Development of Pattern Aware Unit (PAU) for the LCLS Beam Based Fast Feedback System*

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Abstract

LCLS is now successfully operating at its design beam repetition rate of 120 Hz, but in order to ensure stable beam operation at this high rate we have developed a new timing pattern aware EPICS controller for beam line actuators. Actuators that are capable of responding at 120 Hz are controlled by the new Pattern Aware Unit (PAU) as part of the beam-based feedback system. The beam at the LCLS is synchronized to the 60 Hz AC power line phase and is subject to electrical noise which differs according to which of the six possible AC phases is chosen from the 3-phase site power line. Beam operation at 120 Hz interleaves two of these 60 Hz phases and the feedback must be able to apply independent corrections to the beam pulse according to which 60 Hz timing pattern the pulse is synchronized. The PAU works together with the LCLS Event Timing system which broadcasts a timing pattern that uniquely identifies each pulse when it is measured and allows the feedback correction to be applied to subsequent pulses belonging to the same timing pattern, or time slot. At 120 Hz operation this effectively provides us with two independent, but interleaved feedback loops. Other beam programs at SLAC, such as FACET and LCLS II in the future, are pulsed on a different time slot than LCLS, such that PAUs in those systems will respond to their appropriate timing patterns. This paper describes the details of the PAU development: real-time requirements and achievement, scalability, and consistency. The operational results will also be described.

Introduction

Beam Based Fast Feedback

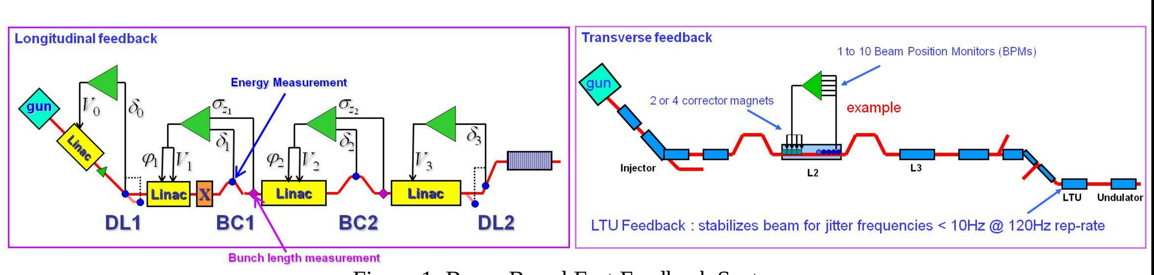

Figure 1: Beam-Based Fast Feedback System

- Pattern Aware Control
  - Pattern-based 120 Hz operation
  - Control of Magnet and RF based on Timing Pattern
- Utilize Fast Feedback Communication (FCOM)/FCOM Network (FNET)
  - Isolated network: no competing network traffic, reliable data transfer
  - FCOM protocol: new efficient protocol for FNET, IP multicasting
- The Fast Feedback replaces MATLAB based slow and non-pattern aware feedback

Motivation

- Increase of beam rate from 60 Hz to 120 Hz
  - beam runs on same AC phase @ 60 Hz
  - two different AC phases @ 120 Hz
- Other power line noise sources are expected
  - LCLS-II
  - Facility for Advanced Accelerator Experimental Test (FACET) any other which shares SLAC main power line will make additional variations
- Pattern
  - A set of the same variation on the power line
  - Encoded in the timing/event patterns
- Timing/Event Patterns
  - A combination of time slots and beam operation information for the entire SLAC facility
  - Beam Code + Time Slot + 5 x 32 bits Event Masks

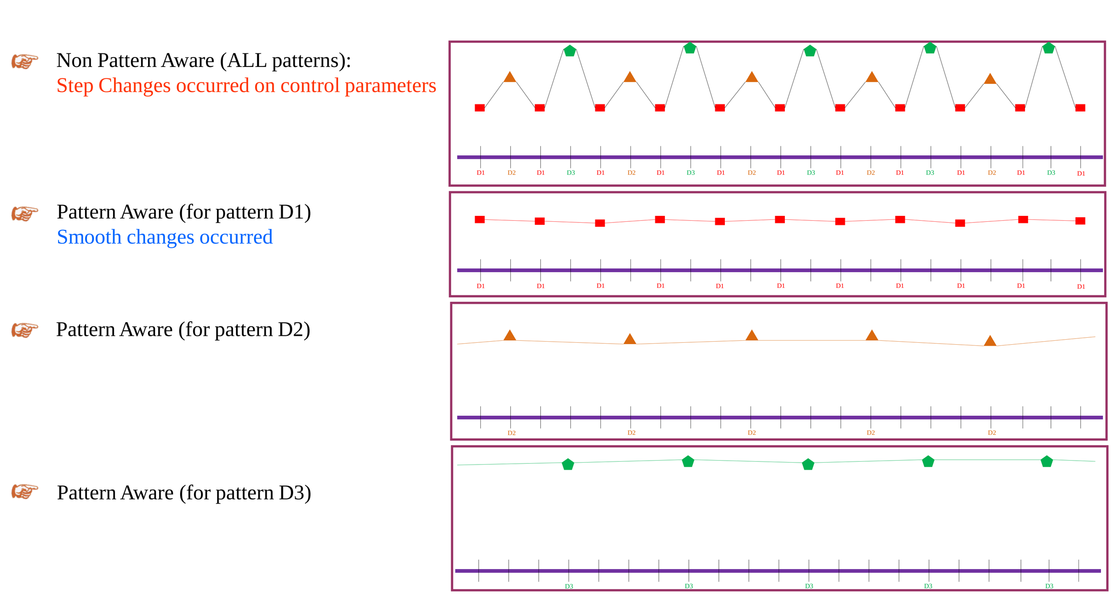

Figure 2: Pattern and Beam Characteristics

- Non-Pattern Aware Feedback
  - Feedback loop has to compensate the step change between the pattern
  - However, a single feedback loop cannot cure the step rise and fall
- To compensate the variation between patterns
  - Employ separate feedback loops for each different patterns
  - Each feedback loop does not experience step change
  - Beam characteristics in different patterns can converge to a desired value smoothly
  - Pattern Aware Operation for actuators: RF and Magnets
- To build generic Software Solution for pattern aware operation
  - PAU can be utilized in any pattern aware application

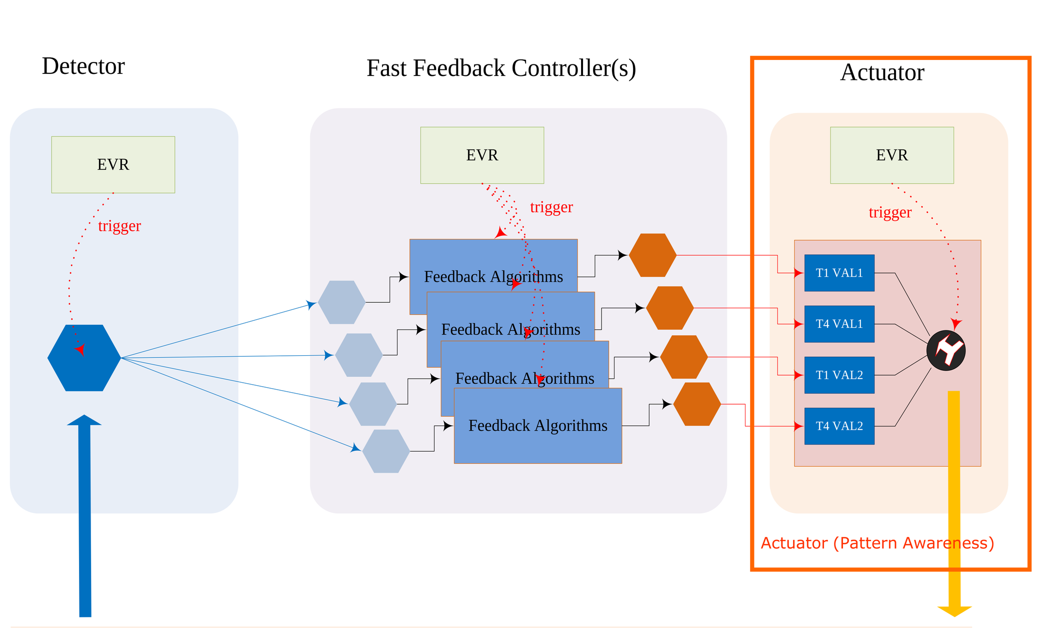

Figure 3: Schematic of Pattern Aware Feedback

Implementation Details of the PAU

Pattern Aware Unit (PAU)

- Pattern Matching
  - Works with Event System (EVR: Event Receiver)
  - Wakes up by the fiducial interrupt 360 Hz rate
  - Pattern
    - beam code / time slot / 5 x 32 bits exclusion mask + 5 x 32 bits inclusion mask
    - Advanced pattern matching to implement set value to the actuator
    - Current pattern matching for getting data from fast feedback system
- Drives the data pull Function
  - Pulls (reads) data from FCOM data slot
- Drives the data push function
  - Executes local regulation loop for RF system
  - Sends I&Q data to PACs (Phase and Amplitude Controller) for RF system
  - Writes DAC value for Magnet System

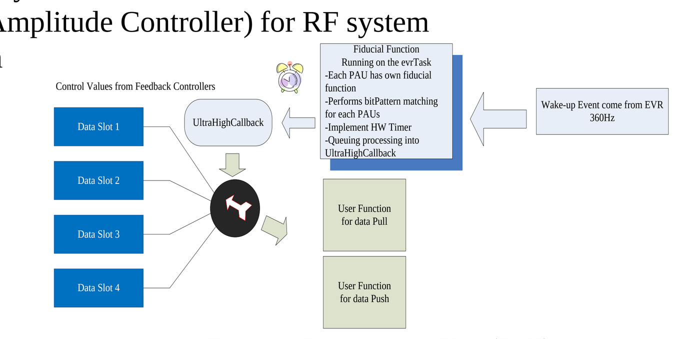

Figure 4: Pattern Aware Unit (PAU)

Processing Flow for PAU

- Fiducial Thread
  - Wakes up by 360 Hz fiducial interrupt from EVR
  - Processes pattern matching
    - Advanced Pattern Matching: set actuator to prepare next beam pulse
    - Current Pattern Matching: get data from fast feedback system
  - Queues pattern matching information to the UltraHighPriority Callback
    - The queuing needs to be delayed by the high-resolution timer
    - This allows accurate adjustable time delay for waiting for data from the fast feedback system
    - Utilizes on-board high-resolution timer on the CPU board: sub-nanosecond resolution

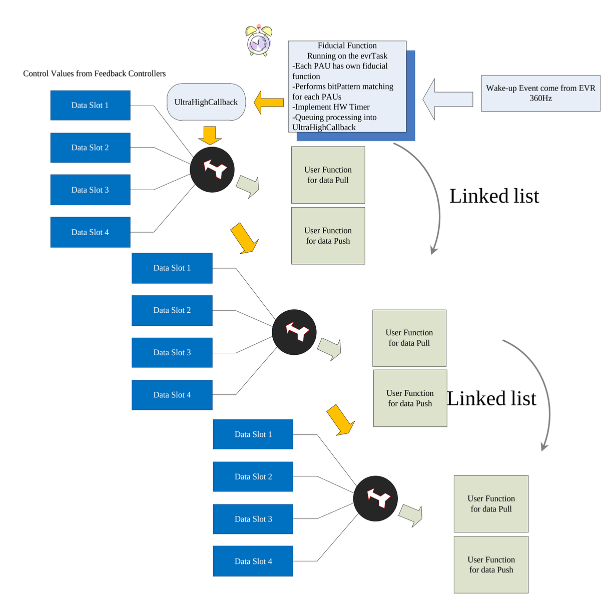

Figure 5: Multiple MUXes in a PAU

- UltraHighPriority Callback Thread
  - Waits on message from fiducial thread / High resolution timer
  - Processes Muxes in the linked list
    - MUX corresponds to a physical quantity: B_DES (set value for magnet strength), P_DES (RF phase), A_DES (RF amplitude)
    - PAU handles multiple MUXes which share same pattern matching
    - This avoids repeated pattern matching with same pattern for each individual quantity
    - Processes User Pull Function with the current pattern matching
      - Pull data from matched FCOM data slot – fast feedback mode
      - Pull data from matched data slot PV – static offset mode
    - Processes User Push Function
      - Measure execution time / latency
      - House Keeping Routine

Timeline for 120 Hz Interlaced Mode

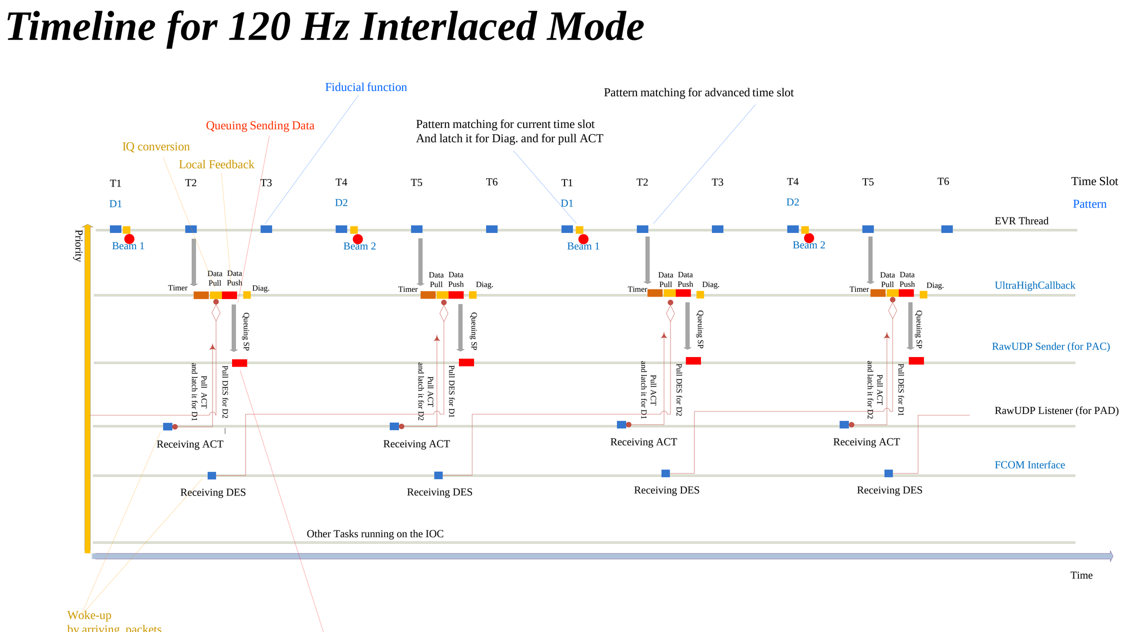

Figure 6: Timeline for the Interlaced Mode

Static Offset Mode

- MATLAB based slow feedback (6x6 longitudinal) is still working for L2/L3 in LCLS
- Provide Pseudo-Pattern Aware for the non-pattern aware slow feedback
  - Slow feedback provides master set value
  - MUX calculates master set value + data slot offset for each data slot and picks correct data slot

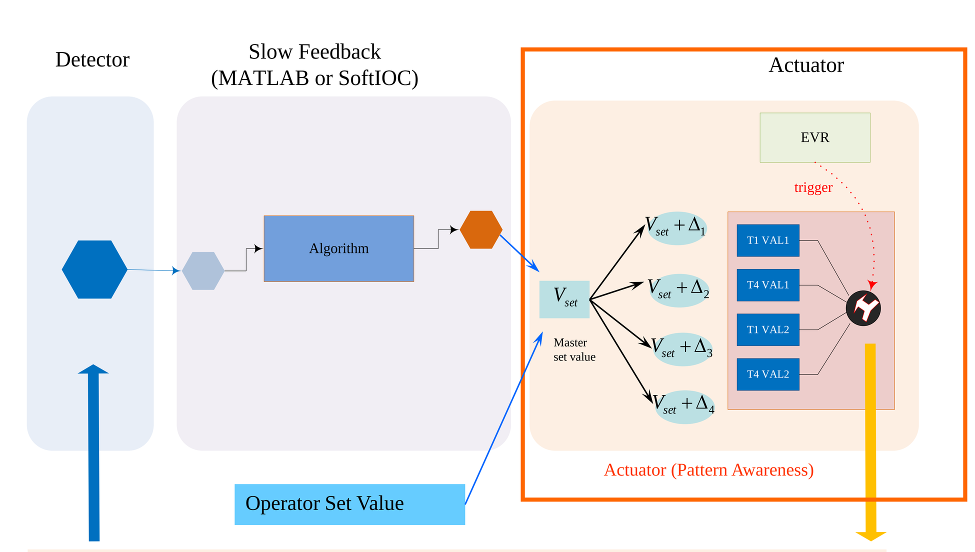

Figure 7: Static Offset Mode and Pseudo-Pattern Awareness

Function Diagram & Interfaces

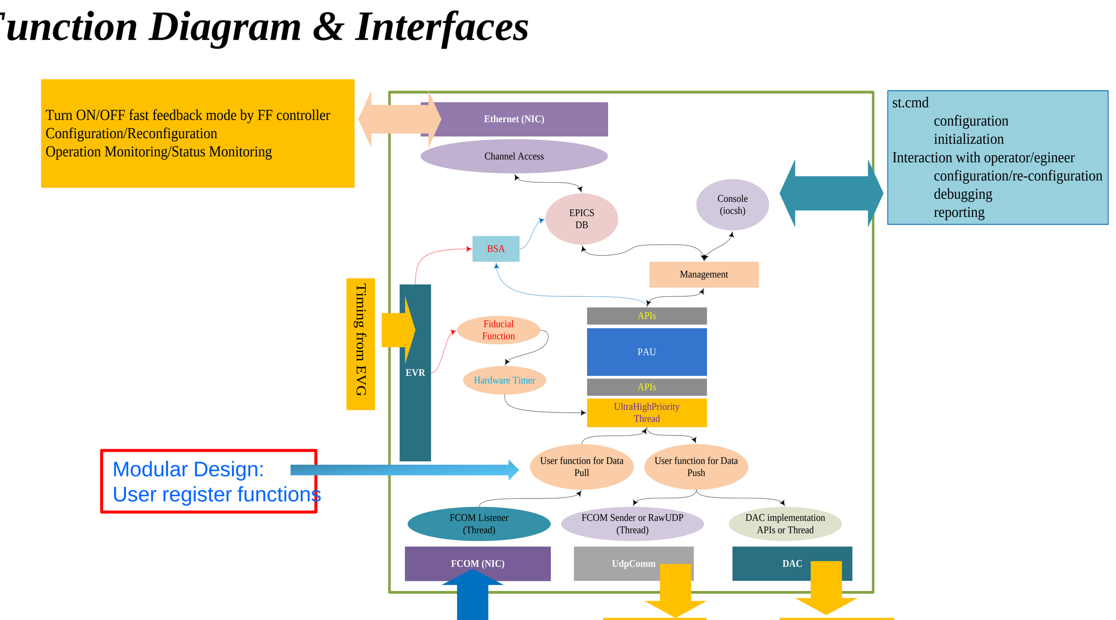

Figure 8: Functional Diagram and PAU interfaces

Association

- Make relationship between 2 MUXes or Multiple Muxes
  - RF local regulation loop and Amplitude&Phase to I&Q conversion
    - ADES/PDES
  - Laser RF Source Selection
    - Required to make relationship between RF sources: PDES for 2856 MHz/PDES for 119MHz/ PDES for TCAV
    - To avoid jumping to a different bucket when switching to different source

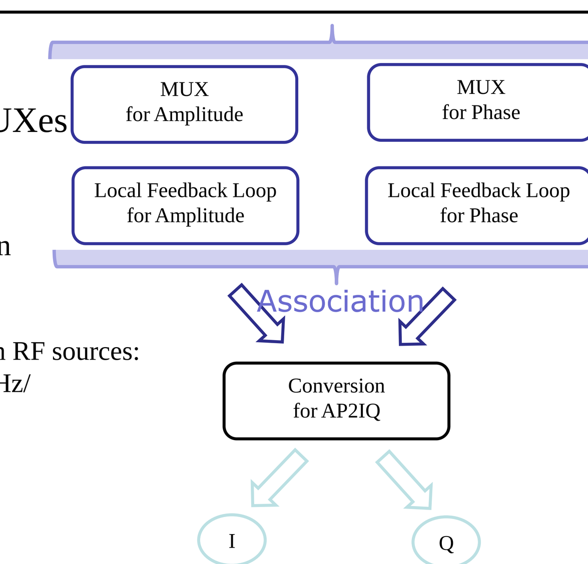

Figure 9: Concept for the Association

Applications

- RF system
  - Use Push function for local regulation loop/AP2IQ conversion
  - Use Pull function for FCOM communication with the fast feedback system
  - Implement L2/L3 Abstraction layer with the Association Concept
    - Delegate MUXes provide Pseudo-Pattern Awareness for MATLAB feedback
    - Slow MUXes and Push function control individual klystron and RF station

Table 1: PAUs for RF system

PAU	MUXes and Associations	Remarks
PAU0 for Thales Laser System	1 station, 2 associations 3 muxes	2856 MHz PDES 119 MHz PDES Delegate PDES
PAU1for Coherent Laser System	1 station 2 associations 3 muxes	2856 MHz PDES 119 MHz PDES Delegate PDES
PAU2 RF Feedback for IN20	6 stations 6 associations 12 muxes	PDES/ADES for gun, L0A, L0B, TCAV0, L1S, L1X
PAU3 Feedback for LI24	7 stations 9 associations 18 muxes 2 virtual layers (L2/L3 abstraction)	PDES/ADES for L2Ref, TCAV3, KLY24_1, KLY24_2, KLY24_3, S29, S30, L2Abstr, L3Abstr

- Magnet System
  - Simpler than RF system: no association
  - Use Push function to write set value directly to DAC
  - Use Pull function for FCOM communication with the fast feedback system

Table 2: PAUs for Magnet system

PAU	MUXes and Associations	Remarks
PAU0 Corrector in LTU0 area	1 corrector 1 mux	xcor_548
PAU1 Correctors in LTU1 area	3 correctors 3 muxes	xcor_488 xcor_493 xcor_593

Performance Measurements and Real-Time Time Deadline

Self-Diagnostics

- Diagnostic Function in PAU
  - Processed last in the PAU processing
  - Provides accurate measurement of processing time for each step in PAU processing and Latency/Delay
- Utilized for the performance measurement and Real-Time Analysis

Table 3: Real-time performance measurement

PAU Processing	Processing Time or Delay
Pattern Matching in Fiducial	2 μsec
ISR delay	3 μsec
User Pull Function	25 μsec
User Push Function	60 μsec
Self-diagnostics and house keeping	15 μsec

Real-Time Deadline

- PAU wakes up 2 fiducials prior to next beam pulse: 5,556 μsec
- Required time for the worst case:
  - PAU processing time: ~ 105 μsec (RF System)
  - Waiting for FCOM communication: ~ 200 μsec
  - Settling time for actuator: ~ 6,000 μsec (Magnet System)
- Time margin to meet deadline: 251 μsec

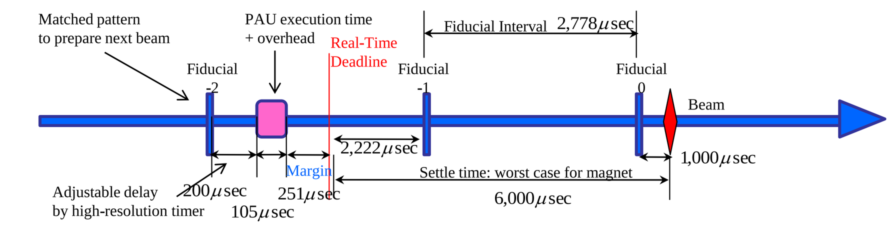

Figure 10: Real-Time Deadline

Summary

The PAU software has been designed as a generic software module for LCLS beam line actuators. It was implemented for adaptability to fit into various systems which have particular and unique requirements. We applied PAU software to the RF and magnet systems, and it has contributed to the stable 120 Hz beam rate operation of LCLS. During this work, we have accomplished the following:

- Integration with the beam-based fast feedback system for the RF and Magnet Systems
- Achieved pattern aware operation
- Support for non-pattern aware longitudinal feedback for L2 and L3; pseudo-pattern aware
- Implementation of the various user pull/push functions for the particular/unique requirement: RF local regulation loop, Amplitude/Phase to I and Q conversion, Abstraction Layer for L2 and L3.

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