Servizio RF ai LNF: LLRF e sincronizzazione al fs

Giornata sulla radiofrequenza nell'INFN
13 settembre 2021

L. Piersanti per il gruppo RF dei LNF

RF group at LNF

Historically the RF group at LNF is responsible for all the RF systems devoted to the generation, control, measurement and feedback of the RF fields of the accelerators in operation (with the exception of DAFNE linac)

DAFNE e+ e- collider and damping ring:

- Custom fully analog LLRF systems (working at **368 MHz** and **73 MHz**) designed and developed at LNF (mid '90s)
- RF power plants (150 kV Thales klystron and 12.5 kW Itelco SSA) and RF distribution (waveguides and coaxial cables)

SPARC e- linac:

- **2x S-band (2856 MHz)** RF stations (PFN modulators – PPT + 45 MW Thales klystron)
- **1x C-band (5712 MHz)** RF station (SS modulator – ScandiNova + 50 MW Toshiba klystron)
- Synchronization system between photocathode and interaction laser with the RF reference (Photodiodes + PLL)
- Fast phase feedback (BW ≈ 1 MHz) for klystron intra-pulse phase stabilization

The RF group is also involved in the design/procurement, test and commissioning of several LLRF and synchronization systems for other facilities: TEX (X-band test-stand at LNF), ELI-NP (Bucarest), STAR (UniCal), EuPRAXIA@SPARC_LAB (LNF)...

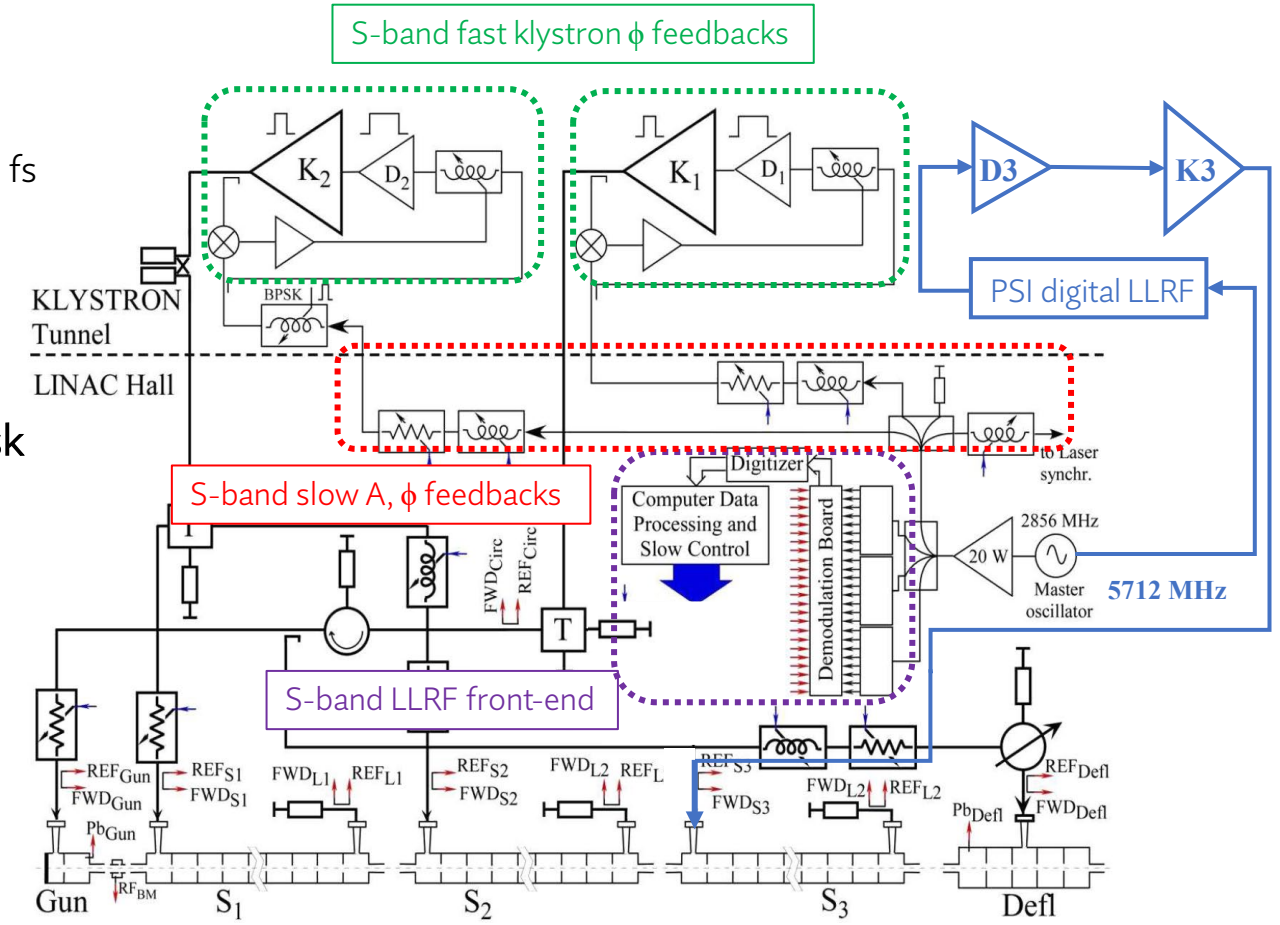
LLRF at SPARC_LAB

S-band LLRF has been developed in 2006 by RF-group at LNF

- Analog front end, direct conversion, connectorized RF components for signal manipulation → ADC: NI-5105 60 MHz, 12 bit
- Analog back-end: RF switch, voltage controlled attenuators, motorized phase shifters (coarse tuning), electronic phase shifters (fine tuning); added jitter <10 fs
- A, φ feedbacks implemented in the control system
- Fast klystron phase feedbacks (**phase jitter < 50 fs w. PFN modulators**)
- No pulse shaping, front-end noise limits achievable resolution

C-band LLRF developed at PSI (Tiara), digital system with RF pulse mask

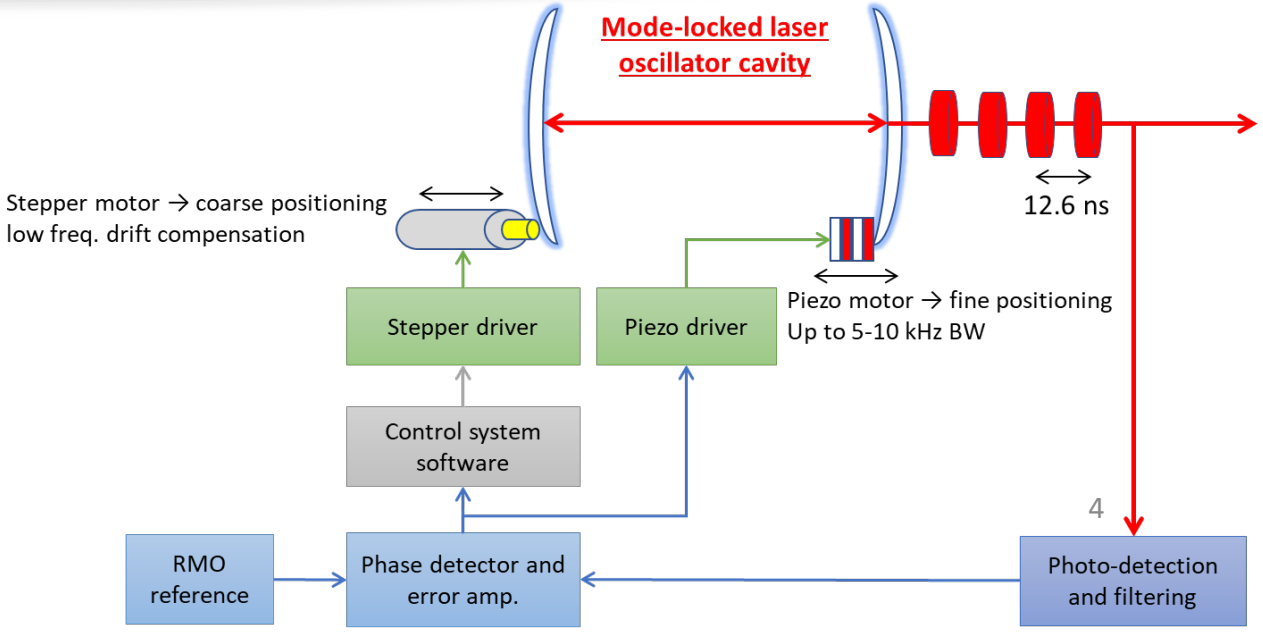
- Front end: ch. isolation >80 dB, IF (39.667 MHz), BW >30 MHz
- ADC-DAC: 16-bit; 238-476 MS/s respectively
- Back end: I/Q differential VM, output BW >40 MHz, added jitter <10 fs
- Amplitude and phase detection only (phase error < +/- 0.05 deg, amplitude <0.1%). Feedback implemented in the control system
- PSI has upgraded its LLRF systems to a new architecture → support issues, NO spare parts



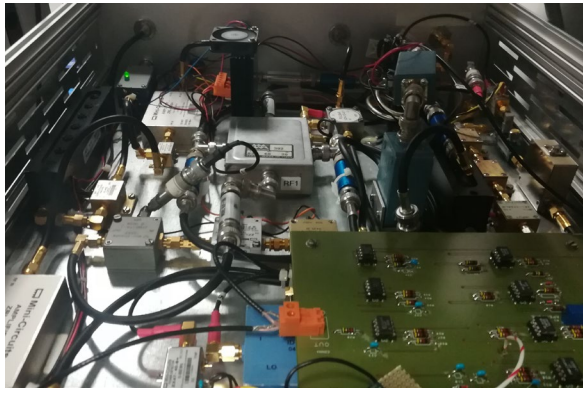
Synchronization at SPARC_LAB

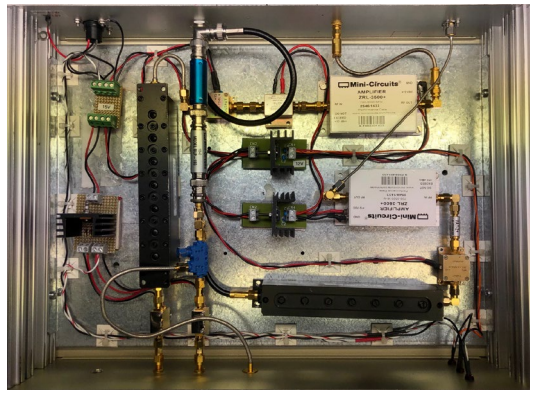
- RF to PC laser synchronization realized using photodiodes for optical-electrical conversion and standard PLL techniques to minimize the relative phase error

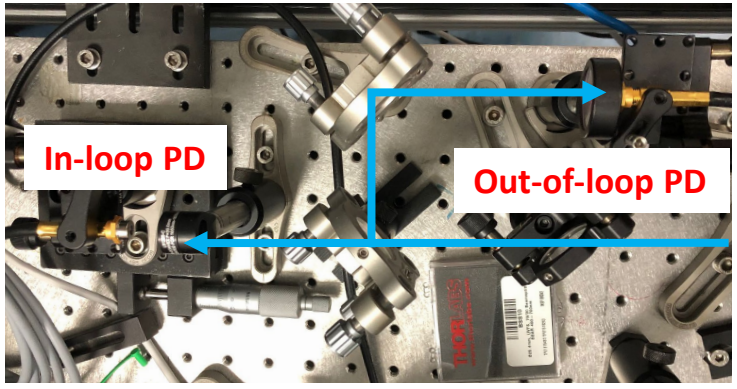
- Turnkey locking electronics, photodiode and Galvo-motor bypassed ⟶ new photo-detector, phase detector and error amplifier designed and optimized at LNF



Recent high resolution measurements showed a residual jitter **<30 fs** between RMO and PC laser







Short term RF group activities 1/2

1. LNF has been funded by Lazio Regional Government for SPARC_LAB facility consolidation (**SABINA project**):
   - Upgrade of RF reference generation system (RMO with integrated jitter 10 Hz - 10 MHz < 30 fs)

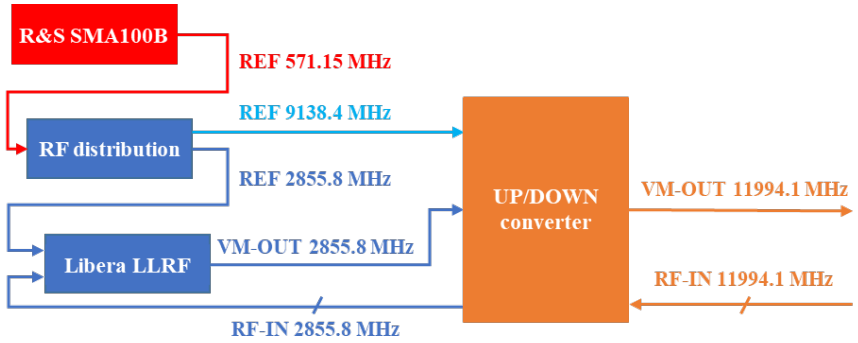
   - Upgrade of the whole LLRF to a FPGA based system (Libera LLRF - manufactured by Instrumentation Technologies)
     - 2 S-band (2856 MHz) systems + 1 spare
     - 1 C-band (5712 MHz) system

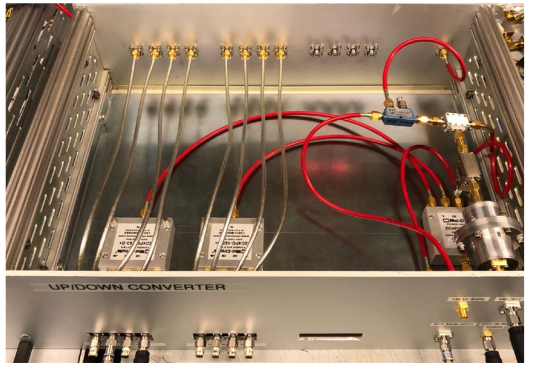
- Temperature stabilized front-end to compensate long-term thermal drifts (< 100 fs at 24 +/- 2 °C)
- Low noise front-end, high dynamic range (RF input from -10 up to 20 dBm)
- Resolution: amplitude: 0.1 %; phase added jitter <10 fs
- Pulse-to-pulse amplitude and phase feedback on independent channels
- Arbitrary waveform pulse shaping
- Similar systems have been already procured from ITech for:
  - ELI-NP project (13 systems, 3 S-band 10 C-band - calibrated, tested in lab but never installed in the facility)
  - TEX (Test-stand for X-band) project (1 S-band system + up/down converter)

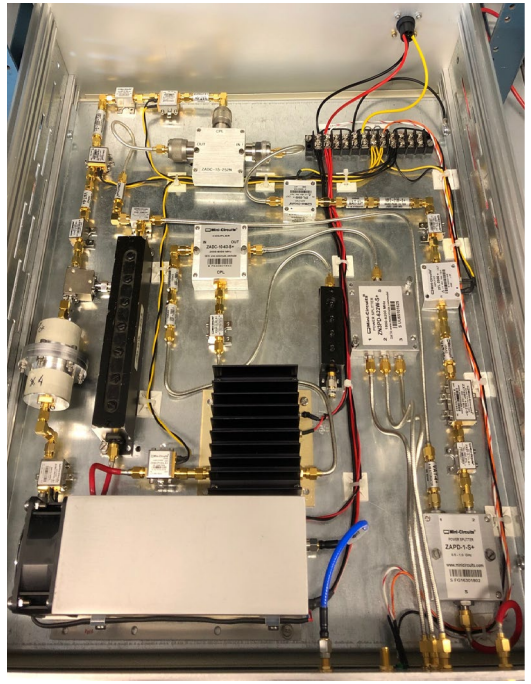
2. Upgrade of the RF-laser synchronization system to a fully optical one (OMO + optical fiber distribution with active length compensation for temperature drifts) manufactured by Menlo Systems

Short term RF group activities 2/2

3. Test, commissioning and operation of the X-band LLRF system for TEX test-facility at LNF
→ S-band Libera LLRF adapted for X-band:
   - Up/down converter (max 12 ch. front-end, 1 ch. back-end)
   - Reference generation and distribution: coherent source for S-band (2.856 GHz) and X-band (11.994 GHz)
   - Custom cavity BP filters (9.138 GHz and 11.994 GHz) for reference and VM output after up-conversion







4. Commissioning of the LLRF system at STAR (UniCal)
   - 1x S-band designed and realized at LNF (SPARC-like)
   - 2x C-band Libera LLRF systems (Itech)

5. R&D on LLRF and synchronization for Eupraxia@SPARC_LAB TDR

Manpower and know-how

Level I-III

- L. Piersanti (RF measurements, EM simulations, feedback & synchronization)
- M. Bellaveglia (RF measurements, control system, feedback & synchronization, beam dynamics simulations)
- L. Faillace (RF measurements, EM & beam dynamics simulations)
- A. Gallo (external consultant…)

Level IV-VIII

- Senior:
  - M. Scampati (power electronics, RF plants, RF measurements)
  - S. Quaglia (electronics, RF measurements, control system and machine protection)
  - P. Baldini (external consultant…)
- Junior:
  - G. Scarselletta, L. Zelinotti (TD)

Laboratory instrumentation

RF lab exceptionally well equipped with state-of-the-art instrumentation:

Frequency domain:

- Spectrum Analyzer — Rohde&Schwarz FSU 26.5 GHz
- Network Analyzer — Rohde&Schwarz ZVA 50-110 GHz (4 ports), ZVA 24 GHz (4 ports), ZVB 20 GHz (2 ports)
- Signal Source Analyzer — Agilent E5052A 7 GHz
- Portable S.A/N.A. — Keysight Fieldfox 14 GHz

Time domain:

- Osc. 20 GHz, 8 bit, 80 GS/s — Lecroy WaveMaster 820Zi-B
- Osc. 20 GHz, 8 bit, 50 GS/s — Tektronix DPO72004B
- Osc. 6 GHz, 12 bit, 20 GS/s — Lecroy WavePro 604HD

RF synthesizers and low phase noise fixed oscillators:

- Synth. 26 GHz (CW/pulsed) — Rhode&Schwarz SMF100A
- Synth. 20 GHz (CW/pulsed, ultra low phase noise) — Rhode&Schwarz SMA100B
- RMO @ 2856 MHz e 5712 MHz (low phase noise)

INFN activities/projects and teaching

Within the Accelerator Division of LNF we have a strong link, and we naturally collaborate, with both accelerating structure design (**D. Alesini**) and linac (**B. Buonomo**) groups, given the common areas of interest and know-how.

Individual/group participation to INFN projects:

- RF measurements for industries & private companies: **LATINO**

  Time domain up to 20 GHz, Frequency domain up to 110 GHz, High power at 11.994 GHz up to 50 MW pulsed, 100 Hz
- New facilities: **STAR**, **EuPRAXIA@SPARC_LAB**
- R&D on LLRF with FPGA: **SINGULARITY**
- Novel accelerator technologies: **MICRON**
- Axion search, wideband cryogenic TW amplifiers: **QUAX, QUB_IT, DARTWARS**

Machine operation shifts (50% technical personnel), experimental run participation and coordination

Master's degree laboratory course (Sapienza Univ. ≈ 100 hours) of theory and measurements of RF structures for particle accelerators (RF-gun, TW clamped structures, pulse compressors) held for physics students + seminars on synchronization for Ph.D. school in Accelerator Physics (Sapienza Univ.)