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U.S. DEPARTMENT OF ENERGY

High-precision RF Controls for next generation accelerators

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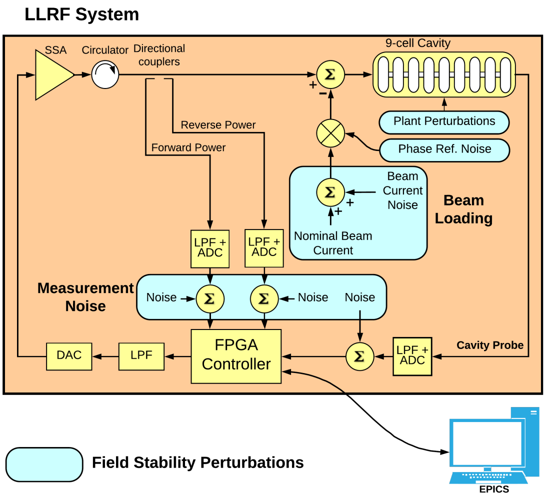
AF7-RF Mini-workshop, December 17, 2020

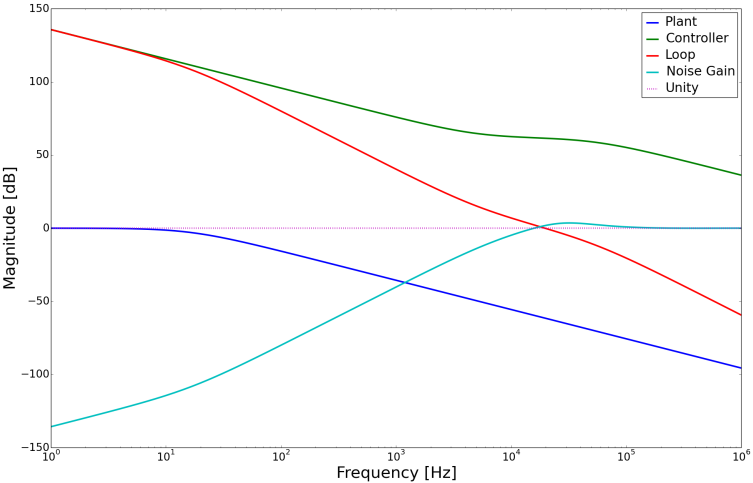
Outline

- 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°

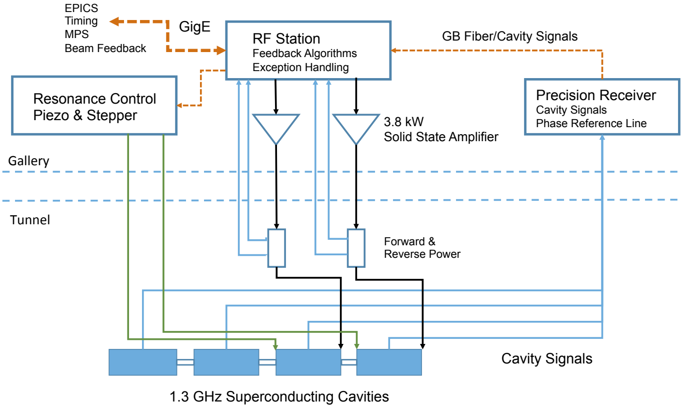
... and adjust with empirical evidence.

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

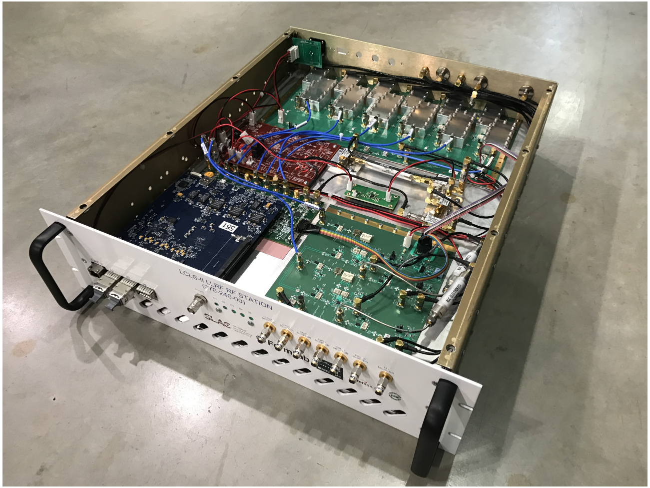
LLRF specs to engineering

- 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

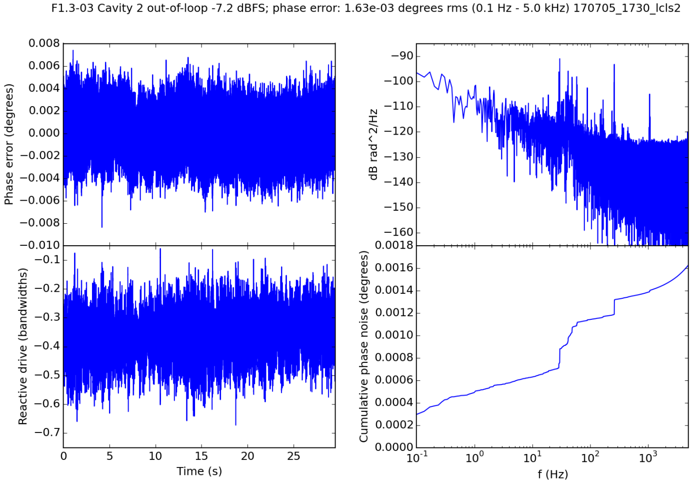
LCLS-II LLRF System Architecture



LCLS-II LLRF RFS Chassis

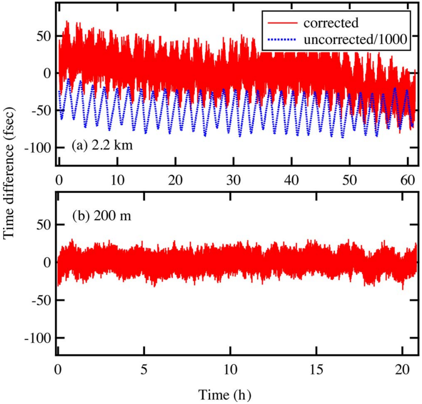


Performance



Timing & Synchronization

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



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†R. Wilcox et. al., Opt. Lett. 34, 20, pp. 3050-3052 (2009)

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

- 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

Challenges

- Duplication of effort & related lack of consistent investment in real innovation
- Complexity:
  - Multi-dimensional problems where system identification is very hard.
  - Examples include resonance controls in SRF cavities, high-level tuning and optimization of accelerators, multi-channel optical coherence controls, etc.
- Precision measurements:
  - Timing & Synchronization from the femtosecond to the attosecond level.
  - RF front-end designs to push the boundaries of current limits or RF stability and beam measurements.

Areas for investment

- Low-cost, easy to deploy/adopt hardware platforms (accessible to all)
- Handling complexity:
  - Invest in FPGA-based data acquisition systems & software infrastructure to acquire, distribute and process high-throughput data from localized accelerator instrumentation and controls.
  - Invest in machine learning techniques to capture complex system characteristics through measurements, using FPGA-accelerated solutions.
- Increasing measurement precision:
  - Invest in digital instrumentation coupled with precision optical systems: e.g. stabilize links with a 10^{14} Hz carrier that can be synchronized to the RF in an accelerator.
  - Invest in novel applications and combination of different RF measurement techniques: heterodyne detection, direct sampling, carrier suppression.

Invest in multi-disciplinary teams, applying a holistic approach to accelerator-centric challenges leveraging off technology innovation in machine learning, telecom, optical and astronomy fields.

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