Elettra Booster RF plant October 2017. Operating up to 18 kW in Continuous Wave (CW) it has replaced the oversized 60 kW transmitter, see Fig. 1.

The Booster's transmitter has been specified as a modular machine with a "hot-swap" option to minimize the MTBF. Two years of operation have confirmed the maturity of this technology, its reliability and redundancy features and has proven a good testbed. Choice of the amplification technology for the Elettra 2.0 project has been driven by the performances of this SSA transmitter.

100 kW Transmitter The new transmitters will serve both facilities and the RF output power level is the first key parameter.

100 kW power level is the minimum output power with four RF plants. It ensures enough margin with the addition of the fifth RF plant fed by the existing 150 kW IOT transmitter. The 100 kW power level is now feasible with the SSA technology even if this power level is demanding for the RF power combination efficiency. Electronic tubes are competitive for larger RF output power in term of initial cost even if the maintenance cost, including the tube replacement, makes this choice less appeal.

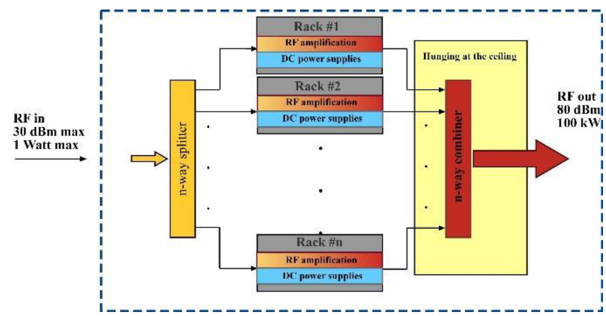

Figure 2: Cartoon of one possible SSA configuration.

The SSA technology does not need High Voltage (HV) power supply so that the phase and the amplitude noise of the amplified RF power is much more lower compared to the tube anode HV power supply use. This built-in side benefit will strongly contribute to achieve the high quality beam demand for Elettra 2.0.

The SSA modularity enables a convenient output power increase when the transmitter's design has been initially planned for. Figure 2 shows the combination of n RF amplification racks and, by implementing the proper splitter and combiner, a new RF amplification rack can be added to increase the power level with a minimal impact on the machine. This feature is called Additional Power Option (APO). APO consists in also a control and auxiliary systems layout ready to implement further active RF amplification boards to achieve larger output power if needed at later stage. This option will be used to cover a potential four RF plants choice for Elettra 2.0 or any future 80 kW IOT production discontinuity.

The new transmitters can be conveniently used in the Elettra storage ring to replace the old ones when the operating and spare klystrons will be ran out. The Elettra beam power request is modest and amounts to 80 kW total, 20 kW per cavity. The facility could run with only three RF plants: two with 100 kW transmitters each and the last with the 150 kW transmitter. The new transmitter installation

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will have no impact at all because of the higher SSA efficiency. The improved efficiency maintains almost unaltered the existing cooling and electrical grid infrastructures designed for the klystron amplifier. The SSA solution fits in well also with the available service gallery room.

The tender procedure for the procurement of four identical turnkey 100 kW CW transmitters @ 500 MHz, including the afterwards APO option to raise to power up to 125 kW is at the final stage and the contract will be awarded within the end of July. Two out of four transmitters will be installed in the RF plants ensuring the Elettra facility reliability. The remaining two units' installation is closely linked to the Elettra 2.0 project schedule.

LLRF

The Digital Low Level RF (DLLRF) system is mandatory to obtain the Elettra 2.0 beam quality.

In 2012 an in-house developed DLLRF prototype has been design and successfully tested in the laboratory and on the RF plant [6]. It was based on the Altera Stratix III evaluation board. Measured RF amplitude and phase regulation accuracy was below 0.2% and 0.2º. Measured bandwidth larger than 20 kHz at full cavity RF input power. A survey is now in progress to evaluate cost/benefits for recovering the now obsolete DLLRF prototype adding the very useful features like RF signal sampling and fast diagnostic as well as the RF high power conditioning integrated procedure. Within end of this year the survey will lead to the final decision to start once again the in-house development or to purchase a turnkey system.

RF Power Run

A wave guide run together with the full RF power circulator shall be installed to cope with the 100 kW CW power level. The components procurements will start shortly but their installation shall wait until the decommissioning of the Elettra machine because the waveguide installation needs a quite invasive work on the radioprotection shielding walls. The user dedicated facility can't accommodate shut down long enough time for this issue.

Therefore the existing 6 1/8" rigid coaxial line run will be used for the new transmitters and the maximum RF power level limited till the installation of the Elettra 2.0 storage ring, see Fig. 3.

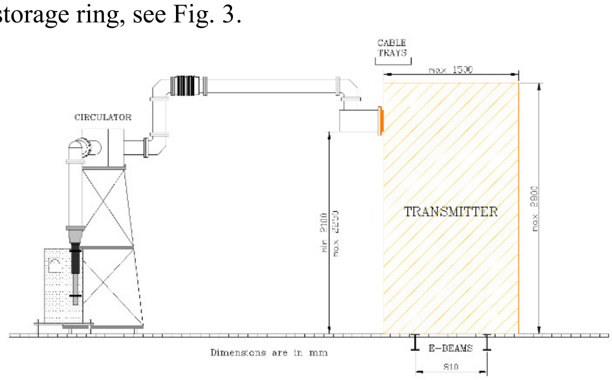

Figure 3: 100 kW with the initial coaxial line run.

Interlock

Beside the transmitter built-in interlock system, each RF plant is equipped with an independent fail-safe hardware wired interlock system. Interlock redundancy is also implemented to fulfil the radioprotection rules for the human safety. A new project is started to revamp the in-house built full analogue interlock board based on a dedicated FPGA board. The FPGA board implementation allows to record the events with a more accurate time sequence. The interlock board will also sample several RF plant DC signals and will storage them in case of fault for diagnostic purpose and post fault analysis.

RF Distribution

The RF distribution manages the RF signal generation and delivering to the RF plants and to other users (transverse feedback and so on). A new Master Oscillator (MO) with high stability option and high spectral purity has been already installed in 2016 but the several watts amplification stages needed in the main RF distribution chain shall be revamped. Even if several tens of watts amplifiers at 500 MHz do not raise any problem, a particular care will be dedicated to preserve the MO spectral purity.

CONCLUSION

The RF system renewal begins thanks to the Elettra 2.0 project and the current Elettra RF plants are benefitting from this project. The 100 kW transmitters project has been funded and is running. The new RF transmitters will be readily installed with no detriment to the user dedicated facility to ensure the requested RF reliability and to bring forward the commissioning phase. Revamping of the other RF plant parts is also started or it is under evaluation.

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