RF applications

Overview of RF activities at LNF-INFN

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RadioFrequency applications in a particle accelerator

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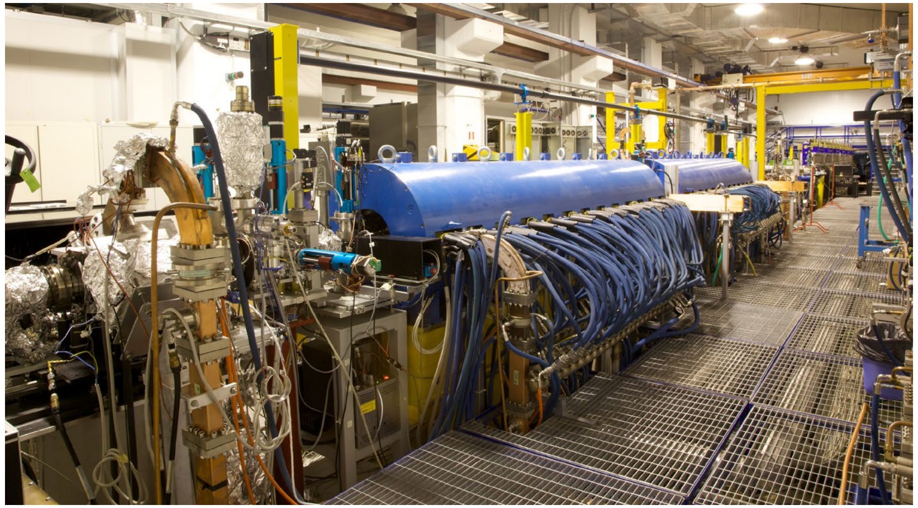
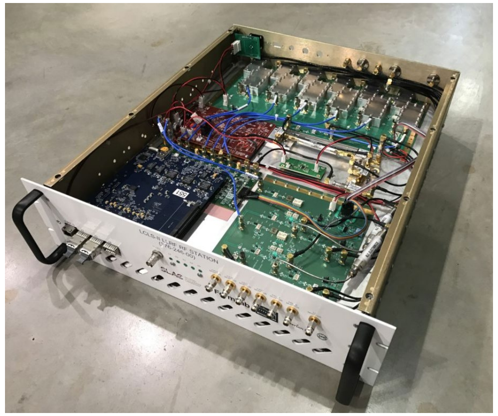
- High frequency (or RadioFrequency - RF) EM fields are widely used in particle accelerators in a large variety of applications:
  - to excite resonant cavities (or travelling wave structures) for **particle acceleration**
  - to excite resonant cavities for **beam diagnostics and feedback**
  - to excite special microwave components for **RF peak power amplification**
  - to **synchronize (at *fs* level)** high frequency oscillators (RF/laser or RF/RF)

SPARC_LAB @ INFN-LNF

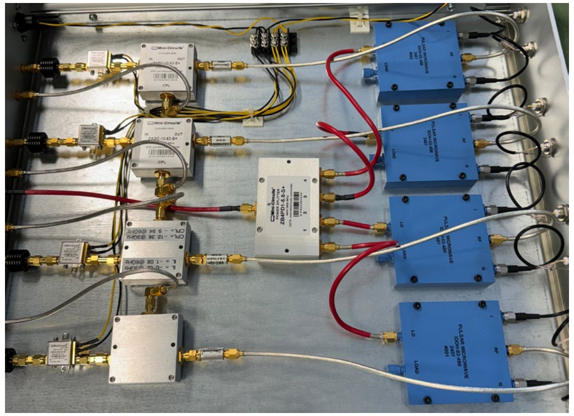


- Depending on their power, we classify them as:
  - **Low-level RF** (< 100 W – coax. cables):
    low power signal manipulation, display, diagnostics,
    feedback, RF reference distribution, PLL, cavity tuning…
  - **High-level RF** (> 100 W - waveguide):
    high power RF distribution, peak power amplification,
    RF conditioning, beam instabilities mitigation,
    high power tests on accelerating structures/components…

Digital Low-Level RF system



Analog Low-Level RF system



C-band klystron

RF applications at LNF

RF group

- Low-level RF controls for EM field stabilization
  - RF reference generation and distribution
  - Design, tests and operation of frequency translation systems
  - Advanced control system development for digital (FPGA-based) LLRF systems (deployed both at LNF and abroad)
- Femtosecond-level synchronization of oscillators:
  - RF/laser: photocathode laser lock at SPARC_LAB
  - RF/RF: klystron intra pulse phase feedback

TEX facility

- EM design of novel accelerating structures and RF components working at 3, 6, 12 GHz
- High power RF tests in C/X-band (6/12 GHz) on novel accelerating structures and waveguide components
- Dark current simulations and measurements on X-band structures

Low-level RF controls for EM field stabilization

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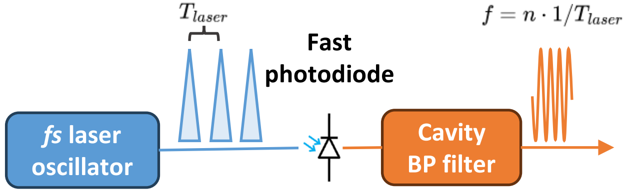
Ultra low-noise RF reference generation

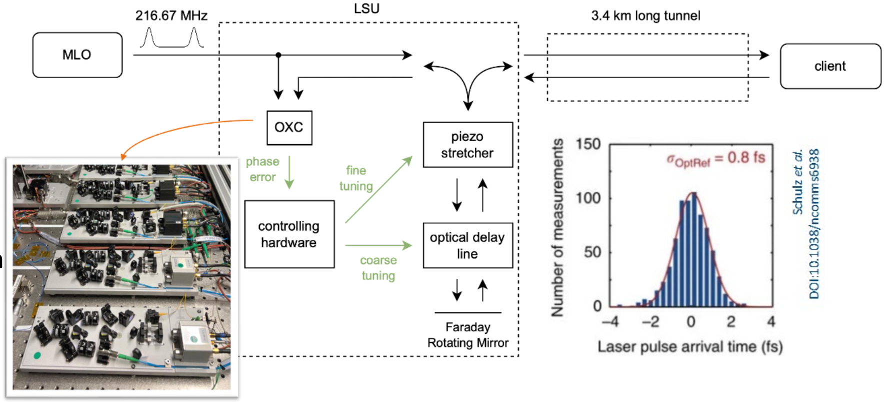
RF synthesizers

Custom µwave master oscillators

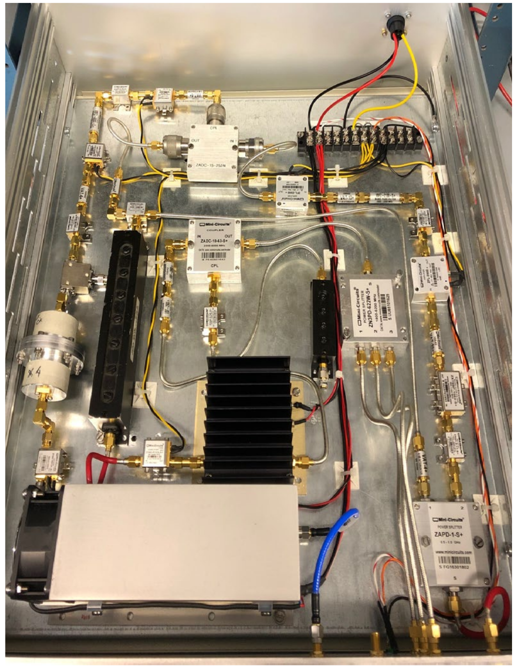
µwave generation from laser oscillators

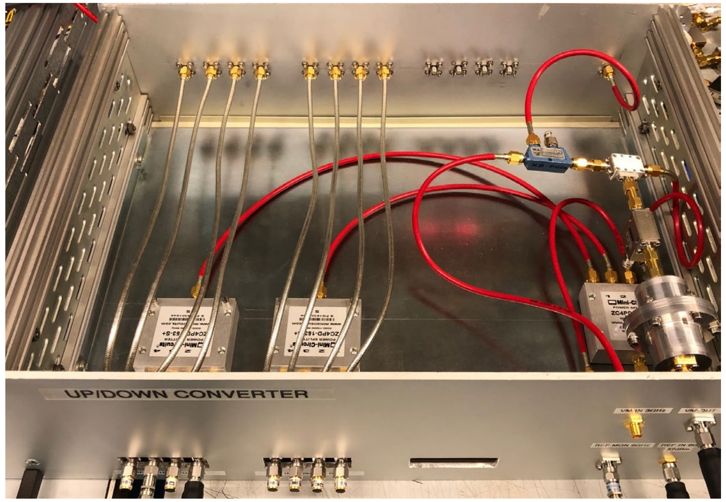


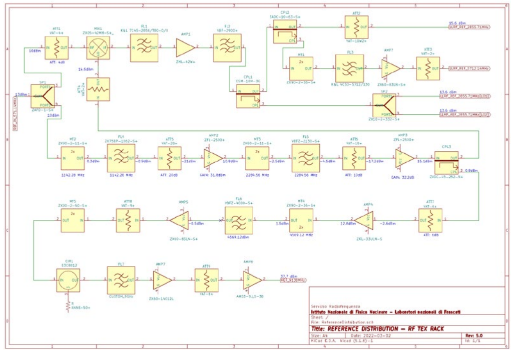
Pulsed laser reference generation/distribution



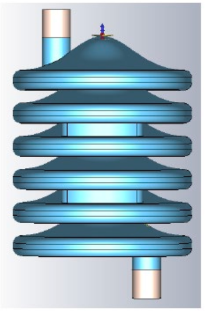
RF reference distribution and frequency translation systems







Custom RF filter design and realization



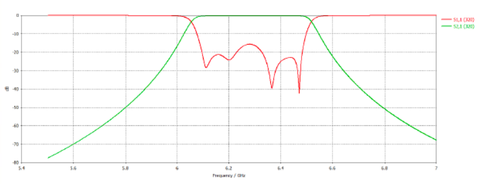


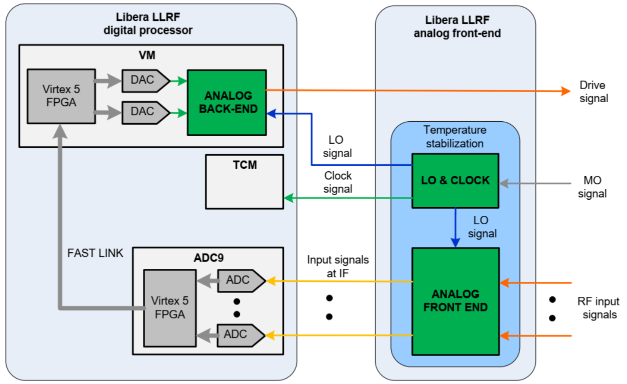
Figure 12. Scattering parameters.

Low-level RF controls for EM field stabilization

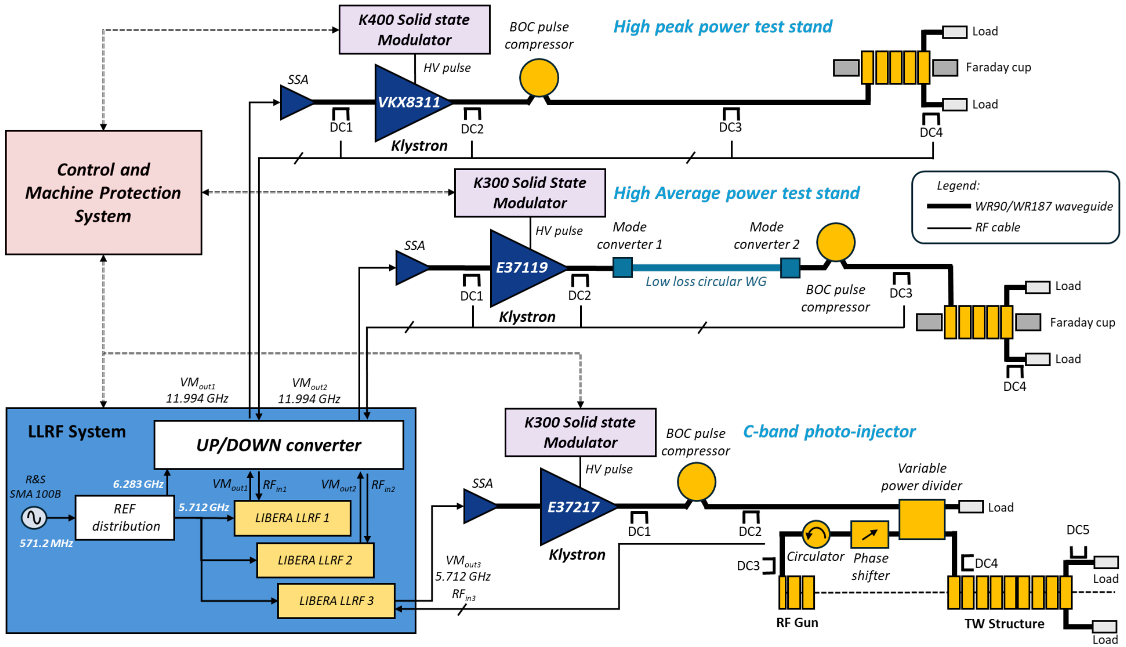
Operation of advanced digital LLRF systems

Main Features:

- Temp. stabilized front-end to compensate long-term thermal drifts
  - < 100 fs for normal operating conditions (24 +/- 2) °C
- Measured resolution:
  - Amplitude: 0.1 %
  - Phase: added jitter <10 fs (S-band <0.01°; C-band <0.02°)
- Pulse-to-pulse amplitude and phase feedback
- Arbitrary waveform pulse shaping



TEX complex LLRF system



Advanced controls development for LLRF systems

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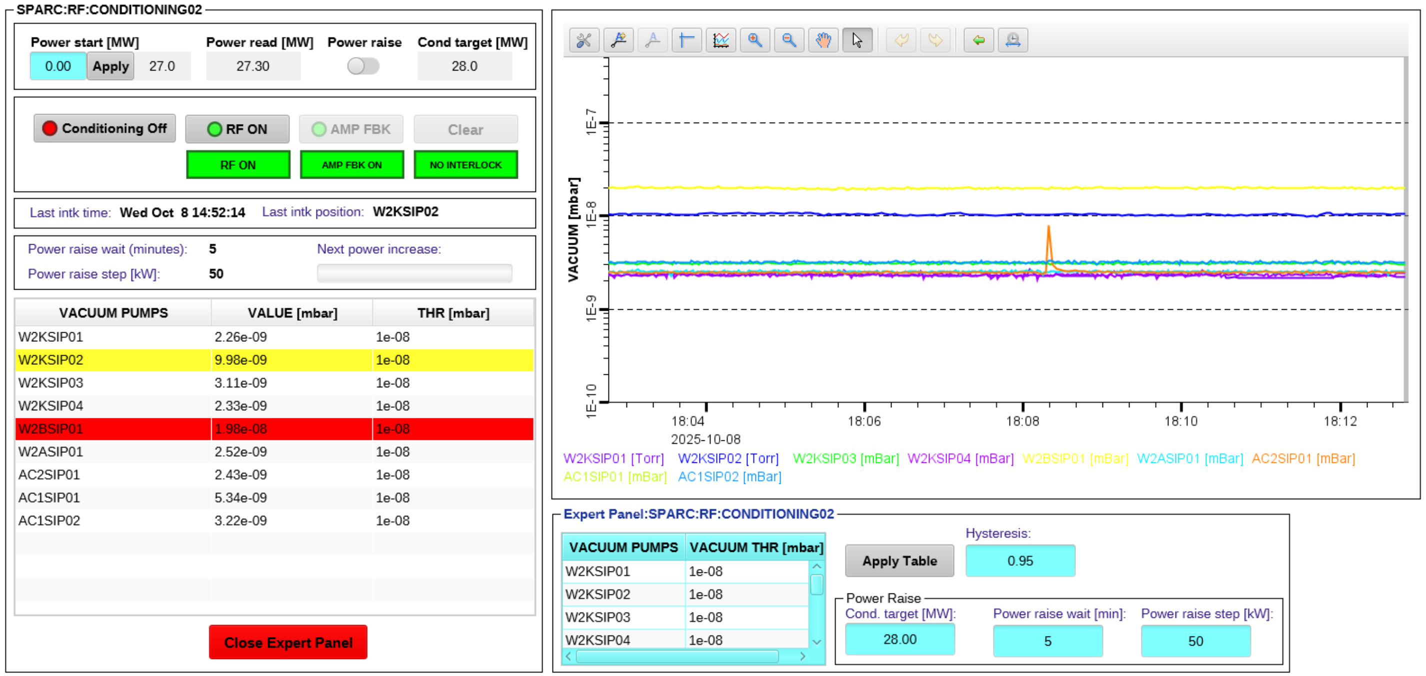
Development of Python softIOC for automatic RF conditioning, handling interlock events triggered by vacuum

Interface designed with CSS Phoebus.

```python
def main(prefix_rf_conditioning: str, prefix_LLRF: str):
    # Init variables
    loop_period=0.1 # Pause in seconds between iterations
    print(vacuum_pumps.get())
    vacuum_over_tsh = False
    # Starting main loop
    while True:
        # WORKS WITH FEEDBACK ALWAYS ON
        # DEFINE INITIAL SETPOINT
        if caget(prefix_LLRF+":app:rf_ctrl") == False and
           conditioning_status.get()==True:
               raise_count.set(0)
        else:
            pass
        •
        •
```



Future developments – Towards a single intuitive platform to unify the management of all LLRF system features

- Developed in Python + Qt (Qt Designer): the flexibility of Python + modern and intuitive graphical interface;
- Acquisition and analysis of signals from the RF front-end (for example, algorithms dedicated to statistics on amplitude and phase stability);
- Feedback loop management for real-time amplitude and phase control;
- Automated calibration procedures;
- Advanced system diagnostics…

Courtesy of B. Serenellini

fs synchronization for accelerator clients

There are many clients in an accelerator facility that require a stable, precise and coherent RF reference

Star-network: ultra stable RF reference is distributed (drift-free) and each client is locally phase-locked to the master reference

Typical clients:

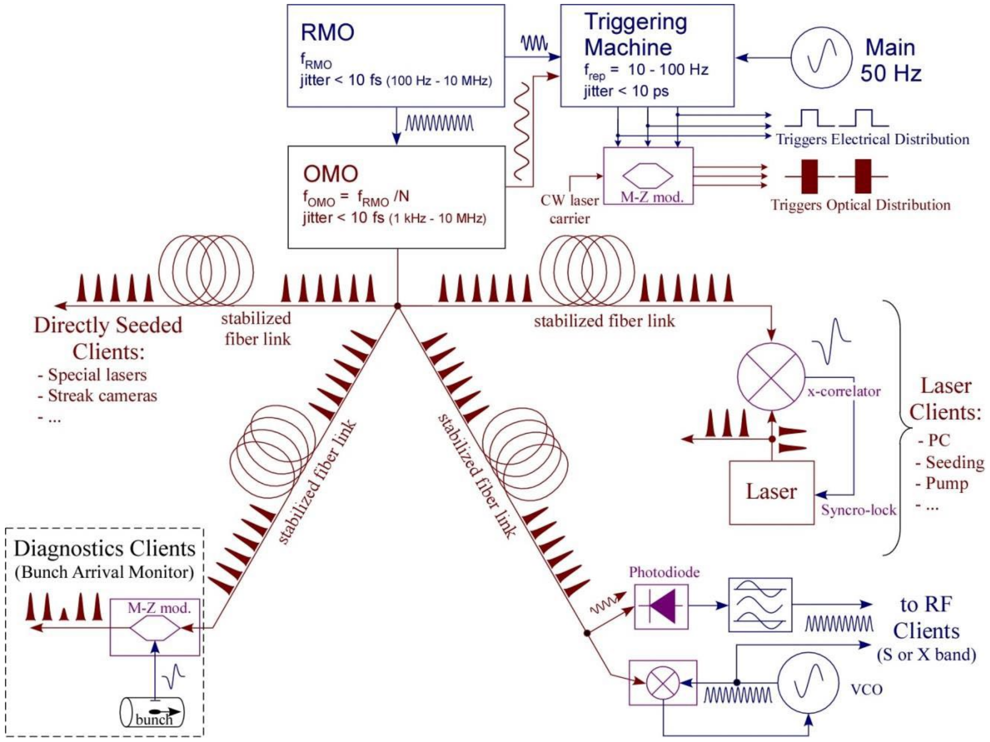
» Low-level RF / RF power units

» Photocathode laser

» Seeding/Interaction/Pump laser

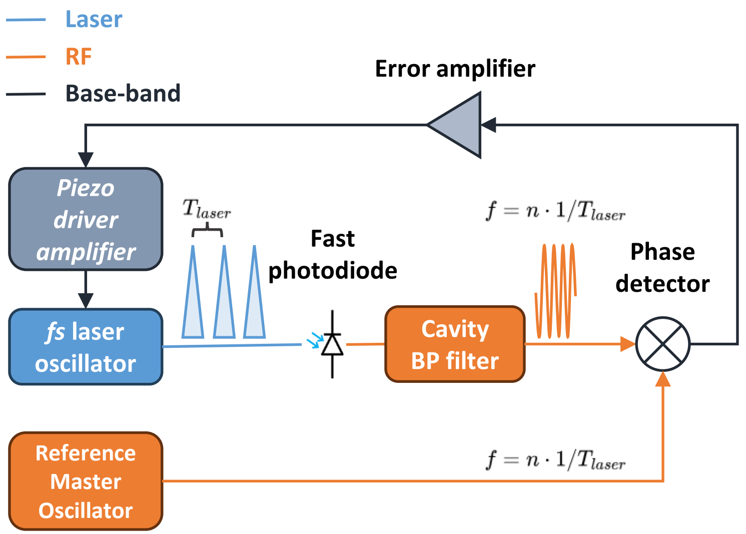
» Diagnostics (cavity BPMs, Electro Optical Sampling, …)

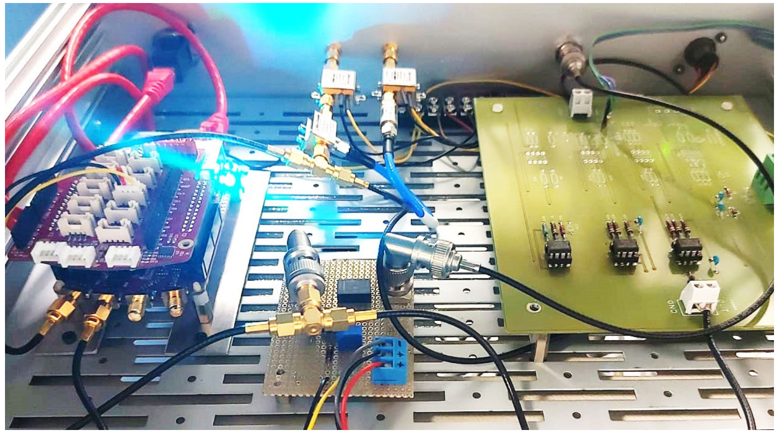
» Users

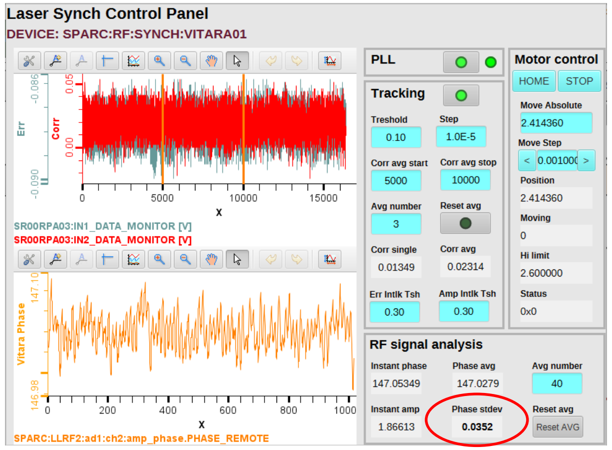


fs synchronization for accelerator clients

RF/laser phase lock

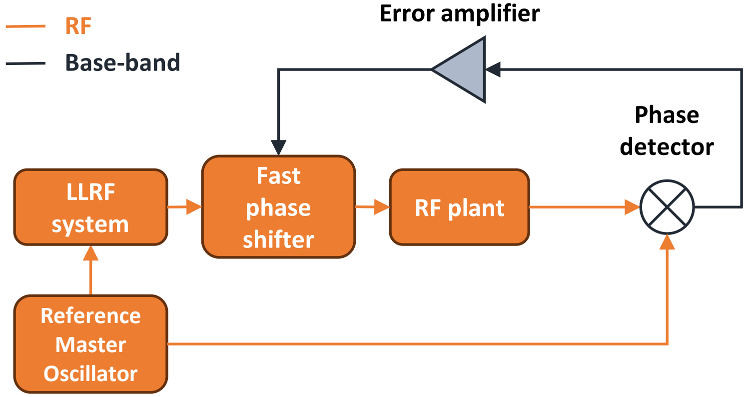


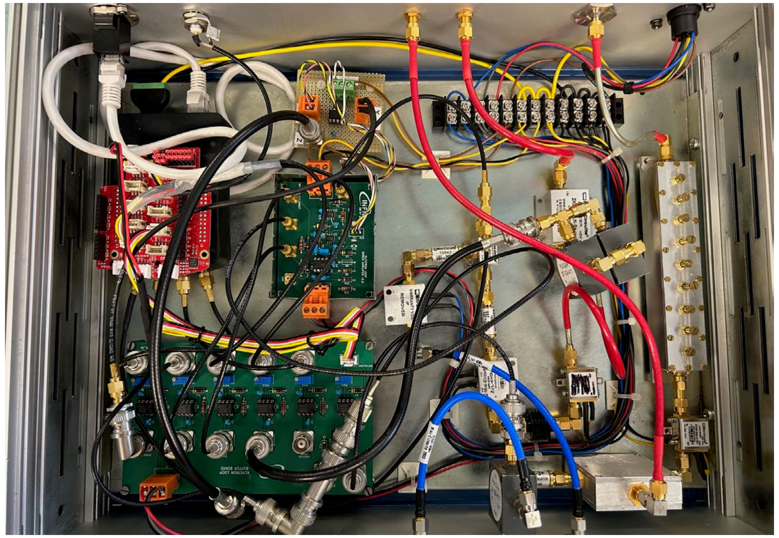


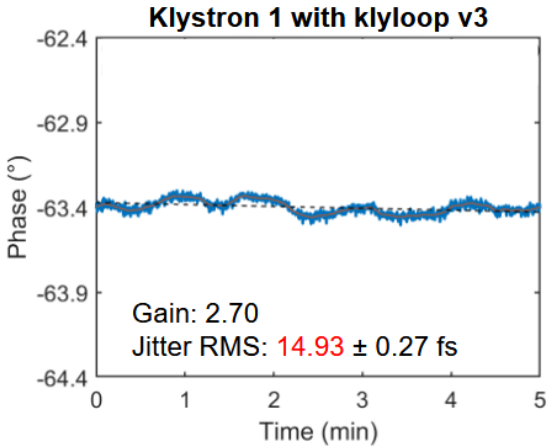


RMS Jitter: 34.2 fs

RF/RF phase lock (intra-pulse feedback)





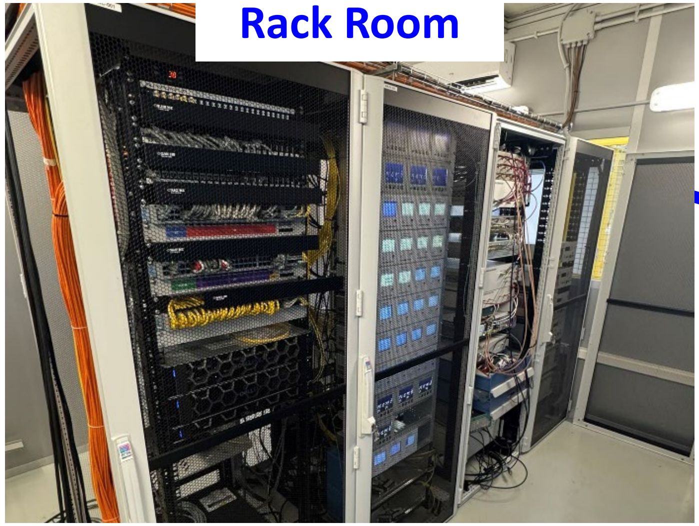


TEX facility

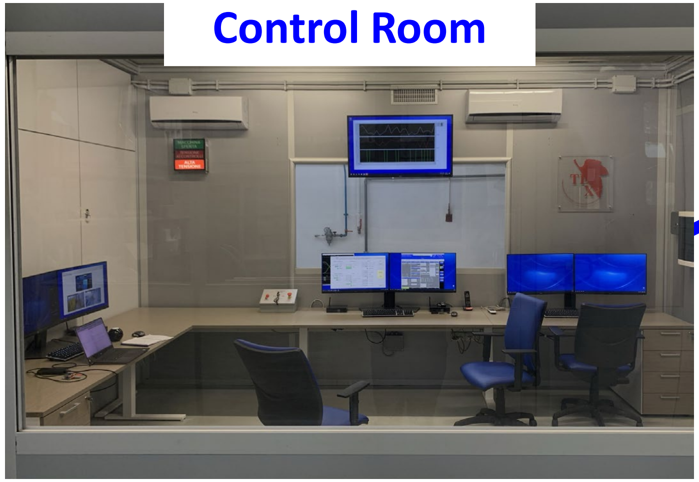
» The **TEst-stand for X-band (TEX)** is conceived for **R&D on X-band applications: high gradient accelerating structures, RF components, LLRF, Vacuum and Control Systems**

» The installation and commissioning of the whole facility has been completed by the end of 2022

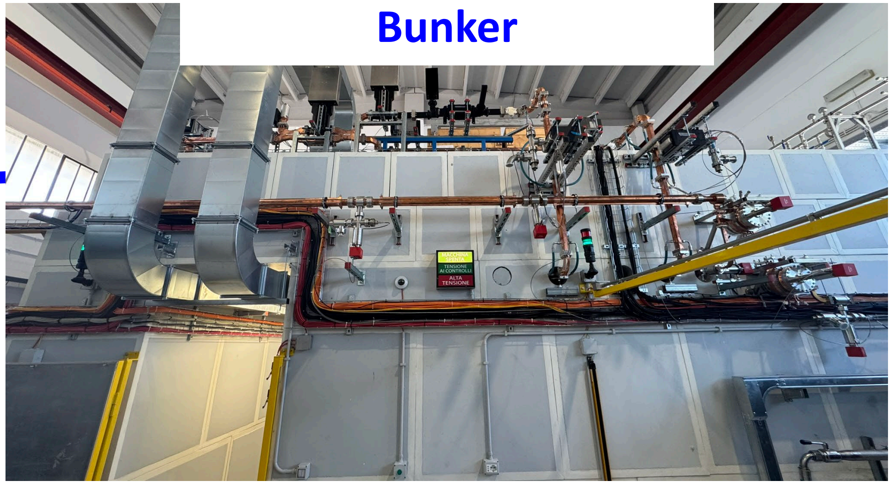
Rack Room



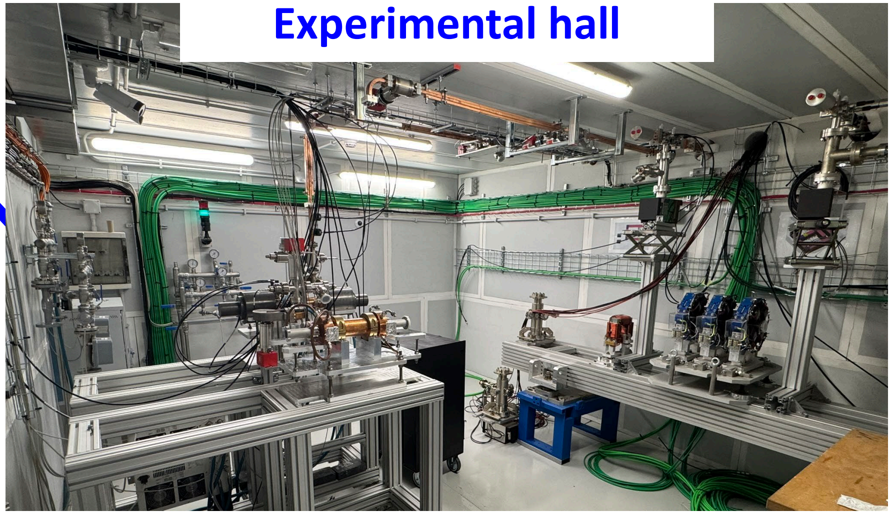
Control Room



Bunker



Experimental hall

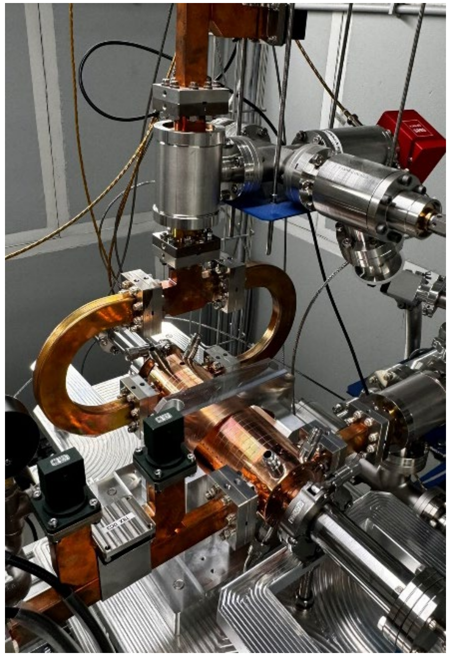


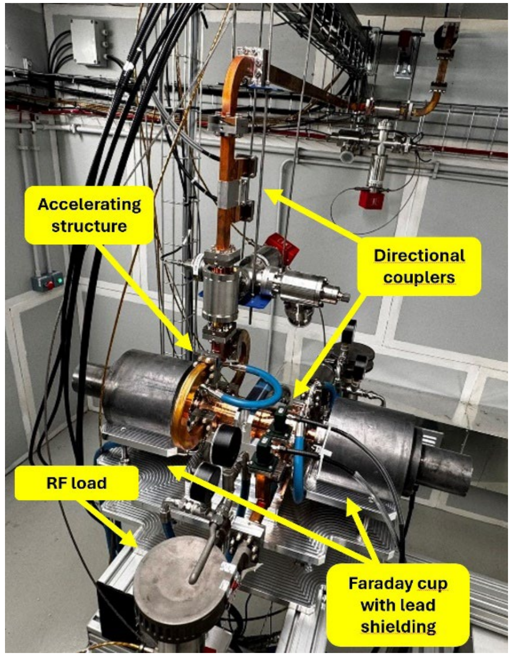
X-band accelerating structures test

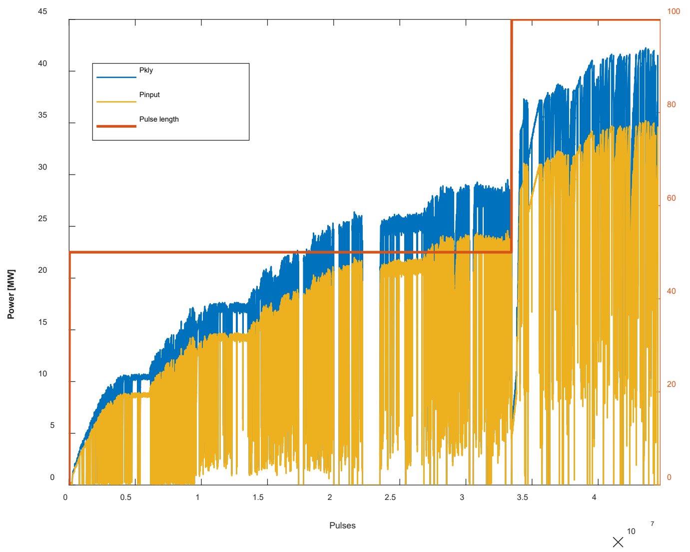
Test of X-band accelerating structures for the **EuPRAXIA@SPARC_LAB** project and for the **ASTERIX** project

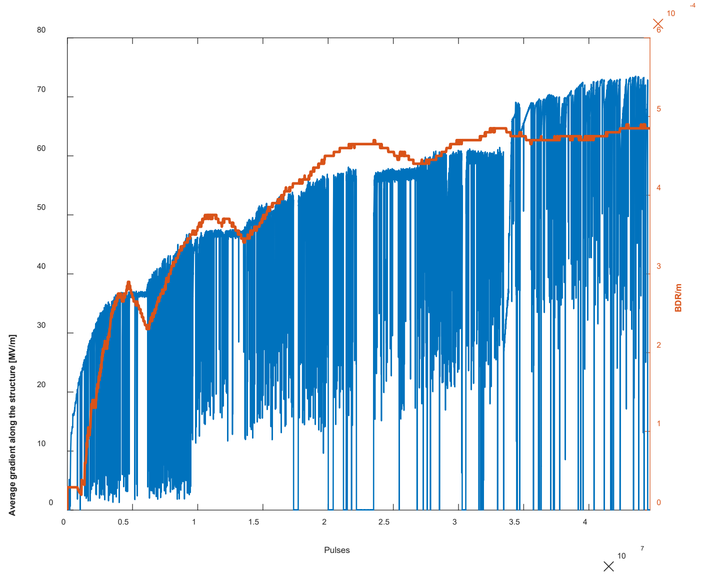
- Low power RF test
- High power RF test and conditioning algorithms
- Dark current simulations and measurements

DESIGN PARAMETER	Value
Frequency [GHz]	11.9942
Average acc. gradient [MV/m]	**60**
Structures per module	2
Iris radius a [mm]	**3.5**
Struct. length L_s act. Length [m]	**0.2**
No. of cells	20
Shunt impedance R [MΩ/m]	100
Effective shunt Imp. R_{sh_eff} [MΩ/m]	347
Filling time [ns]	30
Repetition Rate [Hz]	**100**









R&D on X-band components EM design

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R&D of X-band RF components:

- Electromagnetic design (with Ansys Electronic desktop or CST Microwave studio)
- Mechanical design (Autodesk Inventor)
- Prototyping
- Low power measurements
- High power measurements at the TEX facility

Mode converter and T-pump for circular wg