REMOTE COMMISSIONING OF 400 kW 352 MHz AMPLIFIERS

Elettra Sincrotrone Trieste

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In the framework of the European Spallation Source ERIC (ESS ERIC) In-Kind collaboration, Elettra Sincrotrone Trieste has the task to deliver 26 400 kW 352 MHz Radio Frequency Power Station (RFPS) units. They will feed the Spoke Cavities section of the proton Linac. The manufacturing has been awarded to the European Science Solutions consortium (ESS-C).
The production of the amplifiers is well underway and has reached a steady rate of delivery. Each RFPS is subject to a Factory Acceptance Test (FAT). In this contribution, the main results of the FATs are presented, together with the FAT remote session protocol, specifically developed to cope with the traveling restrictions imposed by the COVID-19 pandemic.

RFPS MAIN FEATURES

Parameter	Value
Operating frequency	352.21 MHz
Nominal peak Power P_N	400 kW
RF Drive $_M$	10 dBm
Gain @ P_N	> 76 dB
Band Width	≥ 2 MHz
Operation	Pulsed, at 5% duty cycle
Pulse repetition rate	14 Hz
Pulse Width	3.5 ms
Input & Output impedance	50 Ω
RF output line	6 1/8 " EIA rigid coaxial line flange
Electrical grid Power Line	AC 400 V, 50 Hz, 3 Phases + Neutral + PE
Electrical grid Control Line	AC 400 V, 50 Hz, 3 Phases + Neutral + PE
Cooling	Forced air and water

The RFPS machine consists of two equivalent transmitters, each one having a RF solid state driver followed by a tetrode-based amplification stage.
One RF input distribution line with phase and amplitude static controls on each RF branch drives both transmitters. Their outputs add together thanks to a 3 dB hybrid combiner.

Thales TH595A tetrodes and TH18595A cavities. Each tetrode is driven by up to 7 kW of RF power.

Front view of the first RFPS unit. Racks from left to right: 1) Human Machine Interface, Supervisory Control System (SCS), Solid State Drivers 2) Grids Power Supplies, SCS FPGA board, electrical distribution 3-4) Tetrode-Cavities 5-6) High Voltage power supply

Personal SAFETY

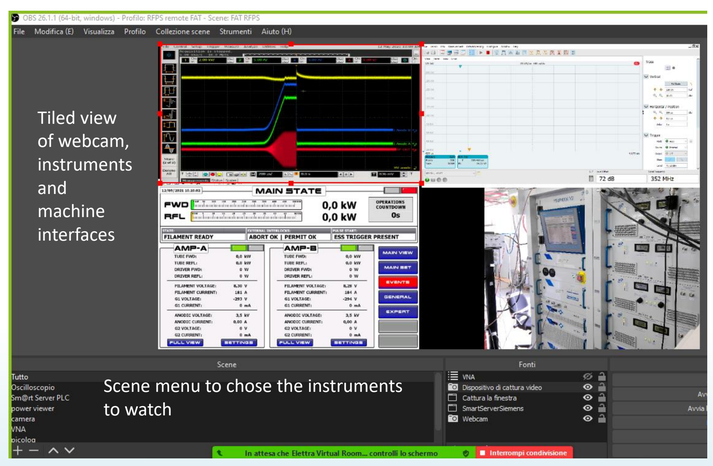
- "Slow" reaction time: ms range
- **SOURCE**: External Interlock (ABORT) and Internal Interlock (Rack Door OPEN)
- Manual E-STOP device
- **RESULT**: full DE-ENERGIZATION and/or shut down sequence

Equipment SAFETY

- **FAST SIGNALS** reaction time << the pulse length: µs range
  - in compliance with tetrode protection requirements (RF off in 100 µs) preventing any RF overdrive & pulse duration too long
  - **SOURCE**: RF reflected powers, RF driving signal, pulse length duration, Anode currents and voltage, G1 & G2 currents and voltages, external PERMIT
- **SLOW SIGNALS** implementation time of several/hundred ms
  - **SOURCE**: flow rates, temperatures sensors, mains, fan units, power supplies.
  - **RESULT:** remove the RF drive & start the shut down sequence

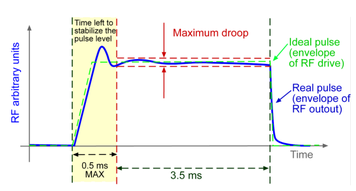
REMOTE FAT SETUP

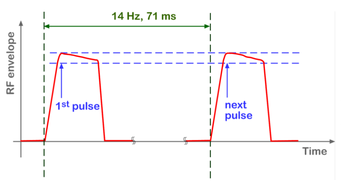
Test bench as configured and used on site



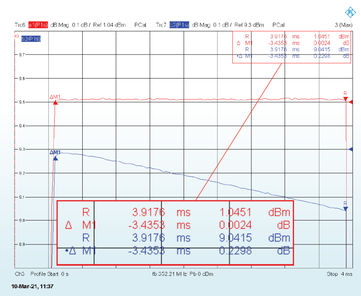
Test bench as it looks at the remote end. The broadcasting software allows to chose between different *scenes* that group the instruments involved in a specific test.

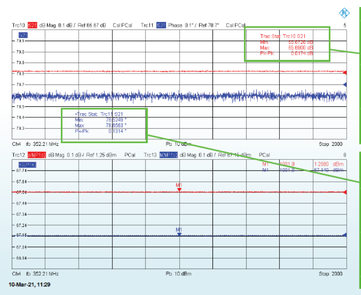
PULSE QUALITY

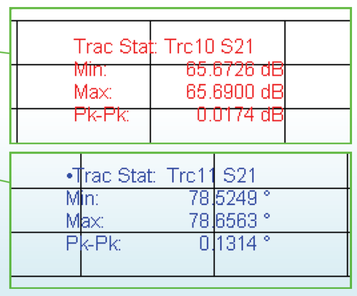




RF pulse quality is verified within the pulse and between subsequent pulses.
Maximum allowed droop: ≤ 0.25 dB
Average amplitude variation $\Delta I \leq \pm 0.5$ %
Average phase variation $\Delta\phi \leq \pm 0.5^{o}$.



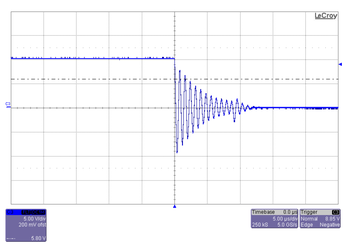




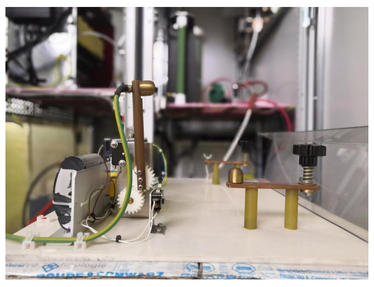
HV MODULATOR TESTING

A high-voltage solid state switch (SSS) is used to protect the tetrodes against arcing and short circuit.

The «wire test» is performed on each SSS unit before starting the actual FAT.



Scope capture showing the SSS opening



Automated jig for the «wire test»

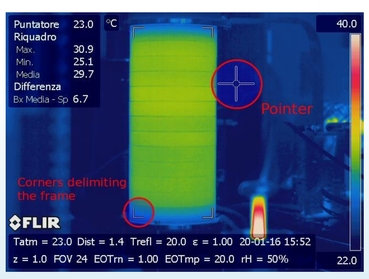
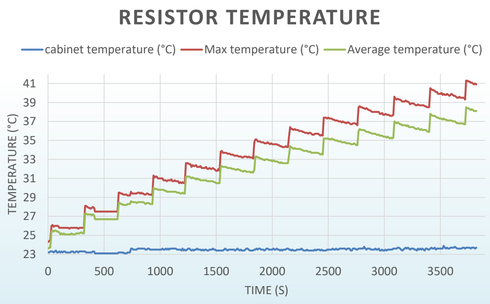


Image from the thermal camera showing the discharge resistor heating up



Plot of the discharge resistor temperature increase

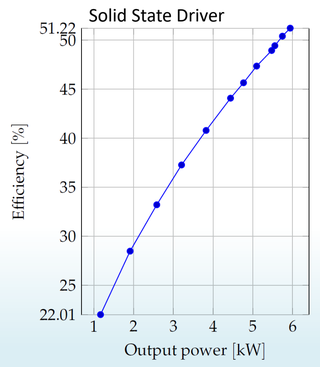
A discharge resistor is part of the HV modulator as a safety device to discharge the capacitor bank after an interlock.

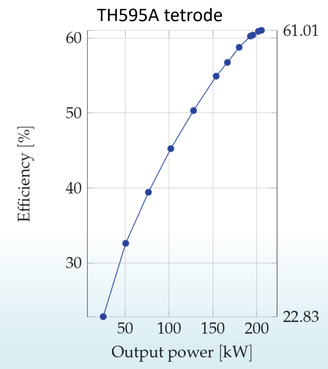
The resistor was tested with a sequence of >10 short circuits and its temperature measured with a thermal camera to assess its dissipation capabilities.

EFFICIENCY

To optimize energy savings, the tetrode and the solid state drivers are not biased when there is no RF pulse.
Achieved efficiency at nominal power:

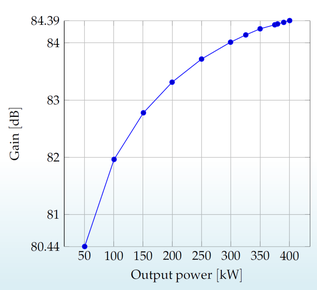
- Solid State Drivers > 50%
- Tetrodes > 60%
- Wall plug to RF overall RFPS efficiency > 45%

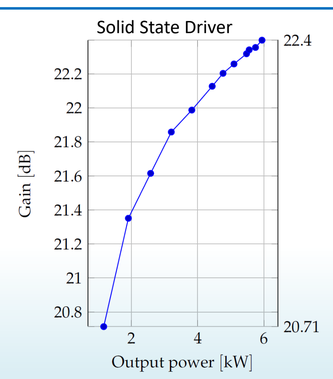


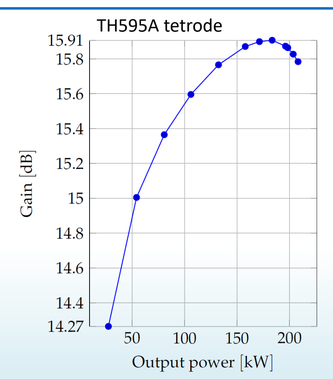


GAIN

Gain is measured at each stage of the amplification chain.

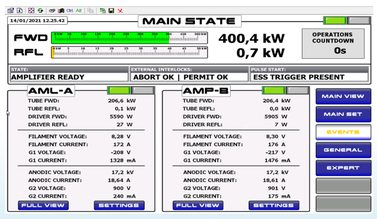




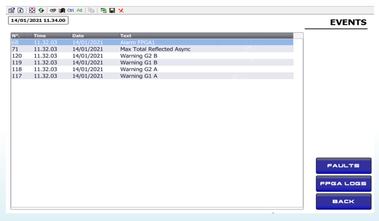


SUPERVISORY CONTROL SYSTEM NOTIFICATIONS

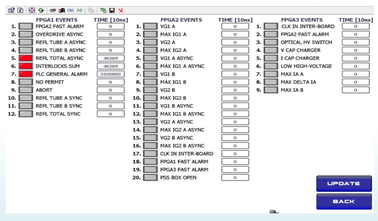
HMI main window



Log of all events



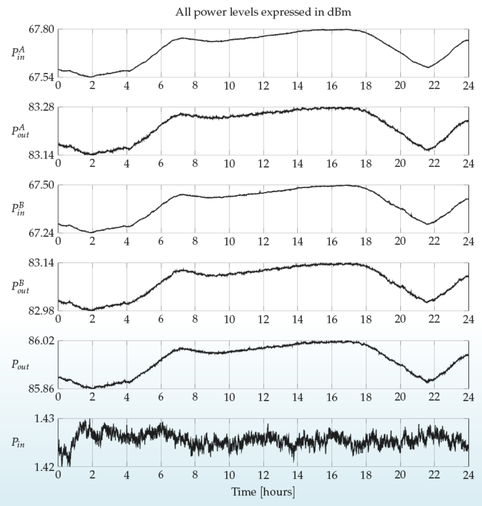
Fast interlock (FPGA) specific log



FACTS AND FIGURES

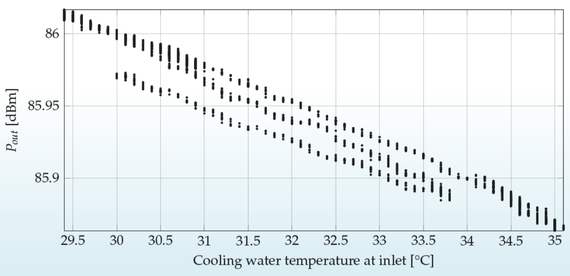
- RFPS number 1 delivered in August 2020
- 9/26 RFPS delivered to date
- 11/26 RFPS passed the FAT to date
- Average duration of a FAT session: 9 days
- 2500 pages of documentation, and counting
- Total time of TH595A operation: 1800 hours and counting

DURATION TEST



As final test, the RFPS runs at full power (> 390 kW) for 24 hours.
Using 6 power meters, the power level is recorded at each stage of the amplification stage.

Inverse correlation between the cooling water at the input and the output power is always evaluated, to verify that the power drift is due to temperature variations, and not due to other effects.



CERTIFIED MANAGEMENT SYSTEM
CERTIQUALITY
UNI EN ISO **9001:2015**
UNI ISO **45001:2018**

COVID-19 pandemic forced a paradigm shift on the execution of an acceptance test. By rethinking the FAT procedure with a step-by-step protocol and the real-time remotization of the instrumentation, the project did not stop and delivered on time. The success of this phase is ensured not only by the very good amplifier performances, but primarily by the excellent cooperation between the involved teams.

IPAC'21