Advanced LLRF Controls & Instrumentation

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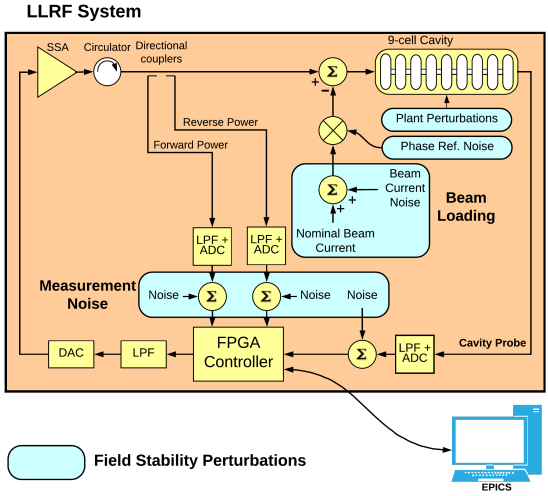
GARD ABP Meeting, April 16, 2020

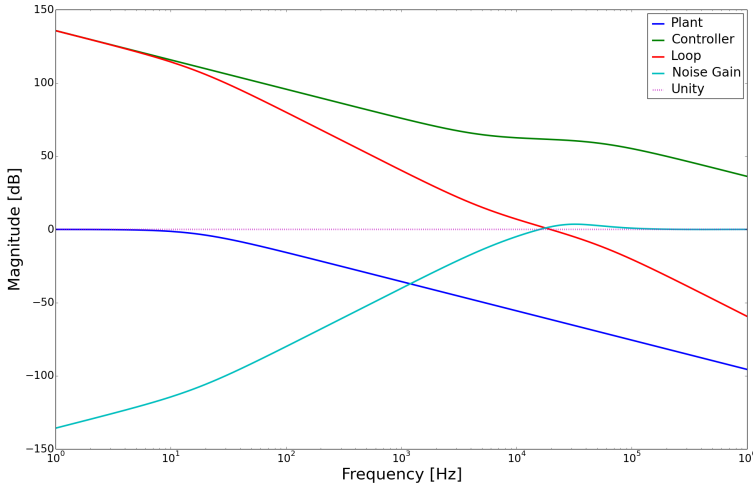
Outline

- What we do today
- What challenges do we encounter?
- Ideas on how to move forward

LLRF System Topology



Analytical Transfer Functions



Physics requirements to LLRF specs

Core physics requirement is 0.01% and 0.01° *

Start with a coarse guideline for uncorrelated noise sources...

Noise Source	Amplitude	Phase
Measurement	0.005%	0.004°
PRL	N/A	0.004°
Plant pert.	0.005%	0.004°
Beam loading	0.005%	0.004°
Other/unknown	0.005%	0.004°

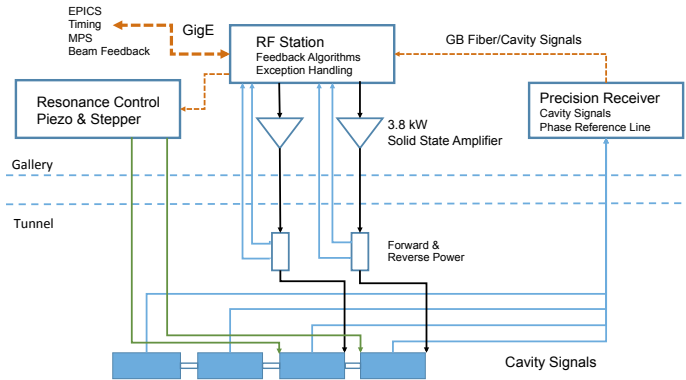
... and adjust with empirical evidence.

*__Source__: Performance and Functional Requirements for the LCLS-II LLRF System (LCLSII-2.7-FR-0371-R0)

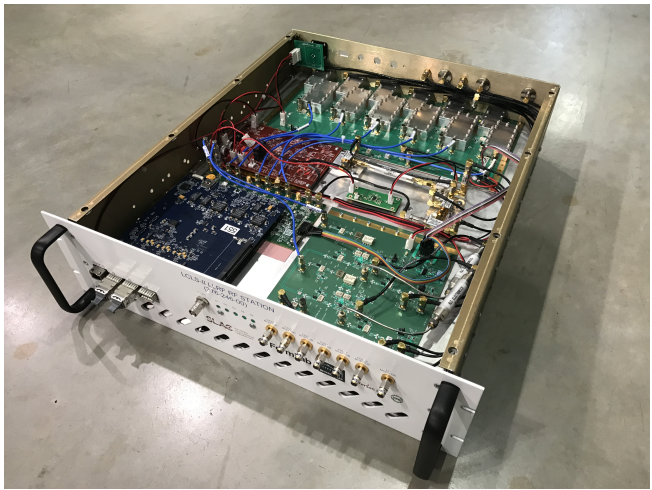
LLRF specs to engineering

- High-Q_L superconducting $\Longrightarrow$ sensitive in the audio band and low bandwidth,
- Tight field regulation specs $\Longrightarrow$ high noise rejection,
- High noise rejection and low bandwidth $\Longrightarrow$ very high gains,
- High gains $\Longrightarrow$ measurement noise is amplified greatly,
- Tight regulation of high-Q_L SRF cavities $\Longrightarrow$ low noise design and careful engineering

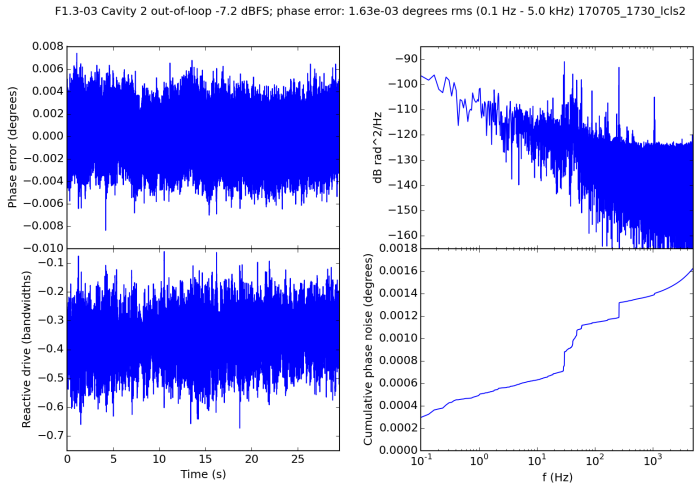
LCLS-II LLRF System Architecture



LCLS-II LLRF RFS Chassis



Performance



Timing & Synchronization

State of the art is synchronization of optical/x-ray/electron pump-probe to 10s of fs.

- UED
  - Short distance
  - Done at SLAC and LBNL (that I know of)
- FELs
  - Long distance (up to several km)
  - Done at LCLS and FLASH/XFEL

LCLS-II chooses beam-based feedback instead (higher rep. rate).

DOE project cycles

Instrumentation development happens mainly through projects.

- (Very) long conceptual design phases
- Sharp edge in funding
- Steep transition for personnel used to operations
- High peak demand in staffing needs
- Crunched schedule (bye R&D phase)

DOE project cycles

"I want it to meet specs, cheap, low risk and I want it now" - DOE project L2 Manager

Thoughts on instrumentation R&D

- A separation between HEP and BES feels like an artificial boundary in this field
- Real technology drivers of the instrumentation itself is in the telecom industry
- Accelerator-centric technology should focus on the application side & engineering, with a holistic approach and by inter-disciplinary teams
- Duplication of effort and little attention to technology transfer is more harmful than lacking R&D programs
- Collaboration is happening organically at the DOE level, but it would be good to have an umbrella R&D program and official coordination
- Technology transfer should have real incentives, not be a nice to have, so we can not only transfer technology to society but also between Labs and Universities

Areas for investment

- Low-cost, easy to deploy/adopt hardware platforms (accessible to all)
- SRF Controls:
  - Pulsed RF and management of Lorentz force detuning
  - Beam loading compensation & feed-forward algorithms (PIP-II, high-intensity beams)
  - Resonance controls through piezo tuners
- Synchronization and beam-based feedback approaches
- Integrated modeling & simulation of beam tracking and feedback controls (possibly FPGA-based)
- Low-latency high-speed communications: for feedback schemes & machine protection

Those who don't think about the **future**
Resolve the present
With tools from the past.