Upgrade of the SPARC_LAB LLRF system and recent X-band activities in view of EuPRAXIA@SPARC_LAB project

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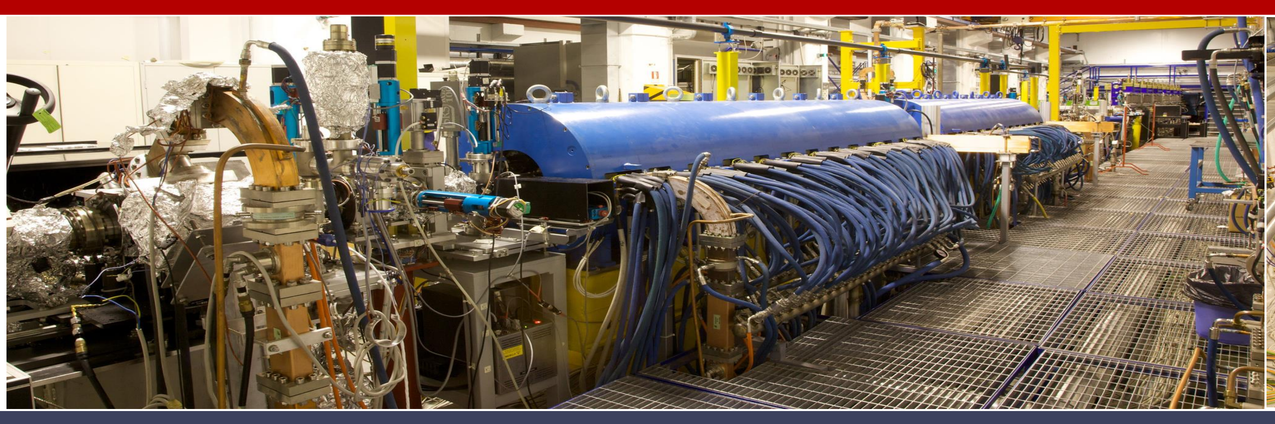
Abstract

SPARC_LAB is a high-brightness electron photoinjector dedicated to FEL radiation production and research on novel acceleration techniques. It has been in operation at LNF since 2005. It is composed of a newly designed brazeless 1.6-cell S-band RF gun, two 3 meter long travelling wave S-band accelerating structures, and a 1.4 meter C-band structure that acts as an energy booster. Recently, a plasma interaction chamber was installed to study and optimize beam-driven plasma acceleration schemes. During fall 2023, a major **upgrade of the entire low-level RF** (LLRF) **system will take place to consolidate and improve performance in terms of amplitude**, **phase resolution**, **and stability**. **The original analog S-band and the digital C-band LLRF systems will be replaced by commercial, temperature-stabilized, FPGA-controlled digital LLRF systems manufactured by Instrumentation Technologies**. Additionally, **the reference generation and distribution will be updated**. In parallel with this activity, there is a growing interest in **X-band LLRF** at LNF due to the EuPRAXIA@SPARC_LAB project. This project aims to build an FEL user facility driven by an X-band linac at LNF in the coming years. To test X-band RF structures and waveguide components, a high-power X-band test stand named TEX has been installed and recently commissioned. A detailed view of the TEX LLRF system, based on a commercial S-band system with a dedicated up/down-converter stage, will be discussed, along with the limitations of such an approach.

SPARC_LAB



Updated layout of the SPARC_LAB LLRF system

Reasons for updating:
- Current direct conversion systems have limitations with noise and offset
- Signal acquisition on commercial digital boards have a non negligible fault rate
- The front-end noise of ~50 *fs* no longer meets today's requirements (<10 *fs*)
- Non-arbitrary pulse shape

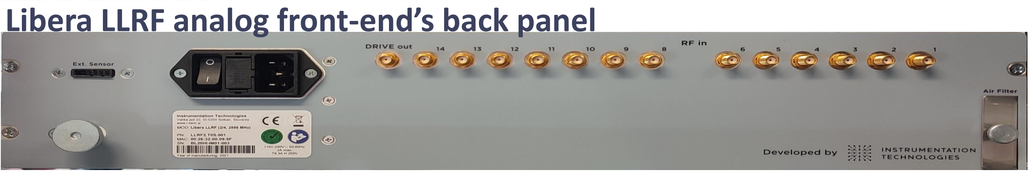
Libera LLRF (S-band) features:
- Thermally stabilized front-end, IF=44.625 MHz, 16 bit ADC at 119 MS/s, 5 MHz BW
- Pulse-by-pulse A,Φ independent feedbacks
- Long-term (24h) stability of RF station: 100 *fs*
- Fully customizable pulse shape (A, Φ), analog VM driven by FPGA (14 bit DAC), 16 MHz BW

Resolutions:
- Amplitude < 0.1% RMS
- Phase added jitter < 10 *fs*

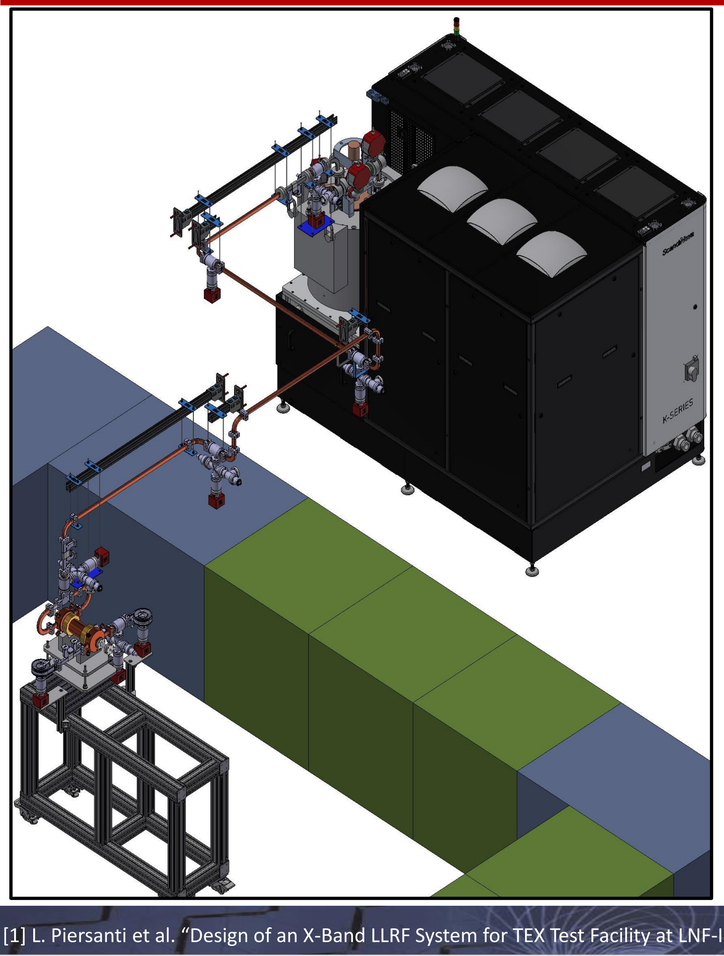
Libera LLRF digital processor's front panel

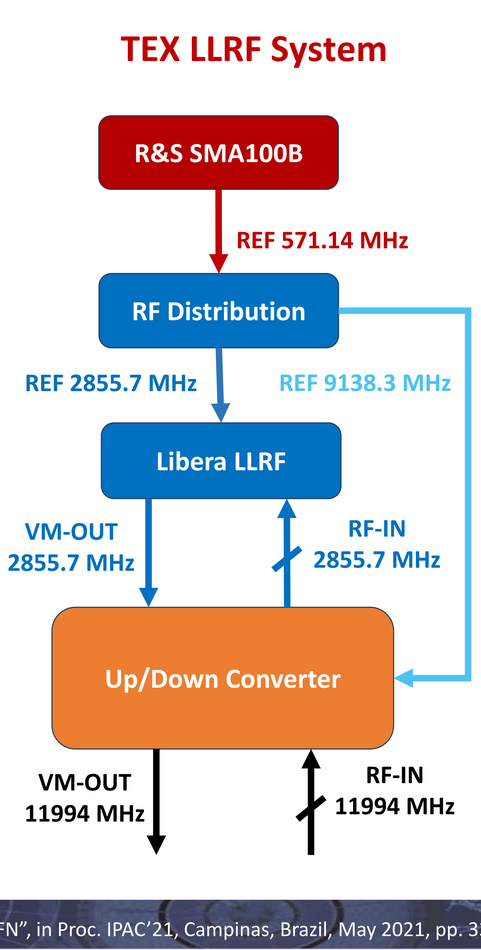
Libera LLRF analog front-end's front panel

Libera LLRF analog front-end's back panel



TEX Facility X-band LLRF System

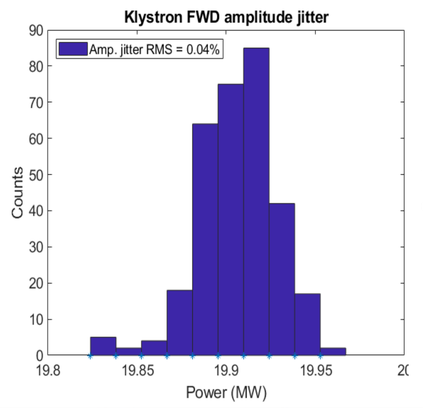


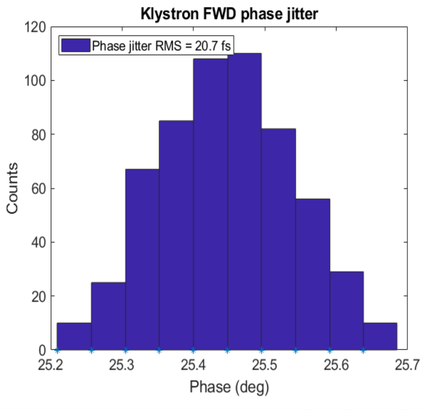


- Digital S-band LLRF system (ITech)
- Custom up/down converter and reference generation stages developed at LNF [1]
- 8 RF input channels (upgradable up to 12)
- Pulse to pulse feedback and VSWR interlock capabilities
- Klystron FWD and REV splitting board for RF mask digitizer

System performance:
- Reached 48 MW at 150 *ns*, 50 Hz rep. rate
- Measurements done with 300 *ns* pulses at 20 MW showed an amplitude and phase stability of the Klystron FWD power of **0.04 %** and **20.7 *fs*** respectively

RF stability first results with 300 ns pulses at 50 Hz





[1] L. Piersanti et al. "Design of an X-Band LLRF System for TEX Test Facility at LNF-INFN", in Proc. IPAC'21, Campinas, Brazil, May 2021, pp. 3371–3374.