THE TEX FACILITY UPGRADE AT INFN-LNF

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Abstract

The TEX (TEst stand for X band) facility at INFN-LNF is a high-power RF test stand dedicated to the qualification of X-band components and accelerating structures for the EuPRAXIA@SPARC_LAB linac and related projects. An upgrade program is underway to extend its capabilities by increasing the available peak and average power, repetition rate and operational flexibility for both X-band (11.994 GHz) and C-band (5.712 GHz) operation. The major intervention includes the installation of two new high-repetition rate RF sources, one X-band and one C-band, together with dedicated waveguide distribution networks and improved diagnostics for breakdown detection, pulse shaping and long-term stability studies. Moreover, the C-band station, with the integration in the bunker of a C-band RF photo-gun developed within the IFAST project, will serve as the first testbed for a full C-band high-brightness photo-injector, enabling experimental validation of compact injector schemes. These enhancements will allow parallel conditioning stations, advanced high-gradient tests of accelerating structures and accelerated validation of RF components under realistic operating conditions for next-generation accelerators. The contribution will describe in detail the upgrade of the TEX facility and its future perspectives.

INTRODUCTION

INFN-LNF has developed a dedicated high-power RF test stand to validate the reliability and performance of the X-band technology in view of the realization of the EuPRAXIA@SPARC_LAB linac [1]. Commissioned in 2022, the TEX (TEst stand for X-band) facility was conceived to reproduce, as closely as possible, the operating conditions of the X-band RF module, enabling systematic testing of accelerating structures and RF components. The infrastructure has been co-funded by the Lazio Region within the LATINO project and is designed to operate as an open user facility for both industry and research institutions.

The availability of a test environment representative of the final accelerator configuration has made it possible not only to assess system performance and reliability, but also to identify critical aspects at both component and subsystem level, including vacuum, controls, safety, diagnostics and LLRF systems. In parallel, the facility has provided a valuable platform for training personnel and consolidating operational expertise in high-power RF systems.

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The initial configuration, developed in collaboration with CERN, was based on an X-band 50 MW RF source driven by a solid-state pulsed modulator capable of delivering high-voltage pulses up to 430 kV, with pulse lengths up to 3 µs at repetition rates up to 100 Hz [2, 3]. Following the commissioning phase, an extensive experimental program was carried out, including the testing of several X-band RF components and accelerating structures [4, 5].

Over the past year and a half, a major upgrade program of the facility has been carried out to significantly expand its testing capabilities. The upgrade has been implemented within Spoke 5 of the PNRR Rome Technopole project and focuses on increasing peak and average RF power, extending the repetition rate and improving the overall flexibility of the facility for both X-band and C-band operation. This upgrade is described in detail in the following sections of this paper.

FACILITY UPGRADE

The main upgrade activities, designed to extend the performance and operational flexibility of the facility, can be summarized as follows:

- Installation of an X-band pulse compressor of the Barrel Open Cavity (BOC) type, developed at PSI, on the existing 50 MW RF line. This system enables temporal compression of the RF pulse, increasing the peak power beyond the klystron output level and allowing high-gradient testing of accelerating structures and RF components.
- Integration of a new X-band (11.994 GHz) RF power station based on a Canon E37119 klystron driven by a solid-state modulator, capable of delivering up to 25 MW peak power at repetition rates up to 400 Hz, enabling high average power operation.
- Integration of a C-band (5.712 GHz) RF power station based on a Canon E37217 klystron and solid-state modulator, capable of providing up to 22 MW peak power at repetition rates up to 400 Hz.
- Implementation of two new RF distribution lines (X-band and C-band), including X-band low-loss waveguide systems, directional couplers, high-power loads, and BOC type pulse compressors, to transport RF power into the bunker for both the two new sources.
- Upgrade of a new C-band Low Level Radiofrequency (LLRF) system, based on Libera LLRF and an enhanced Machine Protection System (MPS) for the

whole facility designed to handle higher duty cycles and increased repetition rates [6].

- Installation of a new dry cooler in the TEX technical area to support the increased thermal load associated with the high repetition rate operation.
- Installation in the bunker of a photocathode laser system based on a Titanium:Sapphire source, required for photo-injector experiments.

After successful factory acceptance tests, the new RF sources have been delivered and installed. Table 1 summarizes the main parameters of these sources available after the upgrade, while Fig. 1 illustrate the final configuration layout of the upgraded facility. In Fig. 2 and Fig. 3, the two new RF sources installed in their final positions and the interior of the bunker are shown, including the two X-band test stands, the photocathode laser system, and the girder for C-band experiments.

Table 1: Overview of the RF sources available at the TEX facility.

Source	M1	M2	M3
RF Frequency [GHz]	11.994	11.994	5.712
Cathode peak voltage [kV]	420	312	254
Beam Current [A]	320	199	196
Max RF Peak Power [MW]	50	25	22
Max RF Pulse Length [μs]	1.5	1.5	2.5
Max Rep. Rate [Hz]	50	400	400
Gain [dB]	48	47	50
Pulse Flatness [%]	≤ ± 1	≤ ± 1.6	≤ ± 1
Pulse to pulse stab. [ppm]	16	17	18

This installation required a substantial reconfiguration of the facility infrastructure, including waveguide routing, cooling systems, control electronics, and diagnostics. Fig. 4 illustrates the main components of the upgraded setup, including the RF waveguide distribution networks, the upgraded LLRF system, the power supply and control racks, and the new cooling plant located outside the building.

The commissioning of the newly installed high-power RF stations has not yet been completed. Once fully operational, this upgraded configuration will significantly enhance the overall performance and operational flexibility of the facility. In particular, the addition of the second X-band station will effectively double the conditioning and validation capability for EuPRAXIA@SPARC_LAB RF components, while also enabling high average power testing and more efficient experimental campaigns.

THE FRINGE PHOTO-INJECTOR

In addition to the increased capability for high repetition rate RF component testing, the introduction of the C-band RF station opens new perspectives for advanced injector R&D. Beyond its role as a test source, this system will be exploited to implement a dedicated experimental line in

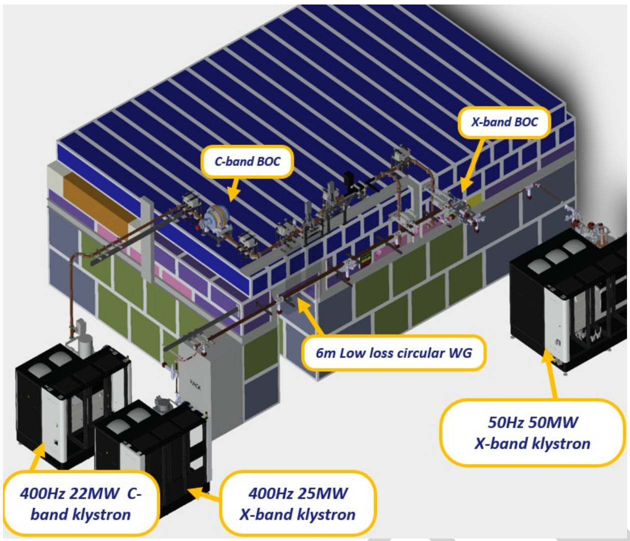

Figure 1: Configuration of the TEX facility area around the bunker, after the upgrade, with the three RF power sources.

Figure 2: The 25MW X-band source and the 22MW C-band source installed in the final position.

the TEX bunker aimed at the realization of a compact, full C-band photo-injector prototype. The concept relies on the integration of a high-gradient C-band RF photo-gun, developed within the IFAST project [7] and a short traveling-wave accelerating structure.

This configuration will enable operation at repetition rates up to 400 Hz, allowing exploration of high average current regimes and providing a test bench for an high brighness injector relized completely in C-band [8]. Possible innovative beam dynamics schemes based on the proposed layout have been investigated, with the aim of enabling their study and experimental validation using this linac [9]. The availability of a fully C-band architecture will also allow systematic investigations of RF-to-beam efficiency, timing and phase stability, and operational robustness under realistic

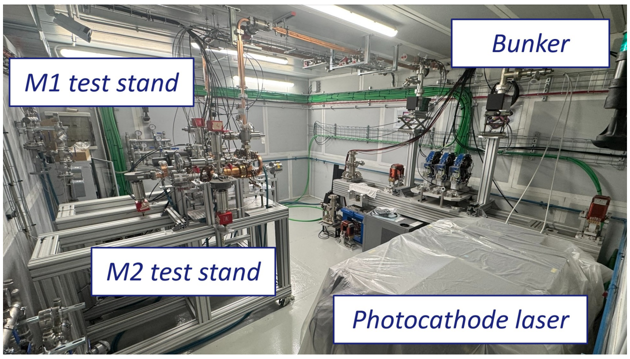

Figure 3: Picture of the bunker experimental area, with the two X-band test stand, the photocathode laser system and the girder for C-band testing.

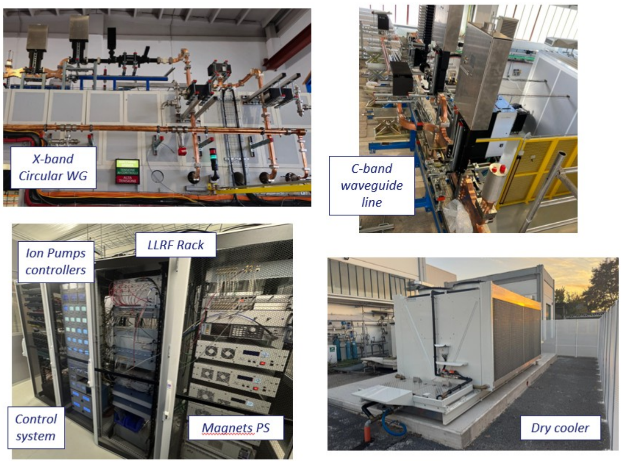

Figure 4: Layout of the TEX facility area around the bunker, after the upgrade, with the three RF power sources.

duty cycles. Several key components of this experimental line, including the photocathode laser system, a beam dump dipole, a quadrupole triplet, beam steering correctors, and diagnostics chambers, have already been procured, enabling the progressive implementation of the injector test facility.

CONCLUSION

Overall, the upgrade transforms TEX into a versatile multi-frequency RF test facility capable of supporting both high peak power and high average power experimental programs, making it a key infrastructure for the development of next-generation high-gradient linear accelerators.

ACKNOWLEDGEMENTS

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