OPERATIONAL EXPERIENCE WITH THE LLRF SYSTEM OF THE FERMI S-BAND RF PLANTS

F. Gelmetti, A. Fabris, M. Milloch, M. Predonzani
Elettra - Sincrotrone Trieste

FERMI is a single-pass linac-based FEL user-facility covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV) and is located next to the third generation synchrotron radiation facility Elettra in Trieste, Italy. The first FEL line in operation (FEL-1) has been opened to users at the end of 2012, while the second FEL line (FEL-2) covering the shorter wavelength down to 4 nm is in commissioning. The 1.5 GeV S-band linac is composed of fifteen 3 GHz 45 MW peak RF power plants powering the gun, sixteen accelerating structures and the RF deflectors. The requirements on beam quality impose tight specifications on the stability of the electromagnetic fields, which can be achieved only installing high reliable and high performance state of the art LLRF systems. This paper provides an overview of the performance of the system, discussing the achieved results, the strategies adopted to assure them and possible upgrade paths to increase the operability of the system.

Introduction

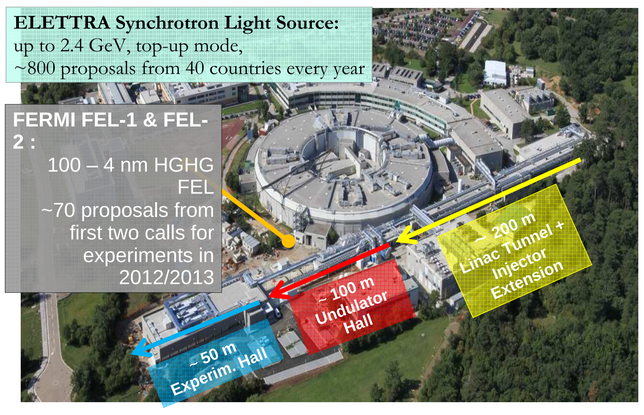
The S-band linac is presently composed of sixteen structure:

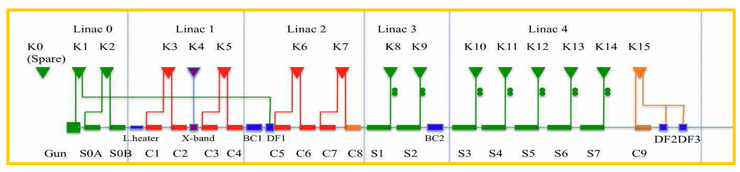
- Two traveling wave (TW) 3 m long
- Seven traveling wave (TW) 4.5m long
- Seven backward traveling wave (BTW) 6.2 m long.

The machine layout reserves the space for two more structures

Fifteen S-band 45 MW, 4.5 µs. pulsed klystrons are installed.

The system is in operation on a 24h/day basis for more than 6000 hours/year.

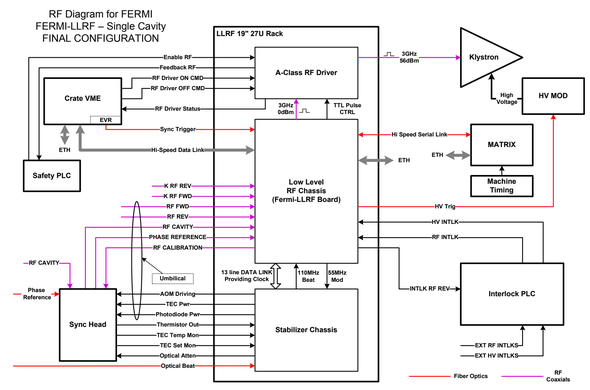




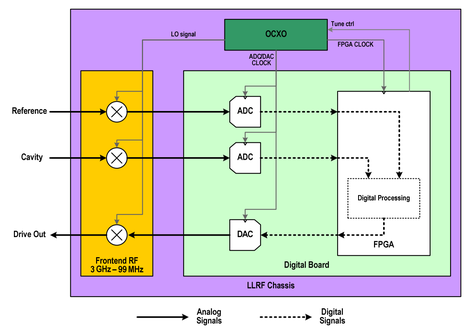
FERMI LLRF

- Specification on amplitude and phase stability: 0.1% and 0.1° at 3 GHz.
- All-digital system, specifically developed for FERMI.
- System developed in the frame of a collaboration agreement between Elettra - Sincrotrone Trieste and Lawrence Berkeley National Lab.
- Loops in operation: amplitude, phase, cable calibration and phase locking loop.
- SLED: phase reversal and phase modulation.
- Intermediate system :
  - Commercial processing board (LLRF4).
  - Installed from beginning
  - **Requirements for machine operation met**
- Final system:
  - Processing board specifically designed for FERMI
  - First two units in operation on the machine.
  - Firmware ported from LLRF4 board to the final board.
  - It will allow further firmware developments of the system.

The final system:



All the connection with the LLRF Rack



LLRF Internal Chassis Outline

Inside the LLRF chassis:

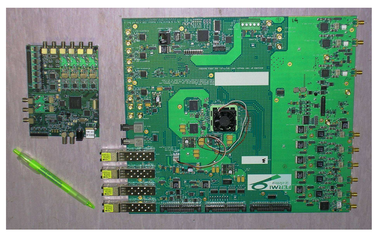
Feature	AD
# ADCs	5
ADCs Resolution	16 bits
DACs Speed	484MHz
FPGA	Virtex-5
FPGA Clock	242MHz
Communications	4 SFP GB
Memory	2 x 2GB
µCont	LPC2364
Power Detectors	4
Additional In/Out	ADC/ DAC

Main features of the AD board:

- More ADC channels.
- Input channels isolation >95 dB.
- Output channel isolation > 75 dB.
- Digital acquisition accuracy 0.017° and 0.029 %.
- DAC output: 0.018°, 0.032 % noise RMS @99 MHz.

Feature	Front End
# Channels IN	6
# Channel OUT	3
VSWR	<1.12:1@3GHz(-25dB return loss)
Input Isolation	>86dB Channel-to-Channel
Output Isolation	>75dB Channel-to-Channel
Noise on Output	0.0025° added in RF up conversion
Noise on Input	0.0005° added in RF down conversion

The FERMI LLRF chassis

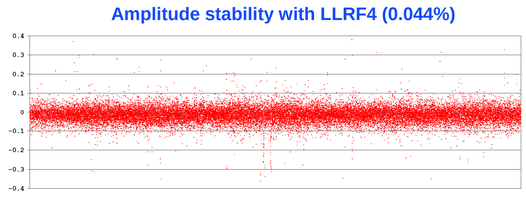


The comparison between LLRF4 and AD board.

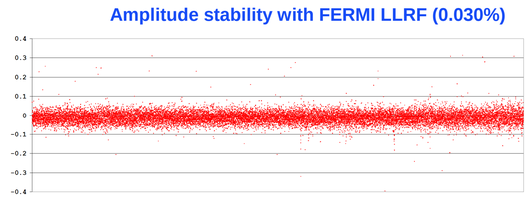
Performance improvement:

With the simple replacement of the LLRF4 board with the FERMI AD board, without any modification of the firmware, the performance of the entire system is improved by 20% in the achieved stability of both amplitude and phase.

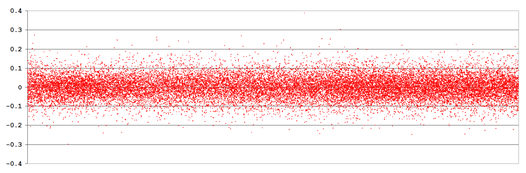
Amplitude stability with LLRF4 (0.044%)



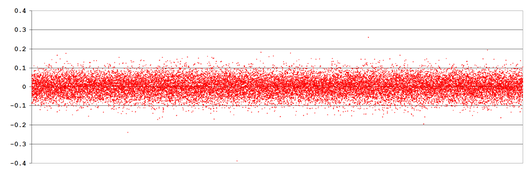
Amplitude stability with FERMI LLRF (0.030%)



Phase stability with LLRF4 (0.058 deg@3GHz)



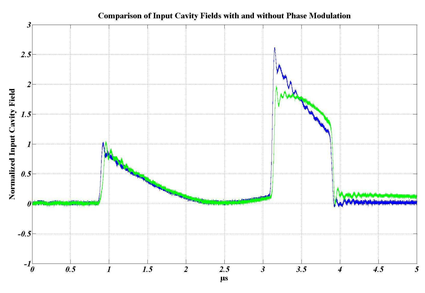
Phase stability with FERMI LLRF (0.046 deg@3GHz)



Long term acquisition (~15 days) comparing the results with the two boards.

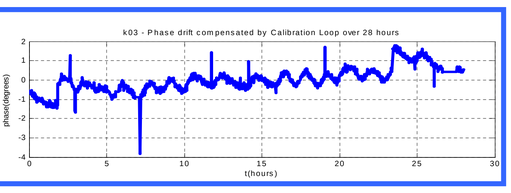
Phase modulation – SLED:

To get the maximum energy the last seven structures have been equipped with a SLED system. Due to breakdown problems inside the sections, that was the result of high peak fields generated during conventional operation, the sections experienced difficulties in reaching the desired gradients. To lower the peak field and make the compressed pulse "flatter", phase-modulation has been implemented on the LLRF.



Cable Calibration Loop:

The cable calibration loop is meant to compensate the elongation of the cables going from the tunnel to the LLRF chassis, improving the long term stability of the phase measurements.



Next Steps:

- Replacement of the intermediate LLRF chassis with the final board is started.
- First two chassis in operation since August without problems
- Plan to complete replacements by 2014.

The new board will allow introducing new functionalities, such as:

- Real time communication between LLRF units.
- Enlarging of average time of calibration and phase reference signals (increase in the Signal to noise ratio of the measurements);
- Intra-pulse feedback (measure and apply correction in the same pulse in particular to correct jitter contributions);
- Investigate iterative learning (to remove periodical known errors).

References:

LLRF Performance Results in Fermi@Elettra", LLRF2011, M. Milloch, A. Salom, et al.

"LLRF Hardware architecture and performance of Fermi@Elettra", LLRF2011, A. Rohlev et al.

"LLRF Firmware of Fermi@Elettra", LLRF2011, L. Doolittle (LBNL).

LLRF 2013

Elettra-Sincrotrone Trieste S.C.p.A. di interesse nazionale
Strada Statale 14 - km 163,5 in AREA Science Park
34149 Basovizza, Trieste ITALY

For additional information, please contact:
Federico Gelmetti, Massimo Milloch
federico.gelmetti@elettra.eu
massimo.milloch@elettra.eu