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Revision History

Revision	Date Released	Description of Change
R0	4/22/2014	Original Release.

1 Purpose

This document describes the global controls requirements, and enumerates the controls subsystems and their interactions. The device lists and specifications are in the subsystem PRDs listed in sections 3 and 7. A separate photon PRD will specify the requirements for all X-ray controls.

2 Definitions

Beam Spreader	A transverse field microwave cavity used to direct the beam to the dump, or SXR or HXR undulators.
BLD	Beam Line Data
BPM	Beam Position Monitor
BSA	Beam Synchronous Acquisition
EPICS	Experimental Physics and Industrial Control System
EPICS IOC	EPICS Input Output Control
EPICS OPI	EPICS Operator Interface
EPICS PV	EPICS process variable, a piece of data in the control system.
FPGA	Field Programmable Gate Array
Event code	A Software / hardware identifier associated with a set of machine pulses.
HXR	Hard X-ray Undulator
LCLS_I	The Room temperature LINAC driven X-ray FEL
LLRF	Low Level RF control system
MPS	Machine Protection System

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Pulse ID	A hardware / software number that uniquely identifies each pulse of electrons / X-rays in the machine
RF	Radio Frequency – narrow band precision system in this context.
SXR	Soft X-ray Undulator
Wire Scanner	A profile monitor based on measuring beam loss when a wire is moved through the beam

3 References

PRD# TBD	Commissioning PRD
PRD# TBD	Event / Timing System PRD
PRD# TBD	LLRF PRD
LCLSII-2.7-PR-0077	PPS Requirements
PRD# TBD	BCS PRD
PRD# TBD	MPS PRD
LCLSII-2.7-PR-0076	LCLS-II Longitudinal Beam-Based Feedback
LCLSII-2.7-PR-0075	LCLS-II Transverse Beam-Based Feedback
PRD # TBD	Event and Timing System PRD
PRD# TBD	RF Reference / precision timing PRD
PRD# TBD	Superconducting LLRF system PRD
PRD# TBD	Cryogenic system PRD
LCLSII-2.4-PR-0090	LCLS-II Beam Spreader
PRD# TBD	RF Gun PRD
PRD# TBD	Transverse Cavity System PRD
LCLSII-2.4-PR-0136	Beam Position Monitor Requirements
PRD# TBD	Beam Current Monitor PRD
PRD# TBD	Beam Loss Monitor PRD
PRD# TBD	Relative Bunch Length Monitor PRD
PRD# TBD	Profile Monitor PRD
PRD# TBD	Wire Scanner PRD
PRD# TBD	Magnet PRD
PRD# TBD	Beam Kicker PRD
PRD# TBD	Undulator Controls PRD
LCLSII-3.5-PR-0051	X-ray Transport and Experimental Systems PRD

4 Responsibilities

N/A	N/A

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5 Global Controls

5.1 Software:

The LCLS-II control system contains a set of software and firmware applications.

5.1.1 EPICS system:

EPICS will be used as the primary non-real-time control system for LCLS-II. The LCLS-II, LCLS-I, Experiment and Accelerator control systems will run compatible versions of EPICS. EPICS PVs from either the accelerator or experiment control systems will be visible on both systems and can be made writeable from both systems if desired. In general, EPICS will be used to control all devices for which it can provide the required performance.

5.1.2 High Level Languages and Applications:

Matlab, Python and Java will be supported for creating high level applications interacting with EPICS for machine control and diagnostics. The existing LCLS-I tuning and diagnostics applications will be modified for use in LCLS-II. The required applications include:

- Profile Monitor – Measures, fits and saves beam profiles from cameras.
- Wire Scan - Measures, fits and saves beam profiles from wire scanners.
- Emittance Measurement – Measures and saves beam emittance and twiss parameters measured with profile monitors or wire scanners using either multiple measurements or quad scans.
- TCAV/ Bunch length – Operates, records and processes data from the transverse cavity bunch profile monitors.
- Correlation Plots – Provides an operator interface to scan one or more PVs according to a predefined pattern while measuring a set of PVs, profile monitors, wire scanners or emittance measurements.
- RF Phase Scans – Scans the phase of RF structures to determine the absolute phase relative to the electron beam.
- Beta Matching – Used data from emittance measurements to adjust quad magnet settings to match the beam to the design.
- Bowtie Plot – Adjusts quad magnet strengths while monitoring downstream orbits to measure the location of the magnetic center of the magnets.
- Beam-Based Alignment for the undulators – Changes electron energy and reads BPMs in the undulators, applying corrections needed for a dispersion free trajectory with BPM readings of zero.

5.1.3 Data Archiver:

A data archiver similar to that used for LCLS-I will be used to store and display accelerator data. A new feature is that pulsed device data (BPMs etc.) must be tagged with event codes to allow independent archiving of beams to the available beam destinations. (HXS, SXR, BSY dump etc.). LCLS-I and LCLS-II data must be available on the same archive display.

5.1.4 Buffered Data / BSA:

Data from pulse-by-pulse devices will be tagged with pulse IDs, and by event codes and stored in ring – buffers at full beam rate. This data will be available to operator consoles and high level applications in a

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fashion that allows multiple device data to be downloaded for a single pulse ID, or for selected combinations of beam codes. This system will allow data to be transferred / translated between BSA as used in the accelerator and the BLD data used for the experiments.

5.2 Hardware:

The majority of controls hardware is expected to fall into one of the following categories:

5.2.1 Digitizer / FPGA:

LLRF, BPM, Bunch Length Monitor and various other device data is expected to be read by a ~100Ms/s digitizer and processed in a FPGA. The FPGA will process the raw data into physics quantities (position, charge etc.); then, possibly in conjunction with a soft or hard core CPU, that data will be made available to the global control systems. The FPGA will save buffers of both the raw data, and the processed data tagged by event code and pulse ID. Those buffers will be sufficient to store 100 milliseconds of raw data and 1 second of processed data for analysis through buffered data / BSA. Where practical, a standard Digitizer / FPGA interface will be used for all fast devices.

5.2.2 Slow ADC / DAC / DIO:

Some systems including some corrector magnets, temperature sensors, etc. will be controlled by conventional slow analog and digital outputs and inputs.

5.2.3 Field-bus devices:

Some commercial and other devices will be controlled through RS422, or other fieldbuses. An abstraction layer will be provided to allow EPICS control and read back of these devices.

5.3 Networks:

A set of hardware networks will provide the functions described below. Note that more than one of these functions may be combined in a single physical network. An example implementation with independent networks is shown in figure 1.

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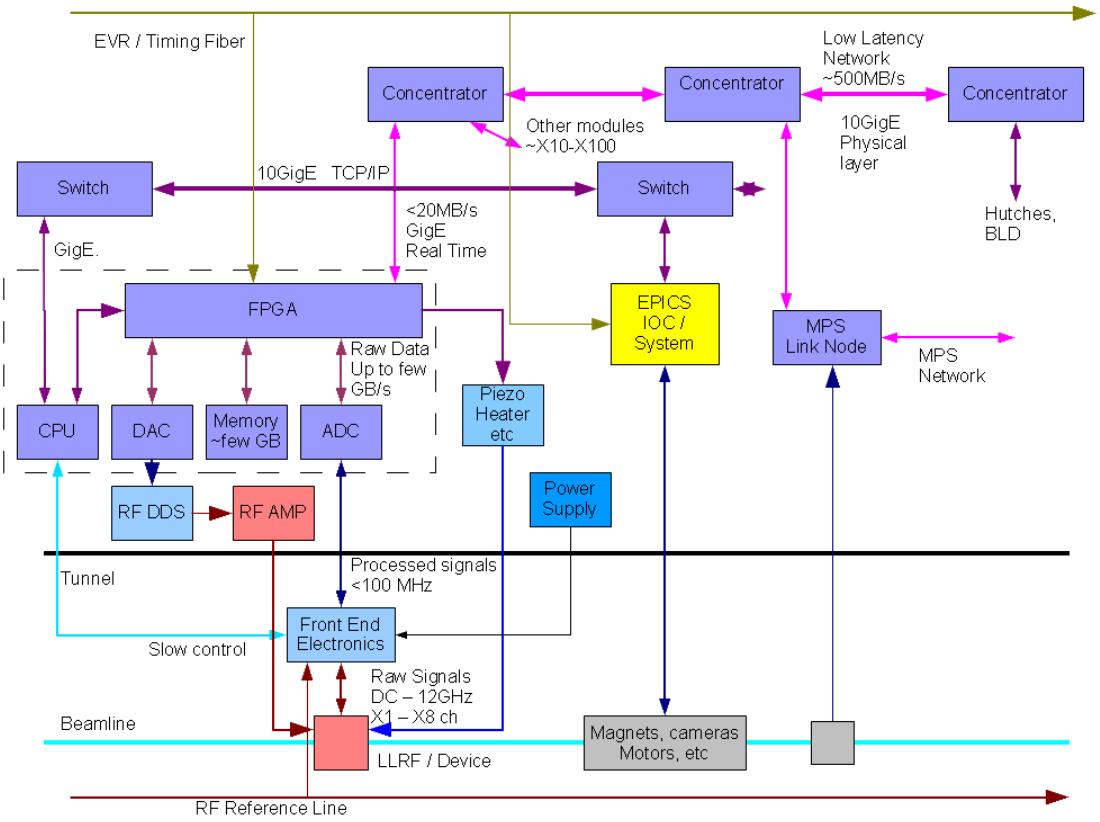

Figure 1: Network Layout

5.3.1 EPICS:

A conventional TCP/IP network will be used for EPICS control. IOCs and OPIs will be able to communicate at 1Gb/s network speeds, with a backbone speed of 10Gb/sec.

5.3.2 MPS:

A low latency network is used to distribute MPS trips and information. The latency of this network will be < 10 microseconds + 1.5 X (speed of light time between the source and receiver). MPS may use the Fast Feedback Network 5.3.4 for low latency beam shutoff.

5.3.3 Event network:

This network is used to distribute triggering events and clocks to devices. It is star configured from a single event generator located in the injector to all devices which require event information. These events specify the function of pulsed devices throughout the accelerator and X-ray systems – for example, determining the operation of kickers to direct the beam into specific beam lines.

5.3.4 Fast Feedback:

A low latency network is used to transport data from selected beam measurement devices to selected control devices.

- The network will support at least 128 individual pieces of data, for example, a BPM “X” measurement tagged with a pulse ID at the full beam rate of approximately 1MHz.

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- Each piece of data can be delivered to up to 25 data processors that calculate the required feedback actuator outputs.
- The actuator data can then be transmitted to up to 25 actuators.
- The total system latency will be less than 5 microseconds.
- The low latency system may also be used to transmit MPS shutoff information, data for specific faults would be sent on a conventional network.

5.3.5 RF Reference line:

A RF reference system provides high stability timing information to LLRF systems and other devices which require better timing than can be provided by the event system. This system transmits fiducial pulses, which can be used instead of the event system fiducials as a timing reference for triggered devices.

- Phase noise shall be < 30 femtoseconds integrated between 10Hz and 10KHz
- Drift relative to a speed-of-light beam shall be <1 picosecond pk-pk over 1 day.

5.4 Timing / Event / pulse ID system:

The event and trigger distribution system controls the prorogation of, and tracks data associated with each electron / X-ray bunch in the machine. This allows feedbacks to operate on a single bunch measured by multiple sensors and for experiments to associate accelerator data with a single X-ray pulse.

Each beam pulse is associated with a unique ID number as it travels through the machine. Note that in high rate operation, multiple pulses are in the machine at any one time and the event system must account for the time delays of the beams and the networks.

5.5 Fast Feedback System:

A distributed fast feedback system is used to control the LCLS-II beams. The feedback system measures a set of input devices (BPMs, toroids, etc.), and controls a set of beam actuators (magnets, RF stations etc.).

- Input Data Rate: The fast feedback system will be able to collect data at the maximum beam rate (~1MHz).This will allow averaging, sorted by beam-codes as needed. The actuator rate for fast feedbacks will be specified in the fast feedback PRDs and may be slower than the beam rate.
- Input Data Processing: The fast feedback system will be able to tag data by pulse ID, and average data by event code or specified combination of event codes. This allows feedback either on specific beam pulses (for example, pulses to the diagnostic line) or averaged for a particular combination of event code (for example, pulses going to the HXR line).
- Event Code Awareness: The feedbacks will be able to track states for selected combinations of event codes. Provision will be provided to update these event code-dependent states when the associated event codes are not issued during a machine configuration change.
- Feedback Algorithm: The fast feedback will consist of a set of feedback loops, each of which operates with a linear NXM matrix from inputs to states, and a PID feedback for dynamics from states to actuators. States from other loops will be available as inputs to allow cascading of feedbacks.

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- High level control: The feedback matrices will be adjusted from external high level applications without disabling the running fast feedbacks. This allows continuous adjustment as machine parameters (for example, compression) are changed. The selection of measurements, states and actuators can be changed by operations, but the feedbacks may be disabled during the change.
- Performance: The fast feedback system device numbers and speed will be determined by the network performance limits described in section 5.3.4

6 Control System Interoperability with LCLS-I

The control system must support all required operating modes with respect to LCLS-I.

- The same HXR undulator, X-ray beam lines and experimental hutches can be driven from either accelerator, and provision for simultaneous operation of the LCLS-I and LCLS-II is required.
- Changing the HXR beamline between the two accelerators must not require manual changes to the controls hardware.
- Some diagnostics and MPS systems must provide for communication between the two accelerators: it is possible that a beam loss in one machine could be detected on a loss monitor for the other accelerator in the same housing.
- The event system must be compatible with the LCLS-I event system to allow simultaneous synchronized use of both accelerators.
- The LCLS-II control system user interface will be designed to be as similar as practical to the LCLS-I interface to reduce the required operator training.

7 Controls Subsystems

The controls system is comprised of the following subsystems, each of which is specified in its own PRD.

7.1 Personnel Protection System:

The Personnel Protection System is a life-safety system designed to prevent beam operation with personnel in the accelerator housing, or X-ray tunnels or hutches. It operates independently from the main control system and uses life-safety rated components. The EPICS control system needs to monitor the status of the PPS system and provide non-safety machine functions required as a result of a change in state of the safety system.

7.2 Beam Containment System:

The Beam Containment System is a safety system designed to prevent exposure to hazardous radiation to personnel outside of the operating accelerator enclosure. It operates independently from the main control system. The EPICS control system needs to monitor the status of the BCS system and provide non-safety machine functions as a result of a change in state of the safety system. The BCS system will provide some inputs to the MPS system.

7.3 Machine Protection System:

The machine protection system protects the hardware against damage. Beam position and beam loss are monitored through a fast interlock system that will stop the beam at a mitigation (shut-off) device. A slow interlock system monitors devices that do not require a fast beam shutoff. The MPS system reports its status, and can be reset and configured through the EPICS control system. The X-ray systems will require MPS as specified in the X-ray Transport and Experimental Systems PRD. The X-

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ray MPS will be able to use electron beam mitigation devices to quickly stop the X-ray beam low bandwidth monitoring and control system.

Vacuum, temperatures and other slowly varying non-beam synchronous systems will be controlled through EPICS. Individual devices may be controlled directly by EPICS IOCs or through field busses.

7.4 Event and Timing System

The event and timing system provides low jitter triggers and beam information throughout the accelerator. Triggers will be activated at rates, delays and pulse widths controlled from a central timing master.

7.5 RF phase and precision timing system:

The RF phase and precision timing system provides high stability timing for the accelerator structures, certain diagnostics, and the experiment system timing reference. This system will be controlled and monitored through EPICS.

7.6 Superconducting Low Level RF Systems:

The Superconducting Low Level RF Systems controls the fields in the RF cavities to the phase and amplitude required by the feedback or other control systems. It also provides monitoring and interlocks for the RF systems. The SCLLRF system also provides information on the cavity operation to EPICS and low latency field information to the fast feedback system. Some low level devices like tuner motors are controlled though the EPICS system.

7.7 Cryogenic System Controls:

The Cryogenic System Controls regulate the temperature / pressure and helium flow to the cryostats, and the operation of the helium refrigeration plant. The majority of this system is provided by the cryogenics plant vendor, but it will provide data and control interfaces to the EPICS control system.

7.8 Beam Spreader LLRF System:

The Beam Spreader LLRF System controls the RF fields in the beam spreader superconducting cavity. The cavity RF will be derived from the RF reference system, but field control will be adjusted by the fast feedback system based on beam position measurements in the undulator and dump lines. MPS will provide inputs to the beam spreader to provide a slow beam shutoff.

7.9 RF Gun and Buncher Low Level RF Systems:

The RF Gun Low Level RF system controls the RF fields in the electron gun. The RF gun system will have inputs from the MPS and BCS systems. The required field level and phases will be specified through EPICS, and some devices including tuners and water systems will be controlled through EPICS.

7.10 Pulsed LLRF Systems:

The transverse cavity beam diagnostics require pulsed RF control systems that function in a manner similar to the LCLS-I LLRF stations. The cavity field control will be event-code aware to allow different field settings for different events. Overall field control will be through EPICS.

7.11 Laser Locking Systems:

The RF gun laser and experiment lasers will be locked to the timing of the accelerator beam. The Laser Locking System controls will interface with the locking hardware and provide timing control. For the RF gun laser the locking system controls will also provide selection of beam timing based on event codes.

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7.12 Laser Control Systems

The LCLS-II laser systems will be controlled through EPICS and the event system. Where practical, all laser controls and diagnostics will be able to be operated remotely.

7.13 Beam Position Monitor controls:

The LCLS-II uses a combination of stripline and warm and cold cavity BPMs. The beam positions (both horizontal and vertical) and measured along with the bunch charge, tagged with a pulse identification, are made available to the EPICS control system, the fast feedback system, and the MPS system. The BPMs will be able to provide prompt orbit and beam loss interlocks to the MPS system on a shot-by-shot basis.

7.14 Beam Current Monitor Controls:

Beam Current Monitors will provide calibrated average currents and bunch charges to the control system. These will be used to calibrate the BPM based bunch charge monitors.

7.15 Beam Loss Monitors:

The beam loss monitors measure the radiation generated by beam loss. These provide information to the MPS system and the EPICs control system. Selected beam loss current measurements will be made available to the BCS system. Where practical the BCS loss measurements will be independent of the other toroid functions to minimize the number of components, which must be controlled as safety systems.

7.16 Relative Bunch Length Monitors:

The bunch length monitors measure pulse by pulse bunch length after each compressor, and in some bends they provide this data to the fast feedback system and to the EPICs system.

7.17 Profile Monitors:

There are electron beam profile monitors (imaging screens) located in the diagnostic lines and X-ray profile monitors in the X-ray lines. These will be monitored by cameras connected to the EPICS control system. Camera triggering will allow data to be collected on specified combinations of event codes, limited by the maximum data rate of the camera. The system will support an average data rate of 10Hz from any one camera or combination of cameras.

7.18 Wire Scanner controls:

Wire scanners are used to measure the averaged transverse beam profiles over about 100 shots and are used in areas where coherent optical radiation may degrade profile monitor based measurements or where average beam powers are too high for profile monitors. The wire scanner motion is combined with loss monitors and beam position measurements for the same pulse ID.

7.19 Magnet Controls:

The LCLS-II has slow correctors and magnets that are controlled through EPICS in a manner similar to that for LCLS-I. A few fast correctors are also included, upstream of each undulator, to drive transverse fast-feedback loops.

7.20 Fast beam kicker controls:

The LCLS-II has fast kicker magnets that are controlled through EPICS and event codes for normal operation, and can be triggered by the MPS system for beam aborts. The various kickers can send the beam to diagnostic lines and/or dumps.

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7.21 Beam Spreader controls:

The Beam Spreader directs the accelerated bunches to either of the undulator lines or to the BSY beam dump. The spreader control regulates the transverse RF amplitude and phase relative to the phase reference system corrected by downstream orbit feedback information from the fast feedback system.

7.22 Undulator Controls:

In addition to BPMS, magnets and loss monitors, the undulators have gap adjustment motors which are controlled through EPICS.

7.23 Photon systems controls:

The X-ray transport system contains a variety of instrumentation that interfaces to the EPICS control system.

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