ACTIVITY REPORT OF THE TEX FACILITY

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1 Introduction

TEX ("TEst stand for X-band") is a dedicated facility at INFN-LNF, specifically designed for testing X-band (11.994 GHz) radiofrequency technology used in linear accelerators [1, 2, 3]. Since its commissioning, the facility has significantly consolidated its key role in the Frascati laboratories, enhancing operations and technical activities. TEX serves as a critical infrastructure for testing advanced X-band accelerating structures, RF components, vacuum and control systems essential to the design of the EuPRAXIA@SPARC_LAB project [4, 5]. Additionally, the facility actively fosters in the last year robust collaborations with both national and international research institutions, as well as industrial partners. Recently, thanks to the PNRR project Rome Technopole [6], TEX underwent a substantial upgrade aimed at significantly expanding its testing capabilities, positioning the facility to effectively support cutting-edge research and future technological advancements.

2 Test of RF components and first EuPRAXIA@SPARC_LAB RF structure prototype

Over the past two years, the facility has enabled high-power testing of various RF components essential for validating X-band technology. Among these components was an ultra-compact X-band RF water load designed at the Paul Scherrer Institute (PSI, Switzerland) and tested in collaboration with them, as well as a low-loss waveguide transport setup designed and developed at Frascati National Laboratories. This setup utilizes two RF mode converters, allowing the transition from a WR90 rectangular waveguide to an overmoded circular waveguide. This type of transmission line is necessary for delivering high-power X-band RF signals over long distances while minimizing signal attenuation [7]. The circular waveguide setup, once designed at INFN and manufactured by a private company, was tested at high power at TEX, demonstrating its functionality at the nominal parameters foreseen for the EuPRAXIA project. Figure 1 shows the circular waveguide test setup, once completed, during the RF characterization with a Network Analyzer and installed in the test bunker for high-power testing.

Another primary achievement was the successful high-power RF testing of the first EuPRAXIA@SPARC_LAB accelerating structure prototype, consisting of 20 cells. Figure 2 shows an image of the 20-cell X-band prototype during low-power characterization, as well as the setup used for conditioning the prototype installed in the TEX bunker. The prototype is connected to the RF power distribution system and terminated at both ends by two Faraday cups. Testing included a comprehensive evaluation of performance parameters such as RF breakdown rate, achievable gradient, and thermal stability. The prototype demonstrated stable operation at gradients exceeding 70 MV/m with a pulse length of 100 ns at a repetition rate of 50 Hz, successfully

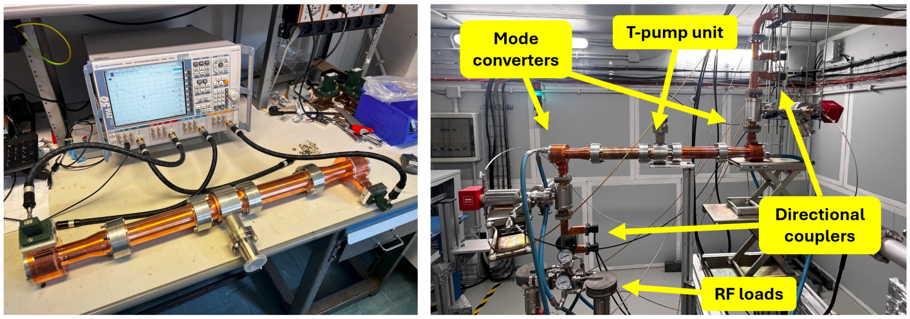

Figure 1: *Mode converter and circular waveguide setup during low-power testing after manufacturing (left), and layout of the circular waveguide setup during high-power testing inside the TEX bunker (right).*

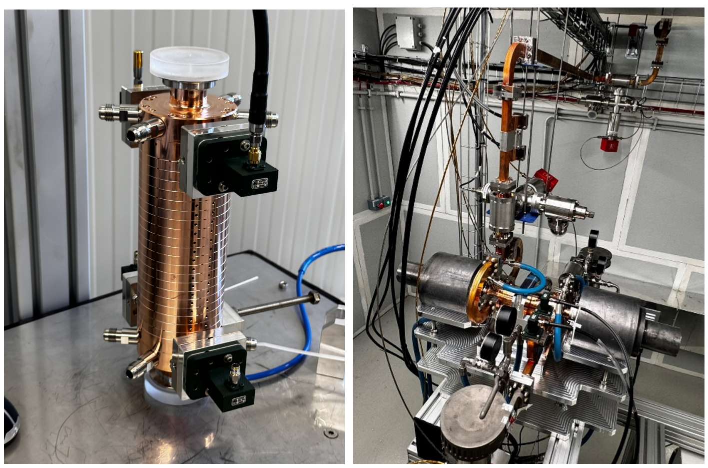

Figure 2: *X-band 20 cells RF prototype of the EuPRAXIA@SPARC_LAB structure (left) and high power test layout of the structure inside the TEX bunker (right).*

meeting EuPRAXIA's operational specifications (60 MV/m) after only 10 days of conditioning. The conditioning history of the prototype is presented in Figure 3. RF conditioning was effectively automated using artificial intelligence specifically designed to monitor all critical test parameters (vacuum levels, RF signals, Faraday cup signals, etc.), gradually ramp up the power, and automatically respond to breakdown events [8]. Additionally, the AI system provided predictive analyses of breakdown occurrences, further enhancing operational reliability.

3 Upgrade of the TEX Facility

An extensive facility upgrade was executed within the framework of the PNRR Rome Technopole initiative. Two cutting-edge RF power sources were installed, significantly enhancing TEX's testing capabilities:

- An X-band (11.994 GHz) RF source, based on the Canon E37119 klystron, capable of reaching repetition rates up to 400 Hz, delivering a peak power of 25 MW. This system will be employed to test RF structures and components under high average power conditions.

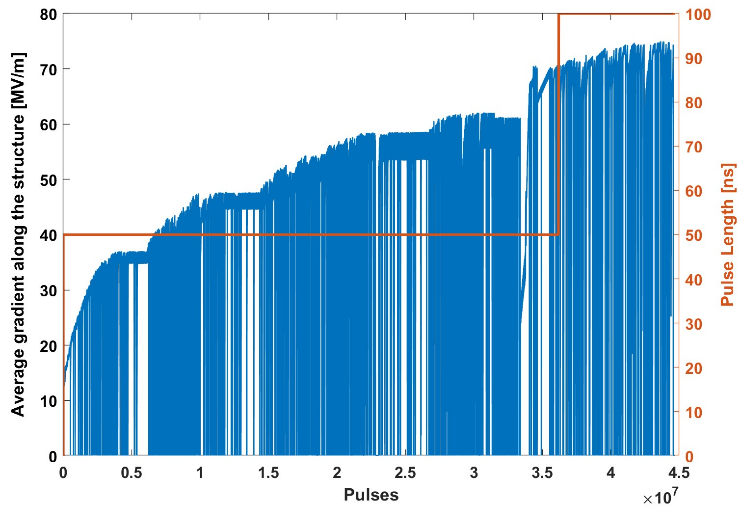

Figure 3: *Conditioning history of the EuPRAXIA@SPARC_LAB 20 cells RF prototype*

Table 1: *Main Parameters of the RF sources installed for the TEX upgrade.*

Parameter	Units	X-band Source	C-band Source
Frequency	GHz	11.994	5.712
RF Peak power	MW	25	20
Gain	dB	47	50
Average RF power	kW	15	21
Cathode peak voltage	kV	312	254
Beam Current	A	199	196
Repetition Rate	Hz	400	400
RF Pulse length	μs	1.5	3.5
Pulse Flatness	%	$\leq \pm$ 1.6	$\leq \pm$ 1
Pulse to pulse stability	ppm	13	14

- A C-band (5.712 GHz) RF source, based on the Canon E37217 klystron, capable of operating at repetition rates up to 400 Hz and delivering peak power levels of up to 20 MW. This source will enable testing of C-band RF components and structures, a technology that is particularly interesting and commonly used in accelerators for medical applications.

The two klystrons are powered by two solid-state modulators (model K300) manufactured by Scandinova (Sweden). After successful factory testing, the sources were shipped and installed in their final position at the TEX facility in Frascati (Fig. 4). In table 1 are reported the main parameters of the two sources. They will be the first sources of their kind to demonstrate reliable operation at such high repetition rates.

The final conditioning test of these sources on a matched load is scheduled for May 2025. Meanwhile, installation of a new C-band low-level RF system, along with the RF power waveguide distribution system, is already underway. These distribution systems will deliver the high-power RF pulses generated by the two sources directly to the experimental area inside the bunker. Additionally, the waveguide layouts of the two new sources and the existing X-band source already

Figure 4: *X-band and C-band high repetition rate RF sources installed at the TEX facility.*

operating at TEX have been equipped with BOC-type pulse compressors [9], which allow an increase in peak power by compressing the length of the RF pulse. In the framework of the Rome Technopole project, the C-band RF source will be used to drive a small electron linac called FRINGE inside the TEX bunker, employing a high-gradient RF Gun developed at LNF within the framework of the IFAST project [10, 11]. Beam dynamics simulations have been carried out to explore the performance of a compact photoinjector based on this C-band Gun [12], and the photocathode laser required to generate the electron beam has been ordered and is expected to arrive by the end of 2025. These enhancements significantly expand the facility's capabilities, enabling simultaneous testing of multiple RF structures and promoting groundbreaking research in high-gradient RF technology, in both X-band and C-band.

4 List of Conference Talks by LNF Authors in Year 2023-2024

Include a list of conference talks by LNF authors.

1. F. Cardelli, RF Power Systems at INFN-LNF, Pulsed High Power RF Sources Workshop, Lund, Sweden, 18 Sept 2023
2. F. Cardelli, RF Structure for Eupraxia@SPARC_LAB: accelerating sections and waveguide components, 15th Workshop on Breakdown Science and High Gradient Technology (HG2023), Frascati, Italy, 16-20 Oct 2023.
3. M. Bellaveglia, Technological challenges for the design and implementation of an X-band LLRF for a user facility linac, 15th Workshop on Breakdown Science and High Gradient Technology (HG2023), Frascati, Italy, 16-20 Oct 2023
4. C. Di Giulio, TEX (TEst stand for X-band) at LNF, 15th Workshop on Breakdown Science and High Gradient Technology (HG2023), Frascati, Italy, 16-20 Oct 2023
5. F. Cardelli, X-band activities at INFN-LNF, 14th International Particle Accelerator Conference (IPAC'23),Venice, Italy 7-12 May 2023. doi: 10.18429/JACoW-IPAC2023-MOOG1

6. F. Cardelli, EUPRAXIA progress with special focus on X-band, CLIC Mini week, CERN, Switzerland, 11-13 Dec 2023
7. F. Cardelli, RF power sources at INFN-LNF, ScandiNova's 14th User Meeting 2024, Seoul, South Korea, 8-10 May 2024
8. F. Cardelli, X-band activities for the EuPRAXIA@SPARC_LAB Linac, International Workshop on future linear collider (LCWS2024), Tokyo, Japan, 8-11 Jul 2024
9. F. Cardelli, Activities on X-band structures at the INFN-LNF, 110° Congresso Nazionale Società Italiana di Fisica, 9-13 Sep 2024
10. F. Cardelli, TEX Facility, 1st workshop on Fundamental research and applications with the EuPRAXIA facility at LNF, Frascati, Italy, 4-6 Dec 2024

References

1. S. Pioli et al., *"TEX - an X-Band Test Facility at INFN-LNF"* in Proc. 12th Int. Particle Accelerator Conf. IPAC'21, Campinas, Brazil, (2021).
2. F. Cardelli et al., *"Status and commissioning of the first X-band RF source of the Tex Facility"* in Proc. 13th Int. Particle Accelerator Conf. IPAC'22, Bangkok, Thailand, (2022).
3. C. Di Giulio, et al., *"TEX (TEst stand for X-band) at LNF."* arXiv preprint arXiv:2308.03053 (2023). Proceeding of International Workshop on Future Linear Colliders (LCWS 2023), 15-19 May 2023. DOI: https://doi.org/10.48550/arXiv.2308.03053
4. D. Alesini et al., *"EuPRAXIA@SPARC_LAB Conceptual Design Report"*, INFN-18-03/LNF, (2018).
5. F. Villa et al., *"EuPRAXIA@SPARC_LAB Status Update"*, Proceedings of SPIE Conference Volume 12581, X-Ray Free-Electron Lasers: Advances in Source Development and Instrumentation VI; 125810H (2023). https://doi.org/10.1117/12.2668643
6. PNRR Rome Technopole project, https://www.rometechnopole.it
7. F. Cardelli, et al., *"X-band activities at INFN-LNF."* in Proc. 14th Int. Particle Accelerator Conf. IPAC'23, Venice, Italy, (2023).
8. S. Pioli, et al., *"Control and Functional Safety Systems Design for Real-Time Conditioning of RF Structures at TEX."* in Proc. 13th Int. Particle Accelerator Conf. IPAC'22, Bangkok, Thailand, (2022).
9. R. Zennaro, et al., *"C-band RF pulse compressor for SWISS-FEL."* in Proc. 4th Int. Particle Accelerator Conf. IPAC'13, Shanghai, China, (2013).
10. F. Cardelli, *"Design and realization of high-gradient C-band standing wave RF gun"*, il Nuovo Cimento C, issue 5, (2024). DOI: 10.1393/ncc/i2024-24272-y
11. D. Alesini, et al., *"Design, realization and high power RF test of the new brazed free C band Photo-Gun."* in Proc. 15th Int. Particle Accelerator Conf. IPAC'24, Nashville, TN, (2024).
12. A. Giribono, et al., *"Dynamics studies of high brightness electron beams in a normal conducting, high repetition rate C-band injector."*, Phys. Rev. Accel. Beams 26, 083402, (2023).