Test and Measurements Results of the Pilot Tone Front End Industrialization for Elettra 2.0

Elettra Sincrotrone Trieste

INSTRUMENTATION TECHNOLOGIES

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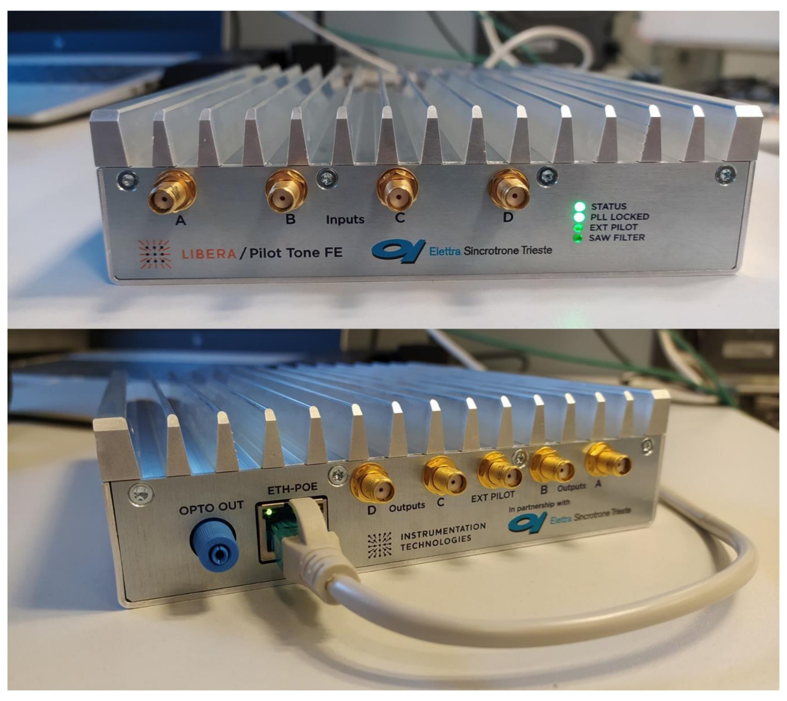
Introduction

In previous conferences we already presented the overall development of the new electron beam positioning system for Elettra 2.0, the low-emittance upgrade of the Italian synchrotron, from the early pilot tone proof of concept [1] to the integration of the complete prototype system in Elettra's global orbit feedback [2]. The partnership signed with Instrumentation Technologies has accelerated the process towards the final industrialized system, foreseen to be installed in 168 locations of the new machine in 2025-2026. In particular, thanks to the modular approach, we firstly focused on the improvement of the pilot tone front end (PTFE) [3] before moving to the digital acquisition unit. In this paper we present the industrialization results of the former, a mature product ready to be produced in series.

Mechanical and electronic improvements



After implementing the foreseen improvements, such as the possibility of changing the bandpass filter, the extra gain stage, the single board design, integrated power over ethernet feature, further modifications have been made for increasing reliability and performance:

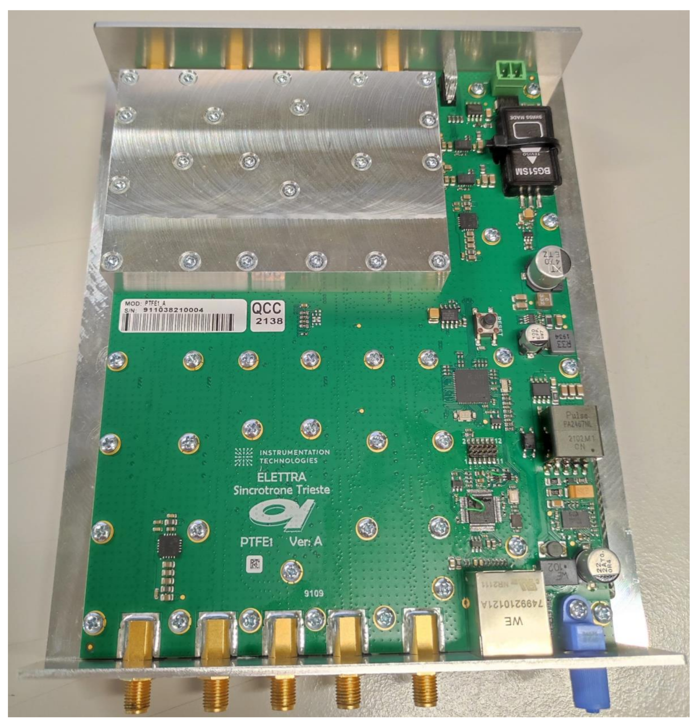
Shielding and heat management: a large-area aluminum heatsink has been applied over the PCB, with mounting holes for future installation on girders. The heatsink serves also as an EMI shield, covering all the RF traces. In addition, another aluminum block covers completely the filters section, reducing external temperature influence.

Amplifiers matching: matching of RF amplifiers was improved, in order to reduce signal reflections and standing waves, with a trade-off between topology of matching circuit, performance and repeatability of the design.

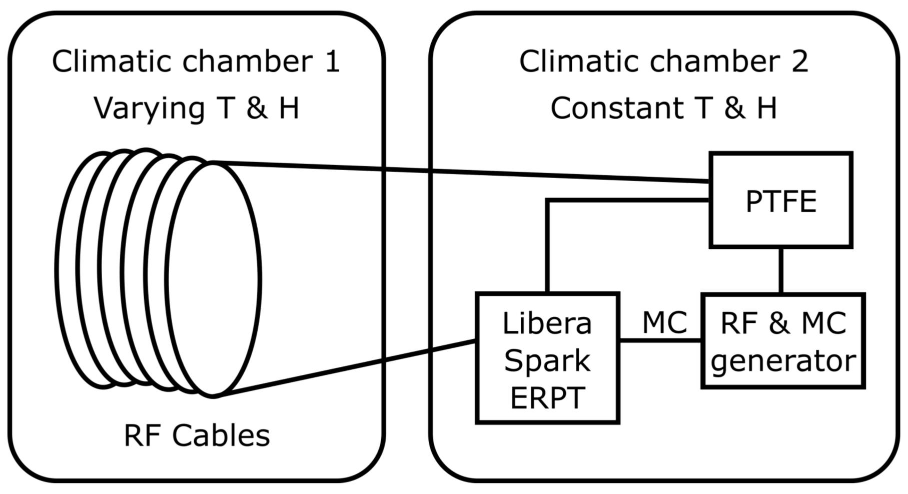
Ethernet controller: the Ethernet to UART communication device has been changed to a Wiznet chip. The new design allows PoE operation and has benefits in term of lower generated heat, power consumption, costs.

Pilot tone generation: accuracy and phase noise of the internal pilot tone generator have been improved with carefully tuning of crystal's load capacitors and with a new implementation of PLL's loop filter.

Power management: the power tree has completely rearranged in order to distribute the load evenly over the voltage regulators and to reduce dissipated power, lowering their dropout voltage.



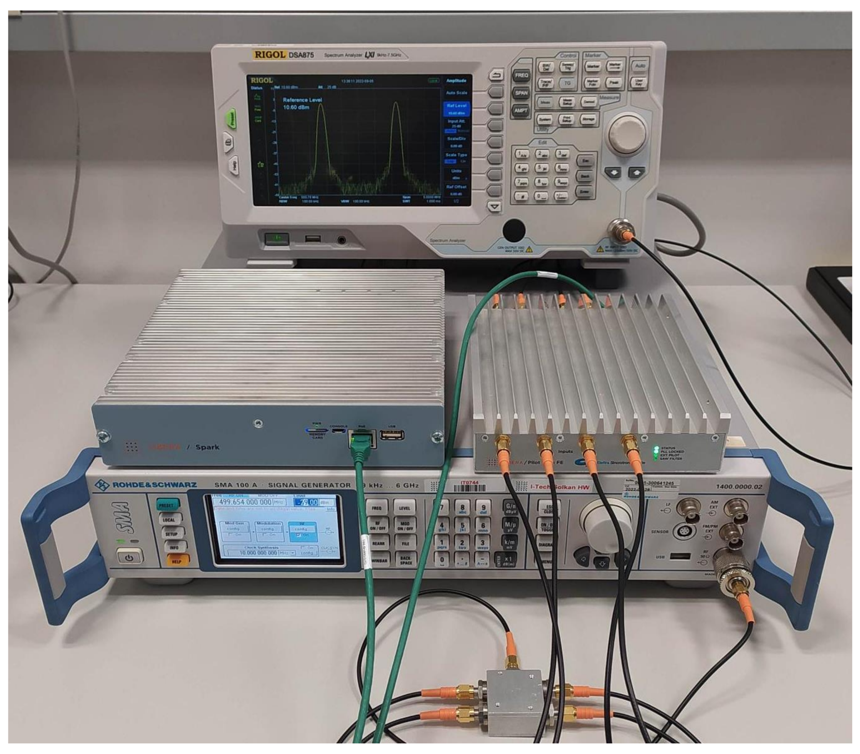
Performance results



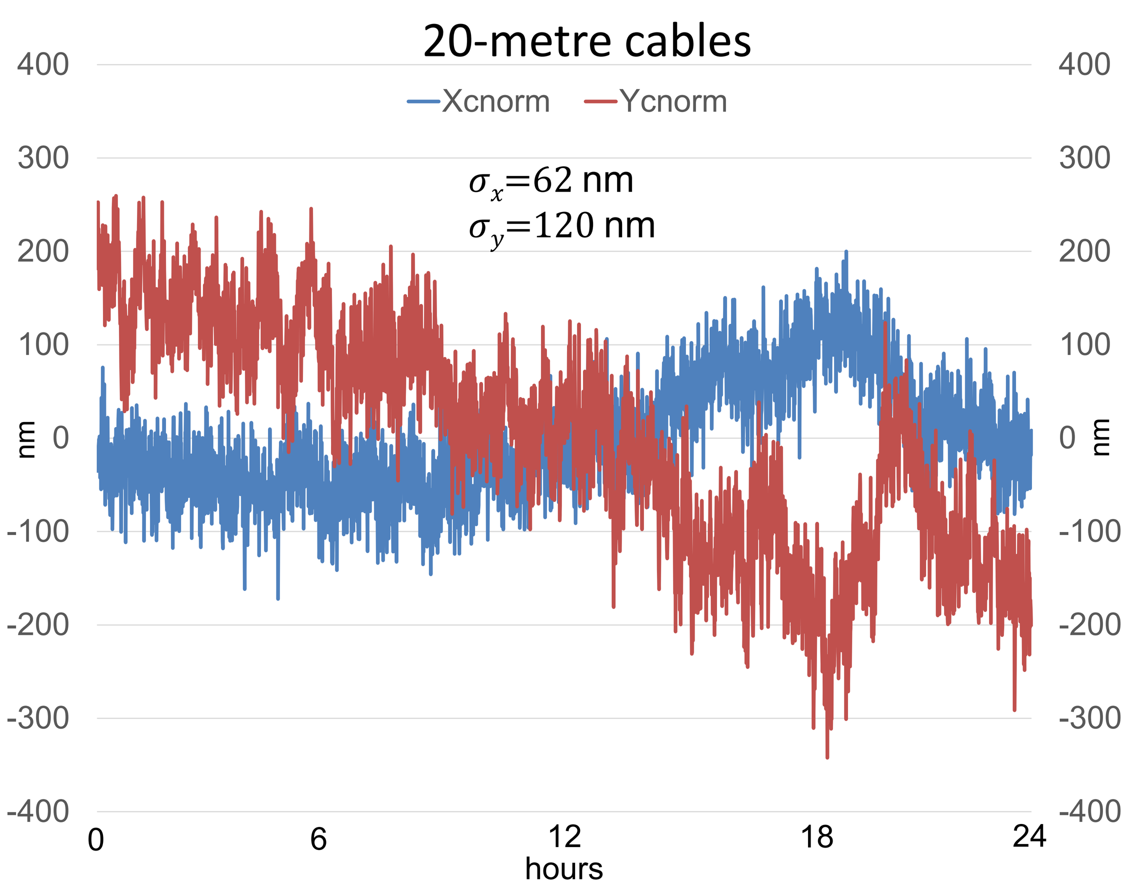
T variation (°C)	X/T proto (µm/K)	X_C/T proto (µm/K)	X/T ind (µm/K)	X_C/T ind (µm/K)
25°-15° step	-8.2	-3.7	-6.5	0.9
15°-35° ramp	-7.8	-3.65	-6.3	1.0
35°-25° step	-7.9	-3.6	-6.2	1.0

Compensation effectiveness

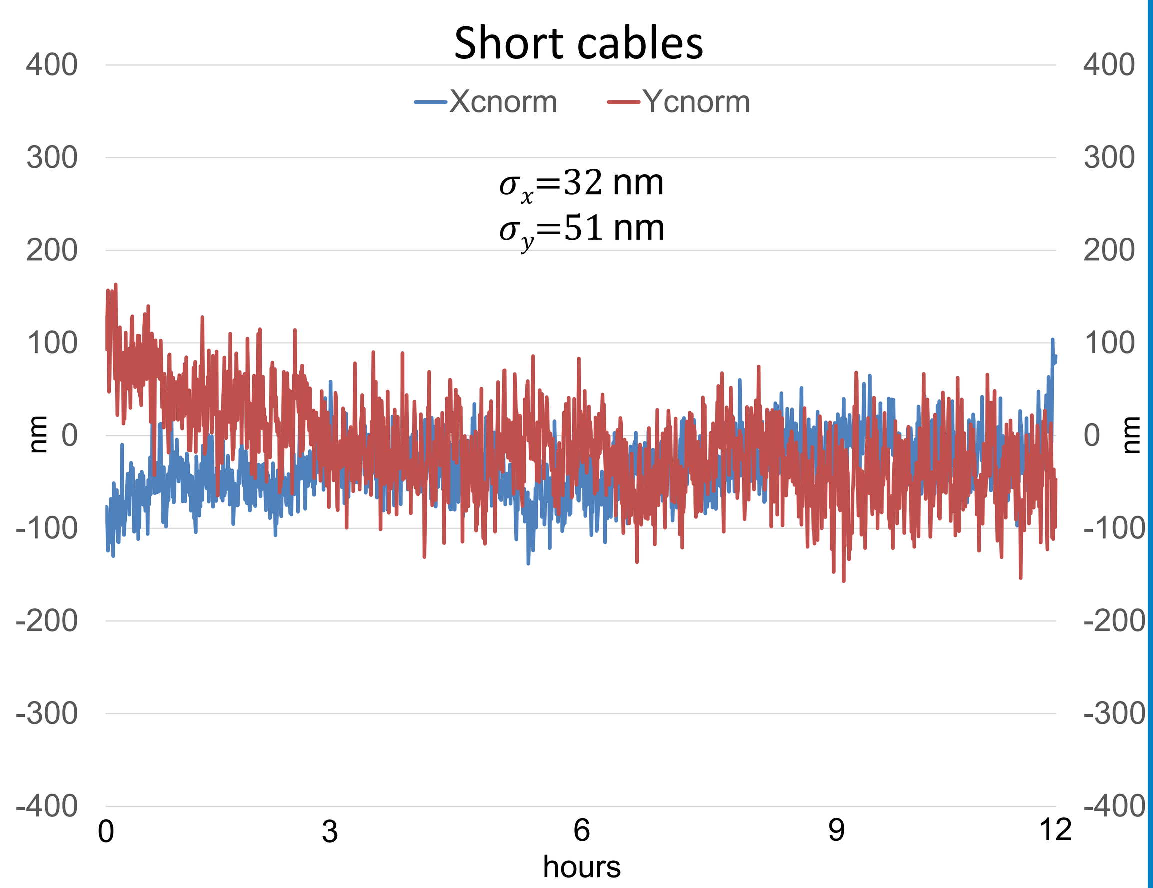
A dedicated setup in two climatic chambers has been prepared to evaluate the effectiveness of the compensation on cables: all the active devices (generator, PTFE and readout electronics) were held at constant temperature and humidity, while a temperature profile was applied in the chamber containing only one cable (LMR-195, 20 metres). It has to be noted that this is a worst case scenario, since in real environments the temperature variation will affect all the four cables in the same way, reducing the produced drift on the calculated position. Three temperature profiles have been applied. Results are quite the same for the various profiles, where the previous PTFE prototype has been compared with the new industrialized version. A reduction of about 4 times of the temperature dependence on the compensated position has been obtained, proving benefits from the improvements made.



Tests at Elettra



We put the PTFE in Elettra service area: its outputs were connected with high-quality short cables to an in-house developed digitizer already presented in [4]. Position calculation is expressed in nanometers, with a scale factor of 20 mm and an equivalent bandwidth of 10 Hz. As a source, we used the signal coming from a single Elettra storage ring pickup splitted in four, in order to emulate a stable beam. Figure on the right shows the results of a long-term measurement in a 12-hour time window. Machine was running at 2 GeV, 310 mA (top-up mode) and a standard multibunch filling pattern. Digitizer was locked to machine clock and RF frequency was 499.654 MHz. Subsequently, we decided to change connection cables from PTFE to digitizer with longer ones (LMR-195, 20 meters), in order to simulate a common situation in beam diagnostics (PTFE in machine tunnel and digitizer in service area). The source was changed to an RF generator that emulates the beam with the same filling pattern, due to scheduled maintenance of the accelerator. The time window was extended to 24 hours. Results are reported in figure on the left. Performance worsening is due to cable losses and to temperature and humidity variation during the measurement.



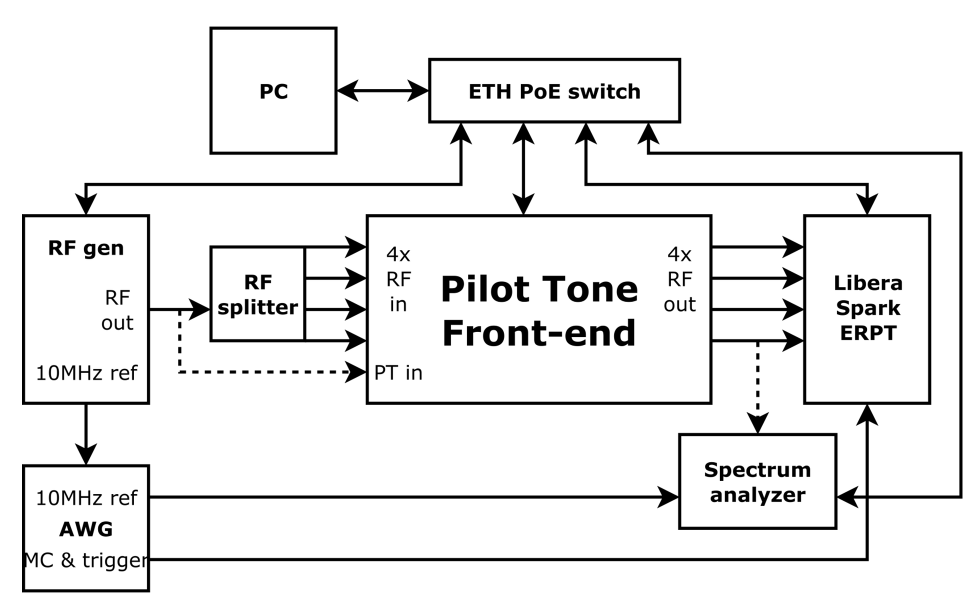
FAT procedure

Rigorous testing is performed to ensure similar and within-spec operation of all mass-produced units. With every new product rolling off the production line, it is important to set up effective factory acceptance tests (FAT) early in the product's lifespan. FATs are divided in three categories:

1. Checking basic functionalities: visual inspections over the board, check on power supply voltages and currents, connection over telnet.

2. RF signal chain: testing setup is presented in figure on the right. A R&S SMB100A signal generator is used for the RF signal and to provide the reference clock to the AWG, spectrum analyzer and indirectly also the machine clock for a Libera Spark ERPT, used as readout electronics. With the spectrum analyzer we determine the accuracy of the pilot tone frequency and amplitude and the RF signal amplitude on PTFE inputs and outputs. Internal pilot tone generator is checked to verify that the PLL remains locked with various frequency settings and that it outputs a signal with consistent power. A frequency sweep is performed on both band-pass filters on all four channels. For the following tests, an internal Libera Spark ERPT is used to evaluate the compensation effectiveness and to quickly assess all four signal paths of the PTFE, measuring signal-to-noise of each channel with following signal combinations: only RF signal present, only PT from internal generator, only PT from external generator and both RF and PT combined. Crosstalk is measured between all channel combinations and a minimum of 50dB isolation is guaranteed.

3. Long-term measurements: the above-mentioned tests are performed on every unit, and since they are all automated, they take less than half an hour to be performed. To balance rigor and effectiveness, one unit out of 10 is tested for a longer period (typically 14 hours), to re-verify long-term behaviour and to root out any systematic defects. In this case, the instrument is left on in the test setup over night with both RF and internal PT signals present and compensated data at 10 Hz rate is logged. A slow and monotonous temperature change is expected overnight and from that the temperature coefficient of position is calculated, with the pass-fail set to 4 µm/K in both directions.



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[2] G. Brajnik et al., "Integration of a Pilot-Tone Based BPM System Within the Global Orbit Feedback Environment of Elettra", IBIC 2018
[3] G. Brajnik et al., "Current Status of Elettra 2.0 eBPM System", IBIC 2021
[4] G. Brajnik et al., "A Common Diagnostic Platform for Elettra 2.0 and FERMI", IBIC 2019

NEXT STEPS

- Review and optimization of the digital platform with hard processor
- Testing the pre-series production of the whole eBPM system
- Cope with worldwide delay of electronic components