PIP-II Postmortem Capture System Interface Specification Document

PIP-II Accelerator Systems, December 2024

Table of Contents

Overview

The following documents outlines interface specifications for postmortem data capture of PIP-II accelerator systems. The intent is to provide a cohesive platform for root cause analysis in the event of machine fault.

Background

The PIP-II Postmortem Capture System (PPCS) is intended to capture detailed diagnostic data immediately before, during, and after a fault condition. This system is triggered by predefined events such as beam trips, power supply malfunction, quenching of superconducting cavities, etc. The data includes real-time and pre-trigger snapshots of key operational parameters such as:

- **Beam parameters:** Position, intensity, energy, and profile data.
- **Subsystem performance**: Current, voltage, temperature, and pressure readings.
- **Event logs**: Chronological records of interlock triggers, alarms, and operator actions.
- **High-speed waveforms**: Oscilloscope-like records of fast signals, such as RF cavity fields.

Role in Postmortem Analysis

Postmortem functionality supports the systematic identification of failure modes by providing a detailed timeline of events leading to a fault. This capability enables engineers and operators to reconstruct the fault conditions and identify patterns or anomalies indicative of a specific failure mode. Applications include:

- **Fault Characterization**: Identifying whether the failure originated in beam dynamics (e.g., misalignment or instability) or hardware systems (e.g., power supply failure).
- **Subsystem Interactions**: Analyzing interdependencies between subsystems to determine if a failure in one component cascaded into others.
- **Validation of Protection Systems**: Verifying that interlock systems and protective measures responded correctly to prevent damage.

System Requirements

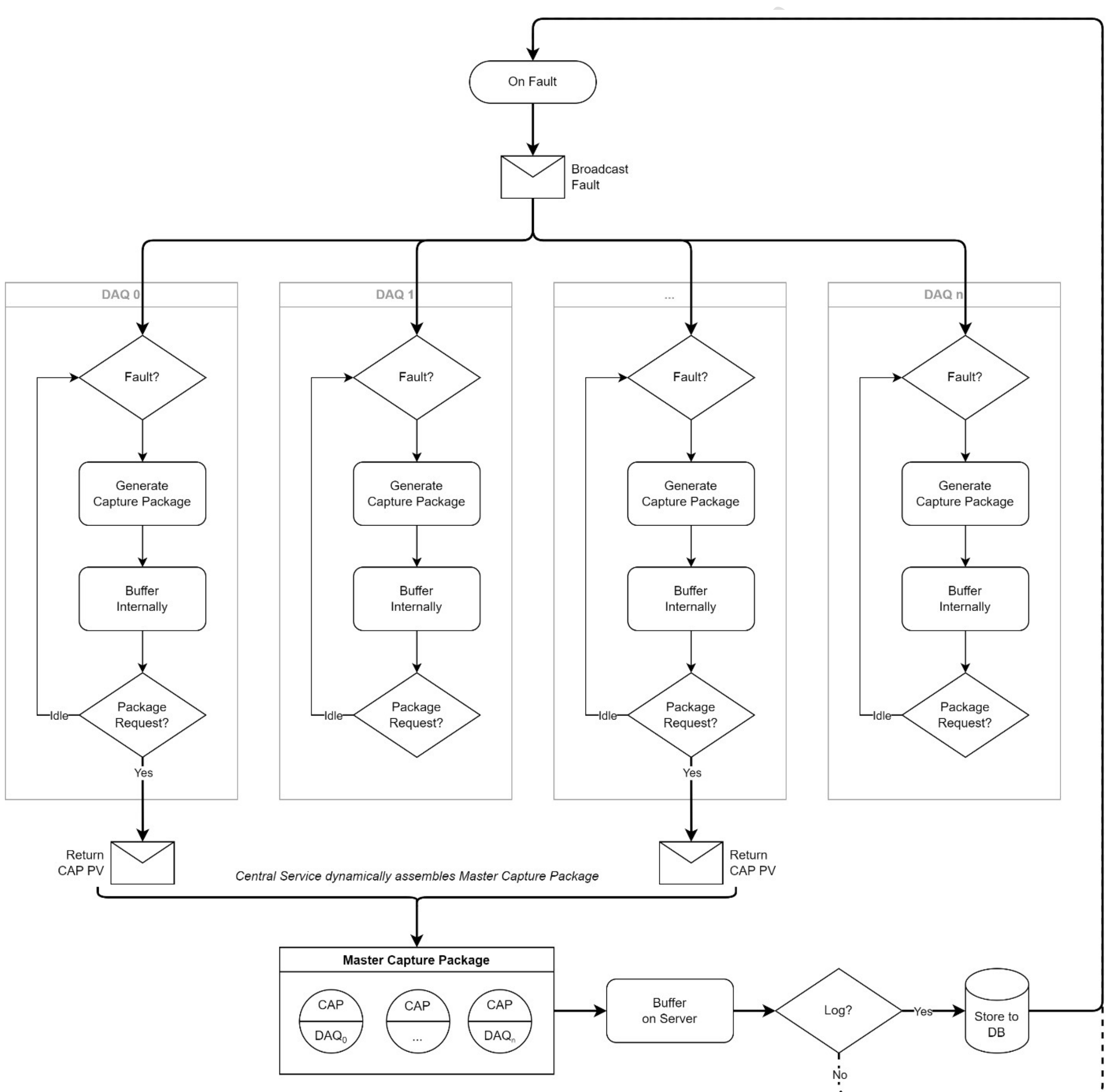
The PPCS requires a high degree integration, synchronization, and configurability from all data acquisition (DAQ) systems. As such the following high-level requirements are outlined:

- **Synchronization**: Alignment to a common time source within 1 microsecond (uS).
- **Availability**: Real-time access to the preceding 1 second of data across all DAQ systems.
- **Data Format**: Standardized record configuration (Capture Package) and identification.
- **Retention:** Dynamic storage and retrieval of the preceding 5 Capture Packages.
- **Configurability**: On-demand access to any of the above information by operators.

System Behavior

The PPCS will act in the following manner:

1) On fault, a message is broadcast to all DAQ devices (both soft and embedded IOC's).
2) DAQ devices will assemble and retain a package with the preceding 1 second of data.
3) On request, DAQ devices will provide the Capture Package to a central service.
4) The central service will assemble a 'Master Capture Package' and log as desired.



Requirements for Data Acquisition Systems

DAQ Systems are hereby defined as any device integrated with specified accelerator systems, capable of recording analog or digital waveforms (RF Protection Interlock, Instrumentation etc.)

DAQ Systems shall have fault reporting capability.
DAQ Systems shall be capable of reporting faults on trigger, clock event, or network request.
DAQ Systems shall retain an internal circular buffer of waveforms in the event of a fault.
DAQ Systems shall compile relevant waveforms for each fault (the Capture Package).

- The Capture Package shall contain the most recent waveform at time of fault.
- The Capture Package shall contain the preceding 15~20 cycles (1 second) from fault.
- The Capture Package shall contain full-bandwidth waveforms up to 500K samples.
- The Capture Package shall contain a timestamp of 1us accuracy for each waveform
- The Capture Package shall contain the Pulse ID for each waveform, when available.

DAQ Systems shall retain internally the 5 most recent Capture Packages.
DAQ Systems shall make retained Capture Packages available upon request.
DAQ Systems shall provide EPICS compatible Capture Packages.

Requirements for Machine Protection Systems

MPS Systems are hereby defined as any device integrated with specified accelerator systems performing Machine Protection related functions (Concentrator, Serializer, Instrumentation).

MPS Systems shall have fault reporting capability.
MPS Systems shall be capable of reporting faults on trigger, clock event, or network request.
MPS Systems shall retain an internal circular buffer of cycle-by-cycle status in the event of a fault
MPS systems shall identify relevant causes for each fault (Traceback)

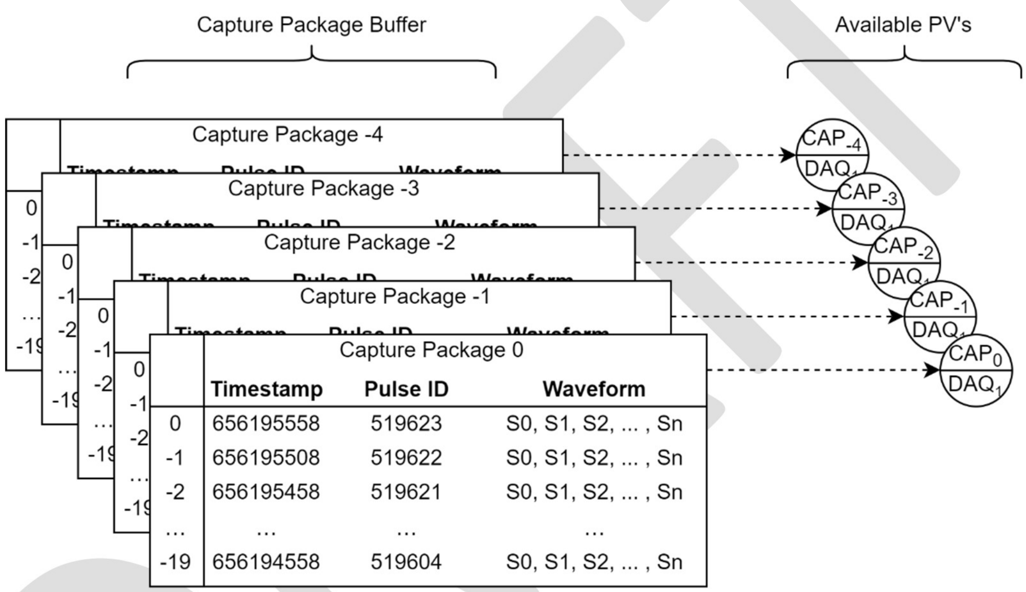
- The Traceback shall contain the originating system or channel of each fault.
- The Traceback shall contain the preceding 15~20 cycles (1 second) from fault.
- The Traceback shall contain a timestamp of 1us resolution for each fault.
- The Traceback shall contain the Pulse ID for each fault, where available.
- The Traceback shall contain the Fault ID for each fault, to be the time at which it occurred.

MPS Systems shall be capable of capturing *all* Tracebacks in the event of cascading failure.
MPS Systems shall retain all tracebacks for a period no shorter than 60 minutes.
MPS Systems shall make retained Tracebacks available upon request.
MPS Systems shall provide EPICS compatible Tracebacks.

Capture Package Format

The Capture Package is a structured dataset containing waveform data and metadata for fault analysis. It includes the most recent waveform and the preceding 15–20 cycles (one second) at full bandwidth (up to 500 Ksps), along with precise timestamps, Fault IDs, and Pulse IDs for accurate correlation. Stored in a five-deep circular buffer, it is accessible via EPICS as Area Detector process variables for seamless integration and analysis.

- The capture package shall present as an EPICS 'Area Detector' (2D) Process Variable.
- The capture package shall be identifiable by the MPS Fault ID
- The capture package shall contain the preceding second of data (15~20 waveforms)
- The capture package shall be stored in a circular buffer, 5 deep
- The capture package shall retain full bandwidth waveforms, up to 500Ksps



Interfaces

The following interfaces shall be available, to be explicitly specified on a per-system basis. Systems shall require one of each interface for capture, time, and cycle correlation. Some interfaces may require a combination of interfaces for full implementation (e.g. MPS Trigger & MPS Multicast).

Data Transfer Interfaces

General IP Network infrastructure will be available for all data acquisition systems.

- The Network Interface shall be available via fiber or RJ-45.
- The Network Interface shall be capable of 1Gbps or 10Gbps rates on request

EPICS Interface

All systems with postmortem functionality shall present Process Variables (PV's) through EPICS

- Capture Packages shall utilize EPICS for postmortem configuration, where required.
- Capture Packages shall conform to a common format for *all* waveforms.
- Capture Packages shall present uniformly (in the same manner) for *all* systems

Multicast Interface

For all systems, a Fermilab network timing interface (Multicast) shall be available

- The Multicast shall be available via general network interface, as defined by a separate ISD.
- The Multicast shall distribute all preceding LCLK events at 10ms intervals
- The Multicast shall contain LCLK event data including Fault ID and Pulse ID.

LCLK Interface

For all systems, a Fermilab machine timing interface (LCLK) shall be available

- The LCLK link shall be available via 1.3Gbps fiber, as defined by a separate ISD.
- The LCLK link shall carry an MPS Trigger ~ a 16b event containing the 32b Fault ID.
- The LCLK link shall carry a Cycle Trigger ~ a 16b event containing the 32b Pulse ID.
- The LCLK link shall be available via external TTL trigger, provided by a separate timing unit.

The following interfaces or combination of interfaces are <u>required</u> for integration.

Timing Interfaces

To maintain 1uS timestamp accuracy, the following interfaces may be utilized.

- IEEE 1588-HA (White Rabbit) ~ a precision time protocol available via fiber on request.

Or

- Pulse Per Second (PPS) ~ a 5V TTL signal provided against a global time reference <500nS
- Network Time Protocol (NTP) ~ a general time protocol to be used in conjunction with PPS.

Machine Protection Interfaces

To initiate fault reporting for each system, the following interfaces may be utilized.

- LCLK Link ~ a 1.3Gbps protocol, carrying an MPS trigger, as defined by a separate ISD.

Or

- MPS Trigger ~ a 5V TTL signal sourced from a Multi-Function Timing Unit (MFTU).
- MPS Multicast ~ a general IP network broadcast containing the preceding Fault ID

Machine Cycle Interfaces

To provide Pulse ID information for correlation, the following interfaces may be utilized.

- LCLK Link ~ a 1.3Gbps protocol, carrying a cycle trigger, as defined by a separate ISD.

Or

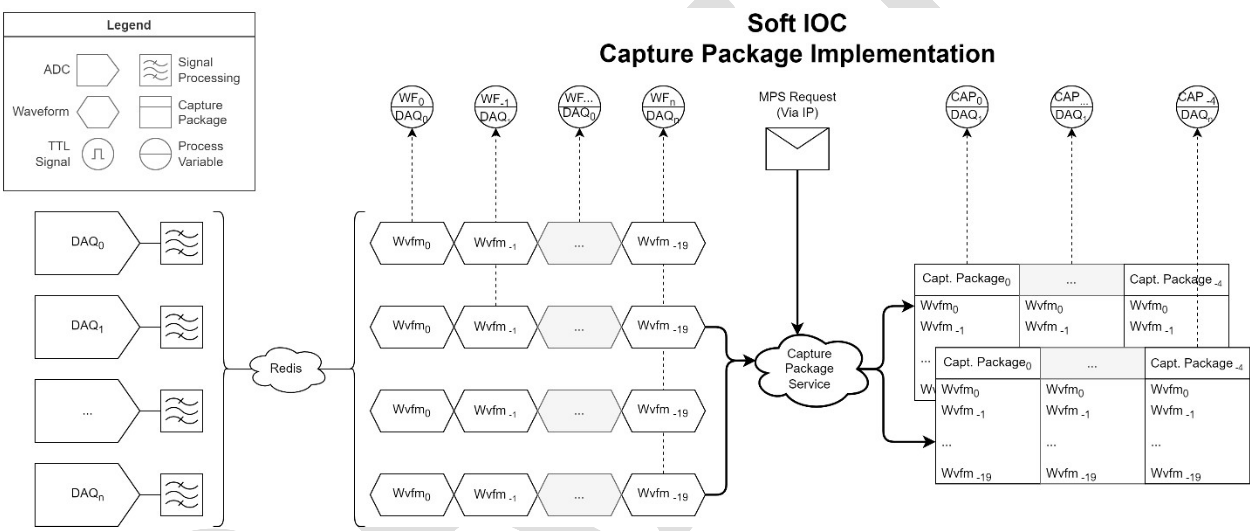
- Cycle Trigger ~ a 5V TTL signal sourced from a Multi-Function Timing Unit (MFTU).
- Cycle Multicast ~ a general IP network broadcast containing the preceding Pulse ID

Example Implementations

The following implementations are outlined. Alternative architectures may be utilized, so long as the functional requirements for postmortem capture are met.

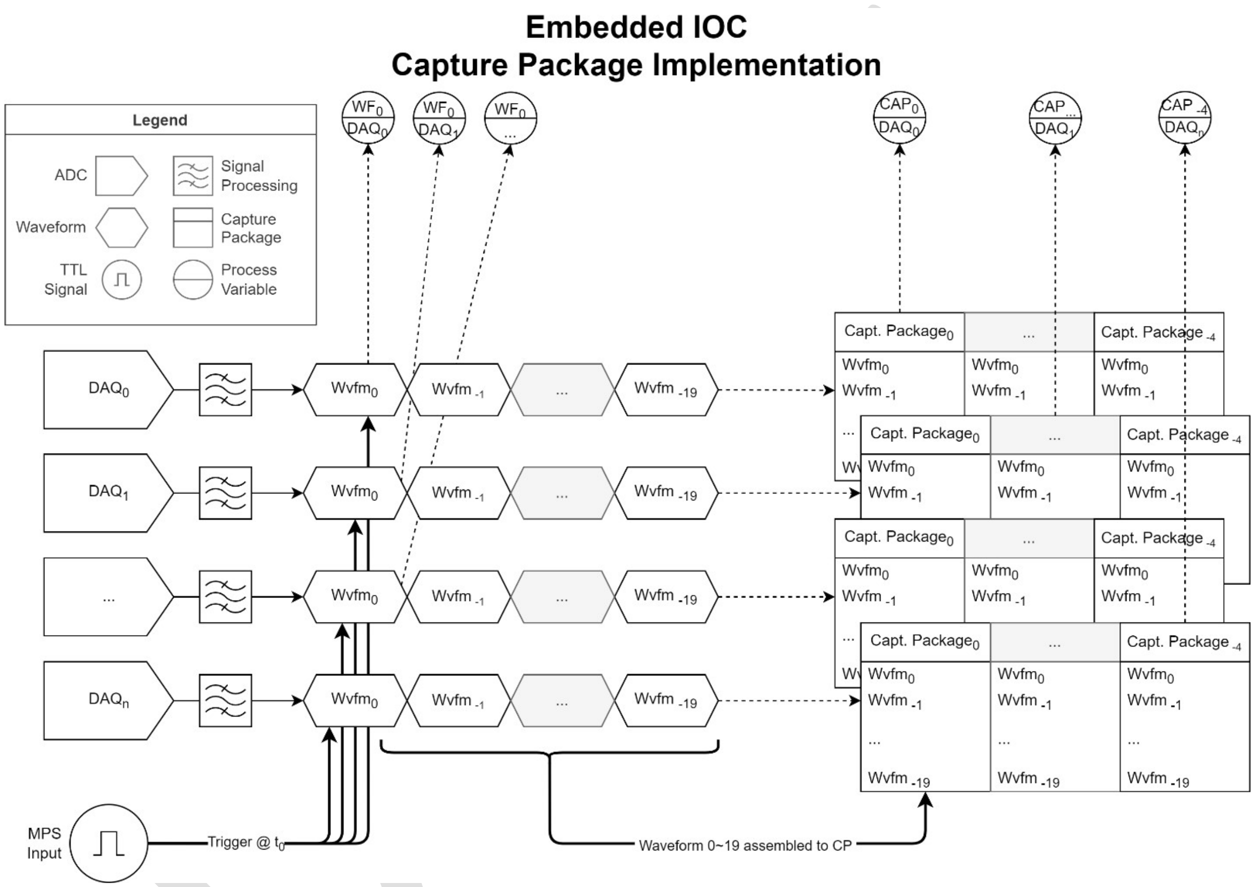
Soft IOC Capture Package Implementation

The following implementation is proposed for postmortem functionality to be embedded server-side from a shared data cache. For each channel, a circular buffer containing the preceding 15~20 cycles (one second) shall be available. On MPS input trigger (via network) select channels shall be compiled to a Capture Package with associated metadata (Pulse ID, Timestamp) and buffered 5-deep internally. The Capture Packages for all channels shall be available as independent PV's.



Embedded IOC Capture Package Implementation

The following implementation is proposed for postmortem functionality to be embedded in the field device. For each channel, a circular buffer containing the preceding 15~20 cycles (one second) shall be available. On MPS input trigger, *__all__* channels shall be compiled to a Capture Package with associated metadata (Pulse ID, Timestamp) and buffered 5-deep internally. The Capture Packages for all channels shall be available as independent PV's.



Embedded IOC Synchronization

The following implementation is proposed for synchronization of waveform data with Timestamps and Pulse ID's. To provide real-time cycle correlation and sub micro-second accuracy, external hardware interfaces are required.