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TEX - AN X-BAND TEST FACILITY AT INFN-LNF

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Abstract

We report the status of the development of an High Power RF Laboratory in X-Band called TEX (TEst-stand for X-Band). TEX is part of the LATINO (Laboratory in Advanced Technologies for INnOvation) initiative that is ongoing at the Frascati National Laboratories (LNF) of the Italian Institute for Nuclear Physics (INFN) that covers many different areas focused on particle accelerator technologies. TEX is a RF test facility based on solid-state K400 modulator from ScandiNova with a 50 MW class X-band (11.994 GHz) klystron tube model VKX8311A operating at 50 Hz. This RF source will operate as resource for test and research programs such as the RF breakdown on RF waveguide components as well as high power testing of accelerating structures for future high gradient linear accelerator such as EuPRAXIA and CLIC. The high power testing will be performed in a dedicated brand-new bunker that has been recently built. RF system, vacuum controls and safety equipments are currently being installed. The first accelerating structure testing is scheduled by beginning 2022. In this document design and tests for all the sub-systems of the facility will be presented and discussed.

INTRODUCTION

In preparation to the activities of the EuPRAXIA@SPARC_LAB projectand the LATINO (Laboratory in Advanced Technologies for INnOvation) Initiative, a high-power test stand for X-band accelerating structures called TEX ("TEst stand for X-band") is being built at LNF. The X-band (11.994 GHz) is at present the most advanced RF technology, with demonstrated capability of providing accelerating gradients up to 100 MV/m and beyond. In this context started the implementation of a new high power X-band test stand at LNF. The area to host the new test stand within the LNF has been identified and it is presently being refurbished to provide all the required services to the facility. The concrete bunker shielding the accessible area from the radiation produced by the structures under test is also being designed and constructed. The facility under commissioning will be used for testing X-band accelerating structure prototypes (EuPRAXIA and CLIC projects), RF components and sub-systems. For the rest of the time the facility will be accessible to external users, including national and international laboratories and companies. The open-access to TEX is one of the services offered by INFN to the external community through LATINO, a project approved and funded by the government of "Regione Lazio" aimed at promoting and increasing the technology transfer between research centres of excellence and the surrounding economic framework. In this document the TEX X-band source is presented and the MPS, control and Low level RF system description is reported. Finally, preliminary results about dark current studies for the EuPRAXIA X-band accelerating structure are reported.

TEX FACILITY

The test stand is based on a pulsed solid state modulator feeding an X-band klystron tube. The input RF pulse is generated by a Low Level RF system, described later, and amplified by a commercial solid state driver amplifier realized by Microwave Amps [1] to a power of more than 600 W. The power source will produce up to 50 MW RF pulses of 1500 ns pulse width and 50-100 Hz repetition rate. The first klystron that will be used is a VKX8311A [2] provided to us by CERN. This klystron is capable of providing up to 1.5 µs long rf pulses of 50 MW at a repetition rate of 50 Hz. The operating voltage of the klystron is more the 400 kV with a nominal perveance 1.2 $\mu A/V^{3/2}$. The klystron is powered by a ScandiNova k400 [3] solid state modulator design to deliver pulses up to 450 kV, 335 A and 1.5 µs flat top length at 100 Hz repetition rate. In Figs. 1 and 2 the pictures of the pulsed modulator and the X-band klystron are reported.

The solid state technology allows to reach a high stability of the output pulse with an high compactness of the overall system requiring only about 6 m^2 of footprints. The site acceptance test of the modulator will be performed in October and the test of the first accelerating structure prototype is scheduled by beginning 2022. In Table 1 the main parameters of the power source are reported.

The power generated by the source is transported into the bunker by a standard WR90 waveguide network. Five ion pumps with getters will ensure the ultra-high vacuum needed by the system. In a secondary phase, as part of the X-band waveguide component testing program, a X-band BOC pulse compressor will be installed increasing the output power available. The waveguide layout is then completed by directional couplers for RF diagnostics and vacuum T-pump units.

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Figure 1: Solid state modulator installed near the TEX bunker.

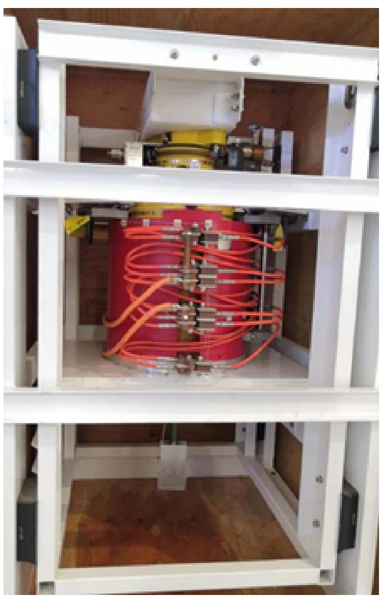

Figure 2: VKX8311A klystron during the unpackage.

Table 1: Main RF Source Parameters

Parameter	Unit	Value
Frequency	GHz	11.994
RF Peak power	MW	50
Gain	dBm	48
Modulator Peak Power	MW	140
Operational Voltage Vk	kV	420
Operational Current Ik	A	320
PRF Range	Hz	1-100
Pulse length (top)	us	1.5
Flat top flatness	%	< ± 0.25
Pulse to pulse stability	ppm	< 50

This source will be mainly used for the test and conditioning of X-band accelerating structure designed for the CLIC and EuPRAXIA@SPARC_LAB project but several X-band waveguide components will be tested as double-high low attenuation waveguide, circular waveguide components, mode converters, brazeless BOC pulse compressor etc. In addition, this station will be a test bench for all sub-systems which are under development in the framework of the EuPRAXIA@SPARC_LAB project. New conditioning procedures, breakdown and dark current studies, high level applications and safety systems will be also tested. The Bunker, modulator hall, technical room and Control room have been already realized last year, actually the modulator has been positioned and connected with water and mains and the machine protection system and safety have been installed. In Fig. 3 is shown a view from the top of the area including the TEX bunker, modulator area and the control room.

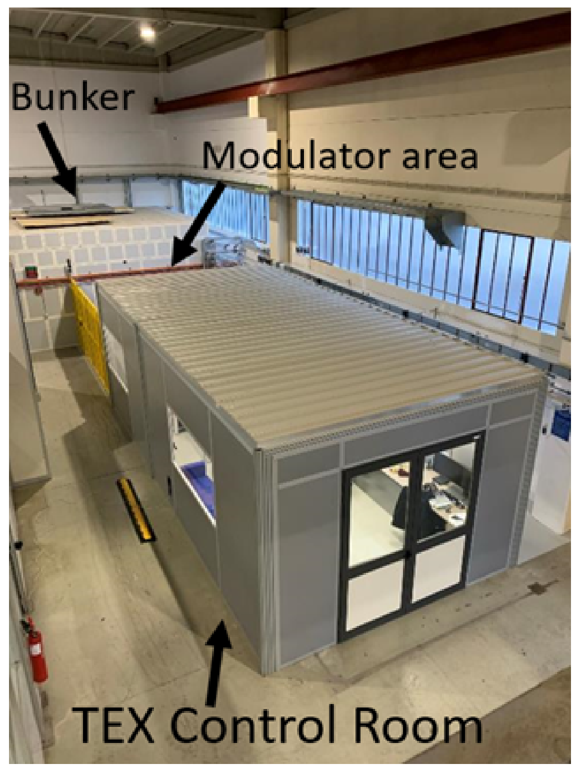

Figure 3: Top view of the TEX bunker and Control room.

Low Level RF System

The X-band LLRF systems was developed starting by the available on the market S-band system, the Libera LLRF, manufactured by Instrumentation Technologies, whose features and performance have been already reviewed in [4, 5] for a similar architecture. The systems has been adapted to work at 11.994 GHz by LNF RF team developing:

- a reference generation and distribution system able to produce coherent 2.856 GHz S-band and 11.994 GHz X-band references;
- an X-band up/down converter;

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- two custom designed cavity band-pass filters to suppress the signal harmonics and the inter-modulation products in the 9.138 GHz reference and the up-converted vector modulator output, respectively.

A block diagram of the complete LLRF system is shown in Fig. 4.

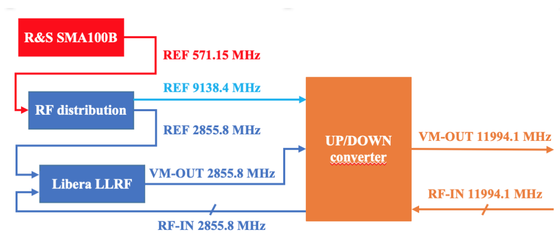

Figure 4: LLRF BLock schema.

Control System and Functional Safety

The Control System (Fig. 5) will be based on EPICS Framework 3.14 [6] with dedicated IOCs for RF Sources, LLRF, Vacuum and cooling. Archiving service will collect PVs and stream data with Kafka [7] to the centralized storage system of the Lab. The facility will be equipped with a middle layer for Machine Learning based autonomous conditioning of accelerating structures. Temporary Operator Interfaces works on LabVIEW platform waiting for an on-going upgrade to web-based UI.

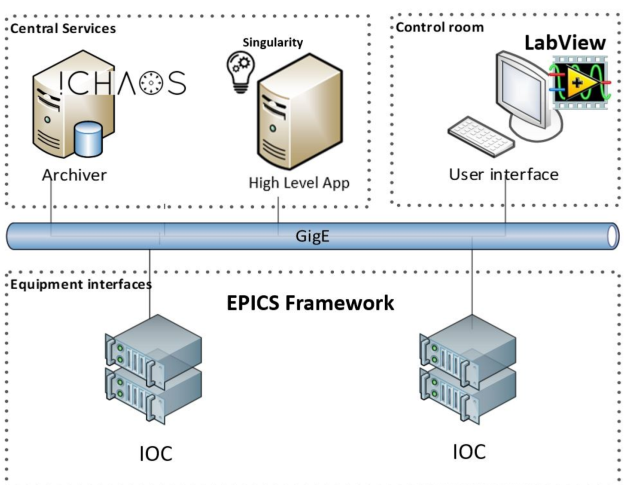

Figure 5: Control System Framework and related services layout.

Both elements of Functional Safety System, as Machine Protection and Personnel Safety, are integrated through FPGA-based SIL-2 compliant systems [8] and equipped with Waveform Mask interlock system for real-time detection of RF breakdown in forward and reflected RF signals [9].

Preliminary Dark Current Studies

In order to design the radiation shielding for the bunker and the instrumentation around the accelerating structure under test we performed an evaluation of the dark current produced. The dark current is produced by field emission from internal surfaces due to peak surface electric field that in an X-band accelerating structure could reach values in excess of 200 MV/m. These field emitted-emitted electrons may be captured by the RF field and transported through the accelerating structure as a current. This current colliding with the faraday cup and the surrounding environment generate a background radiation that needs to be evaluated and shielded. To evaluate the spectrum and the value of the dark current for the 108 cells EuPRAXIA@SPARC_LAB structure [10] operating at 60 MV/m we perform simulation with the PIC solver of CST Studio Suite [11], starting for the works reported in [12, 13]. The CLIC case simulations have been replicated in order to found a scaling factor between CLIC (100 MV/m, 24 cells) and EuPRAXIA structures thus evaluating the expected current directly scaling the current measured at the X-box test stands at CERN. Preliminary results show a current of the order of 10 nA for the case of the EuPRAXIA structures and the relative spectrum is reported in Fig. 6. Accurate studies about the dark current evaluation are in progress.

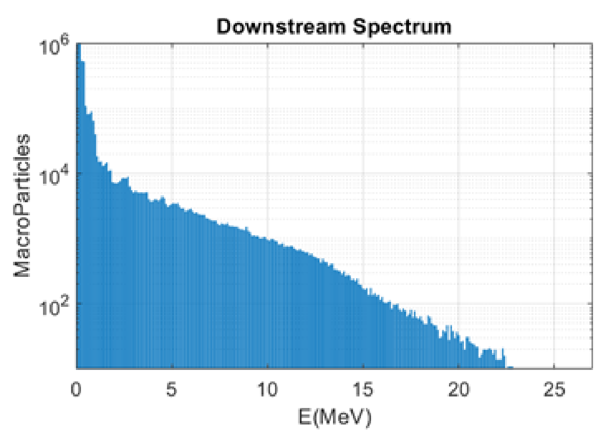

Figure 6: Downstream spectrum of the Dark current generated by the EuPRAXIA@SPARC_LAB structure operated at 60 MV/m.

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