12TH INTERNATIONAL ORGANIZATION OF CHINESE PHYSICISTS AND ASTRONOMERS ACCELERATOR SCHOOL

OCPA-2025

KHAOYAI, NAKHON RATCHASIMA, THAILAND | 29 JULY - 7 AUGUST 2025

Siam Photon

THAI SYNCHROTRON NATIONAL LAB

Control Technology

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Chinese Academy of Sciences

Outline

1. Control System Overview
2. Hardware Platform, Interface, Protocol
3. EPICS Basic, Modules, Applications
4. Control Infrastructure, Services, HLA
5. Machine Protection, Timing, Feedback
6. Summary

What is an accelerator control system?

All particle accelerators depend on control systems to **integrate** different **devices** and the autonomous **controllers** that are distributed throughout the facility into **one coherent infrastructure**. The control system provides an **abstraction layer** between hardware and the operators, and creates the **environment** that allows scientists to carry out their experiments. It also enables the technical support groups to compare previous data with current one in order to enhance the performance of their systems.

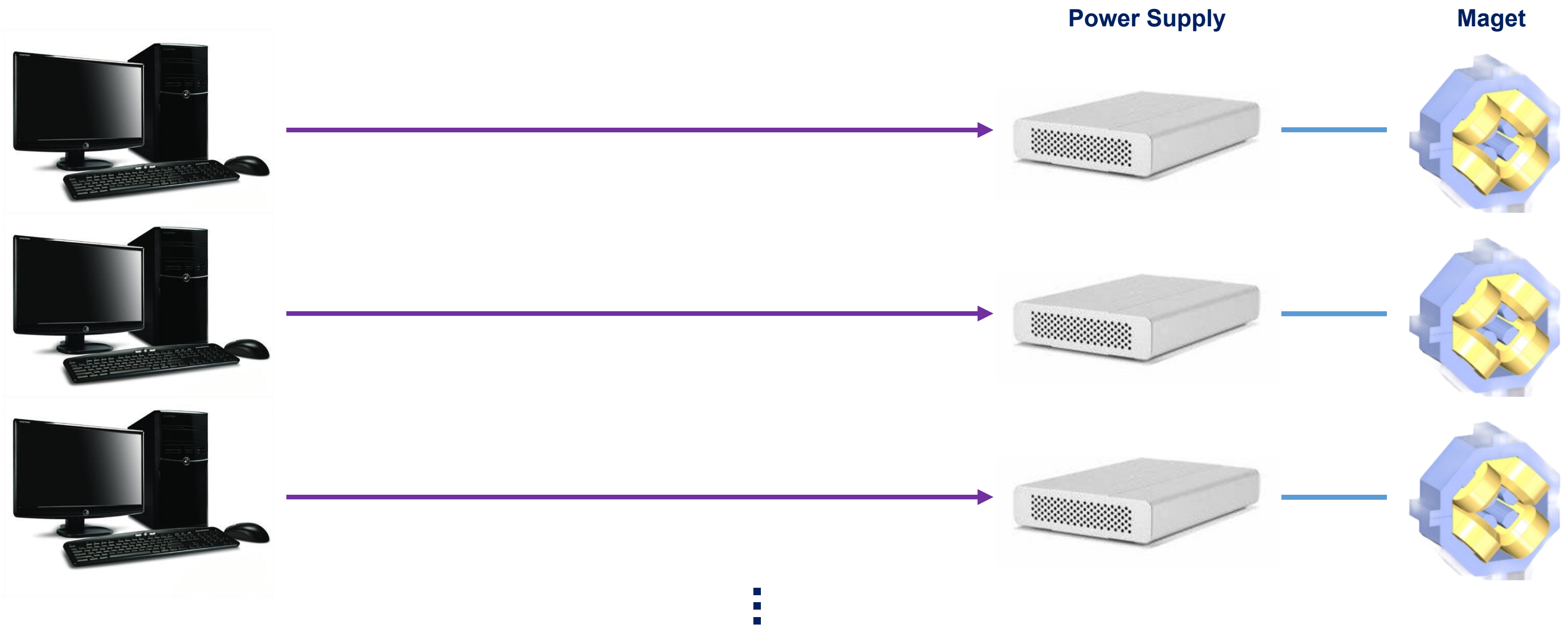
--- Elke Zimoch, Paul Scherrer Institute

What is an accelerator control system?

What is an accelerator control system?

If there is **1** power supply, we only need to consider the simple **connection** and usable **software**.

What is an accelerator control system?



If there are **1,000** or **10,000** devices, we need to consider the control system **architecture**, communication **network**, hardware **platform**, software **framework**, user-friendly interface, historical data storage & analysis tools, fault alarm and diagnosis, interlock or timing system. It is also necessary to ensure the large-scale system's **scalability**, **maintainability** and **reliability** .

Control System Architecture

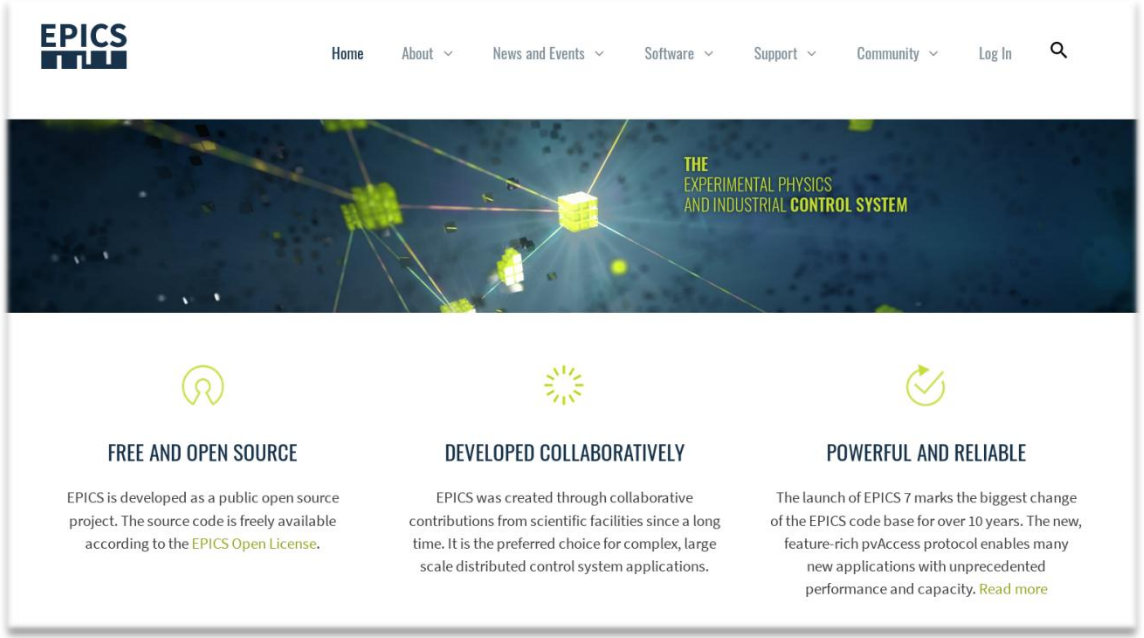
Electrical cabinets	~1,000
Electrical equipments	~10,000
Hardware signals	~100,000
Software signals	~1,000,000

1

- The **architectures**, **protocols** and **standards** are crucial for the design and implementation of large-scale control system **integration**.
- Adopt **mature technologies** and **standardized products** to minimize the R&D costs and timelines, while ensuring system stability and reliability.
- EPICS, TANGO, DOOCS, TINE, MADOCA, as well as commercial SCADA systems.

EPICS

- Experimental Physics and Industrial Control System: Control System **Architecture** + Software **Toolkit** + **Collaboration**
- EPICS is a set of tools and applications which provide a **infrastructure** for use in building distributed control systems.
- EPICS uses **Client/Server** and **Publish/Subscribe** techniques to communicate between the various computers.
- EPICS is developed through a **collaborative** open-source process where anyone is free to contribute to the **community**.
- EPICS is provided under an **open source** license called the EPICS Open License, which is similar to the BSD license.

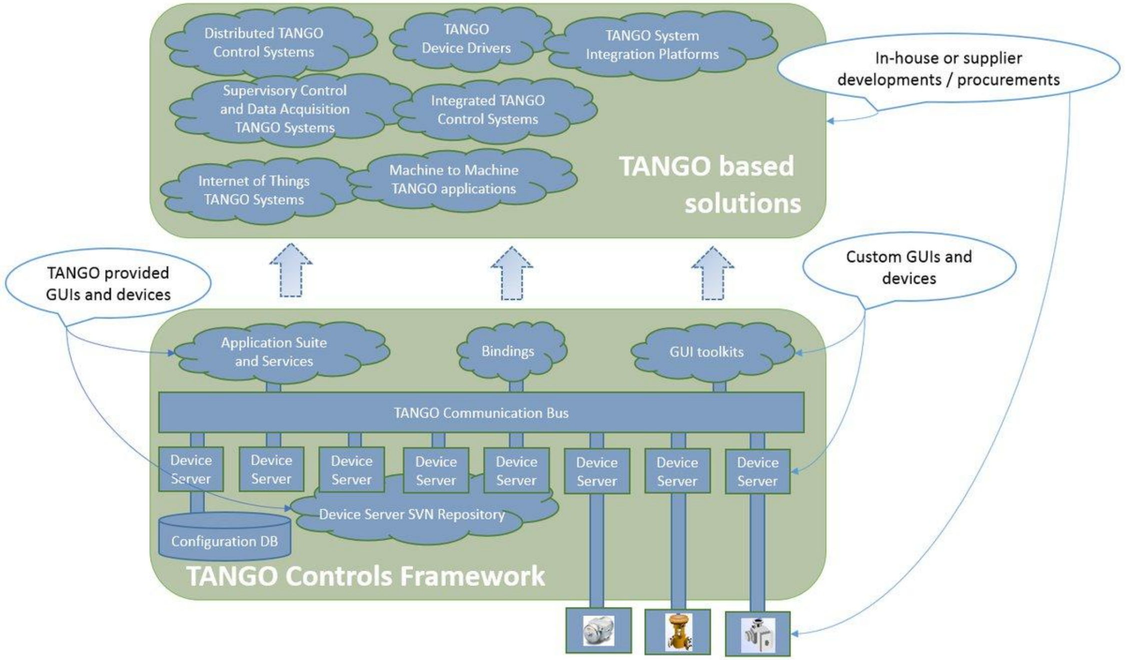


- BEPC, KEKB, RHIC, FRIB
- ESRF, DLS, SSRF, HEPS, HALF
- LCLS-I/II, SwissFEL, SHINE
- SNS, ESS, J-PARC, CSNS
- LIGO, ITER, EAO, ASKAP
- most facilities in Asia

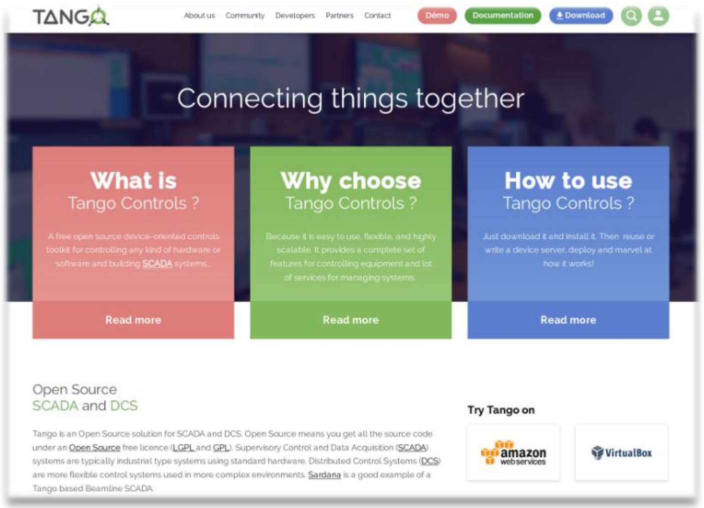
https://epics.anl.gov/
https://epics-controls.org/

Tango Controls

- Tango Controls is a **toolkit** for connecting hardware and software together.
- It is a mature software which is used by tens of sites to run highly complicated accelerator complexes and experiments 24 hours a day.
- It provides full support for C++, Python and Java.
- It is **free** and **open source**. It is ideal for small and large installations.



ESRF, SOLEIL
ELETTRA, ALBA
PETRA III, MAX-IV
ELI, CEA, SKA
...

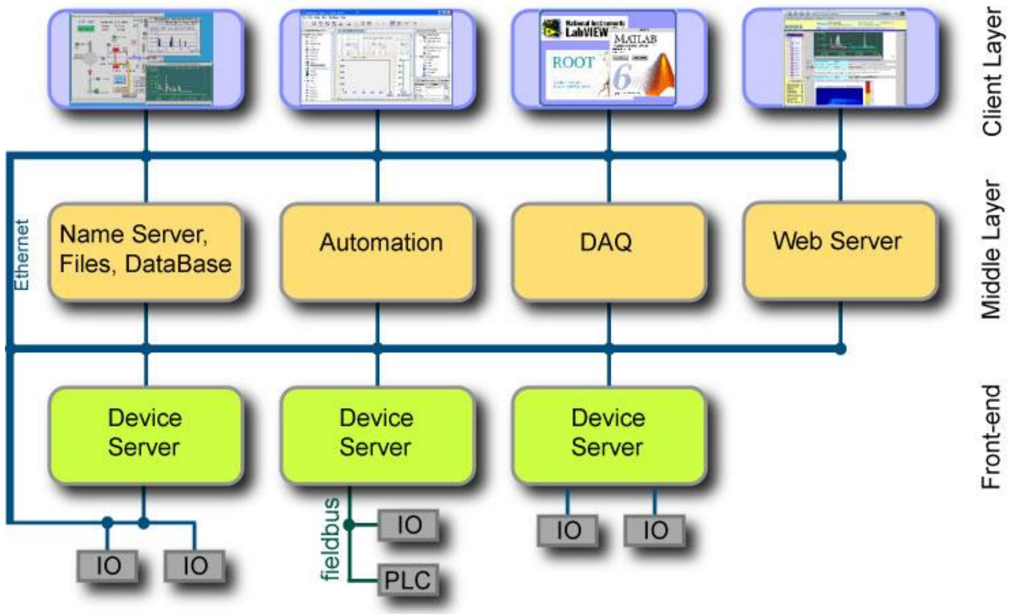


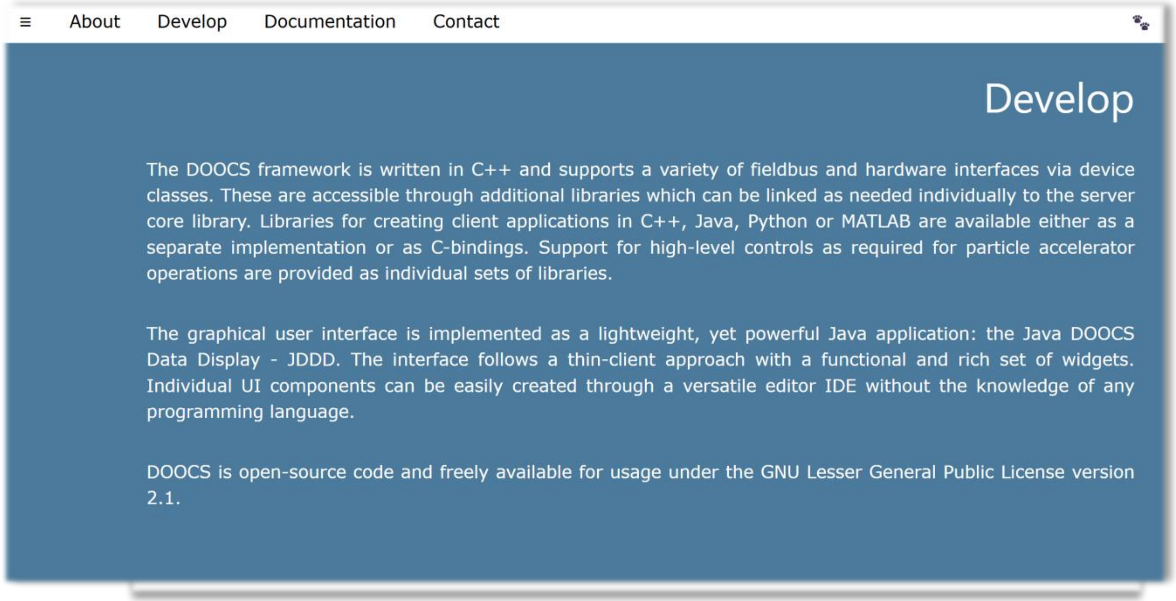
150+ active members
500+ device classes
3 Million lines of code
1 000+ downloads of the core
40+ international partners

https://www.tango-controls.org/

DOOCS

- The **Distributed Object-Oriented Control System** - DOOCS - provides a versatile software framework for creating accelerator-based control system applications.
- DOOCS is based on an distributed client-server architecture combined with a device-oriented view.
- The GUI is implemented as a lightweight, yet powerful Java application: the Java DOOCS Data Display - JDDD.
- DOOCS is **open-source** code and freely available for usage under the GNU Lesser General Public License version 2.1.

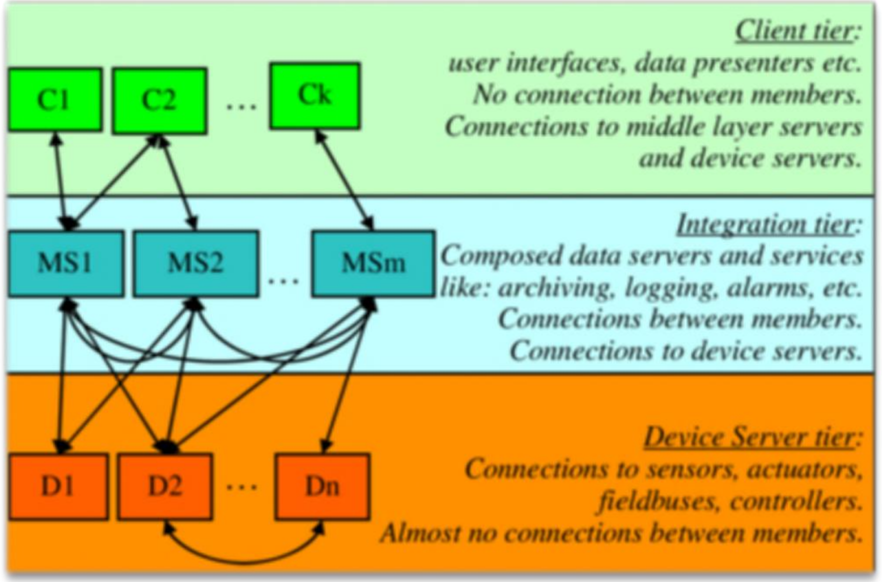


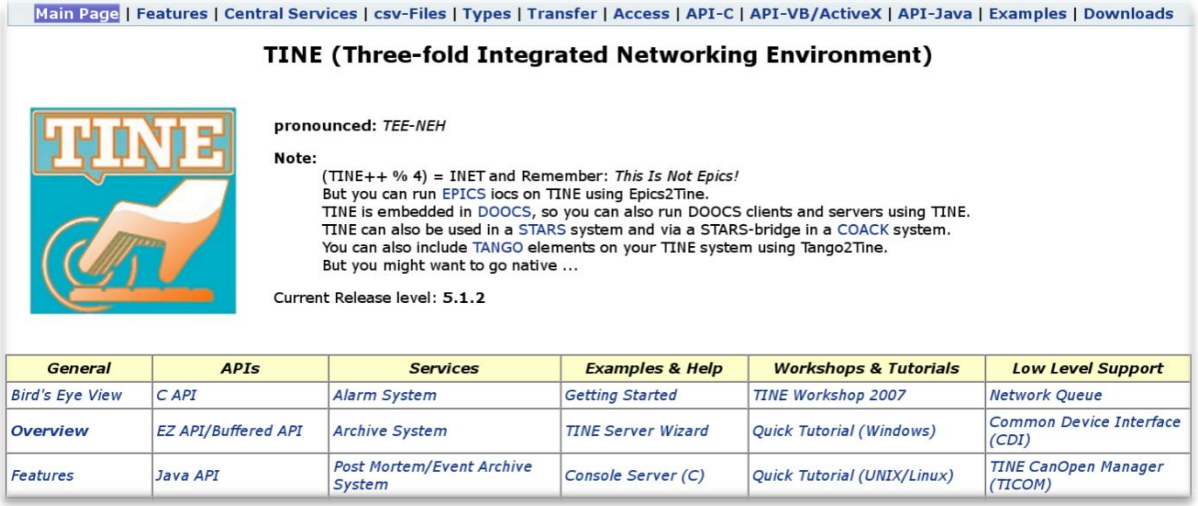


https://doocs-web.desy.de/

TINE

- TINE (**Three-fold Integrated Networking Environment**)
- Multi-platform: MS-DOS, Win16, Win32, UNIX, Linux, VxWorks, …
- Multi-protocol: UDP, TCP, IPX, PIPE, …
- Multi-architecture: Client - Server, Publish - Subscribe, Producer - Consumer, …
- TINE is embedded in DOOCS, users can run DOOCS clients/servers using TINE.
- Users can also include TANGO elements on your TINE system using Tango2Tine.





Main Page | Features | Central Services | csv-Files | Types | Transfer | Access | API-C | API-VB/ActiveX | API-Java | Examples | Downloads

TINE (Three-fold Integrated Networking Environment)

pronounced: *TEE-NEH*

Note:
(TINE++ % 4) = INET and Remember: *This Is Not Epics!*
But you can run EPICS iocs on TINE using Epics2Tine.
TINE is embedded in DOOCS, so you can also run DOOCS clients and servers using TINE.
TINE can also be used in a STARS system and via a STARS-bridge in a COACK system.
You can also include TANGO elements on your TINE system using Tango2Tine.
But you might want to go native ...

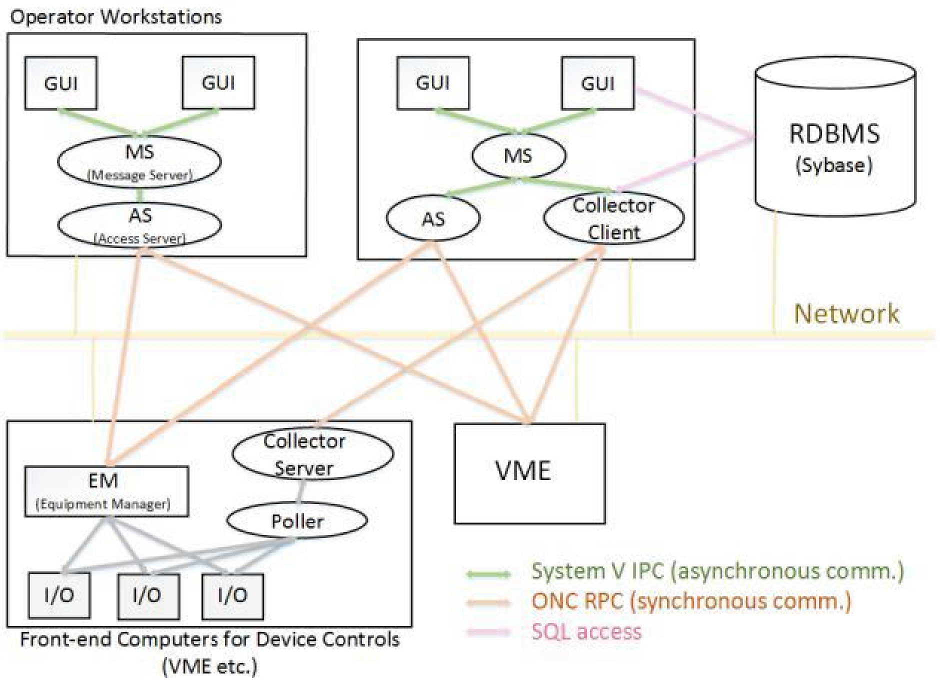
Current Release level: **5.1.2**

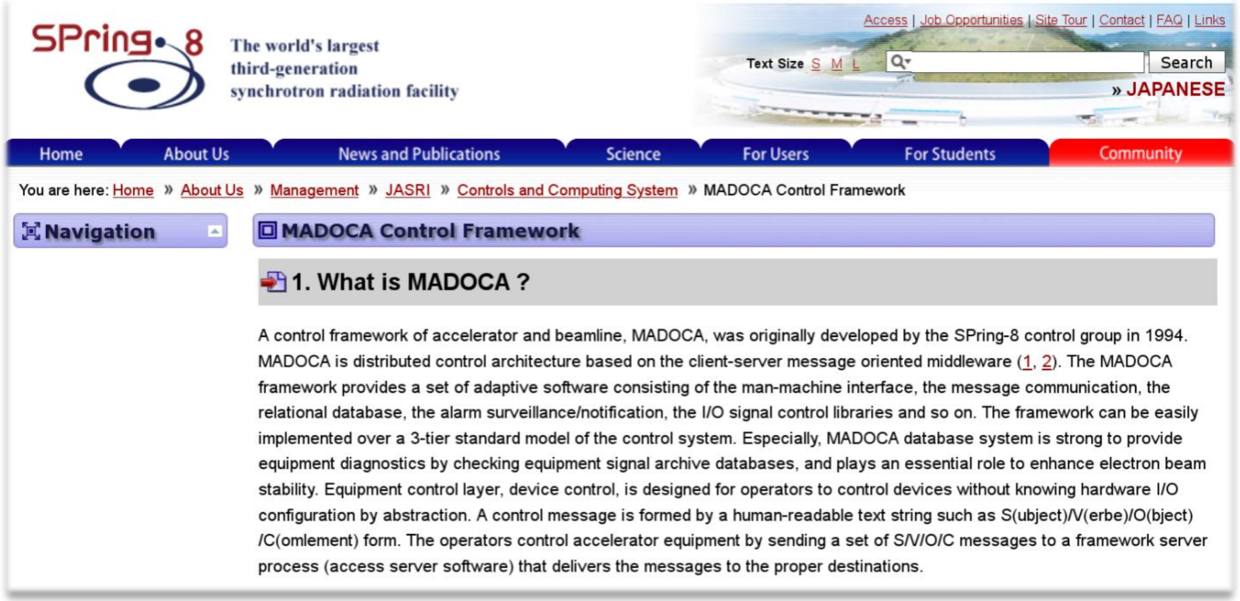
General	APIs	Services	Examples & Help	Workshops & Tutorials	Low Level Support
Bird's Eye View	C API	Alarm System	Getting Started	TINE Workshop 2007	Network Queue
Overview	EZ API/Buffered API	Archive System	TINE Server Wizard	Quick Tutorial (Windows)	Common Device Interface (CDI)
Features	Java API	Post Mortem/Event Archive System	Console Server (C)	Quick Tutorial (UNIX/Linux)	TINE CanOpen Manager (TICOM)

http://tine.desy.de/

MADOCA

- MADOCA (**Message and Database Oriented Control Architecture**) is a control system framework originally developed at SPring-8.
- It has been utilized for control systems in various accelerator facilities, including SACLA, NewSUBARU and HiSOR.
- The framework consists of the Message Server (MS), Access Server (AS), and Equipment Manager (EM).

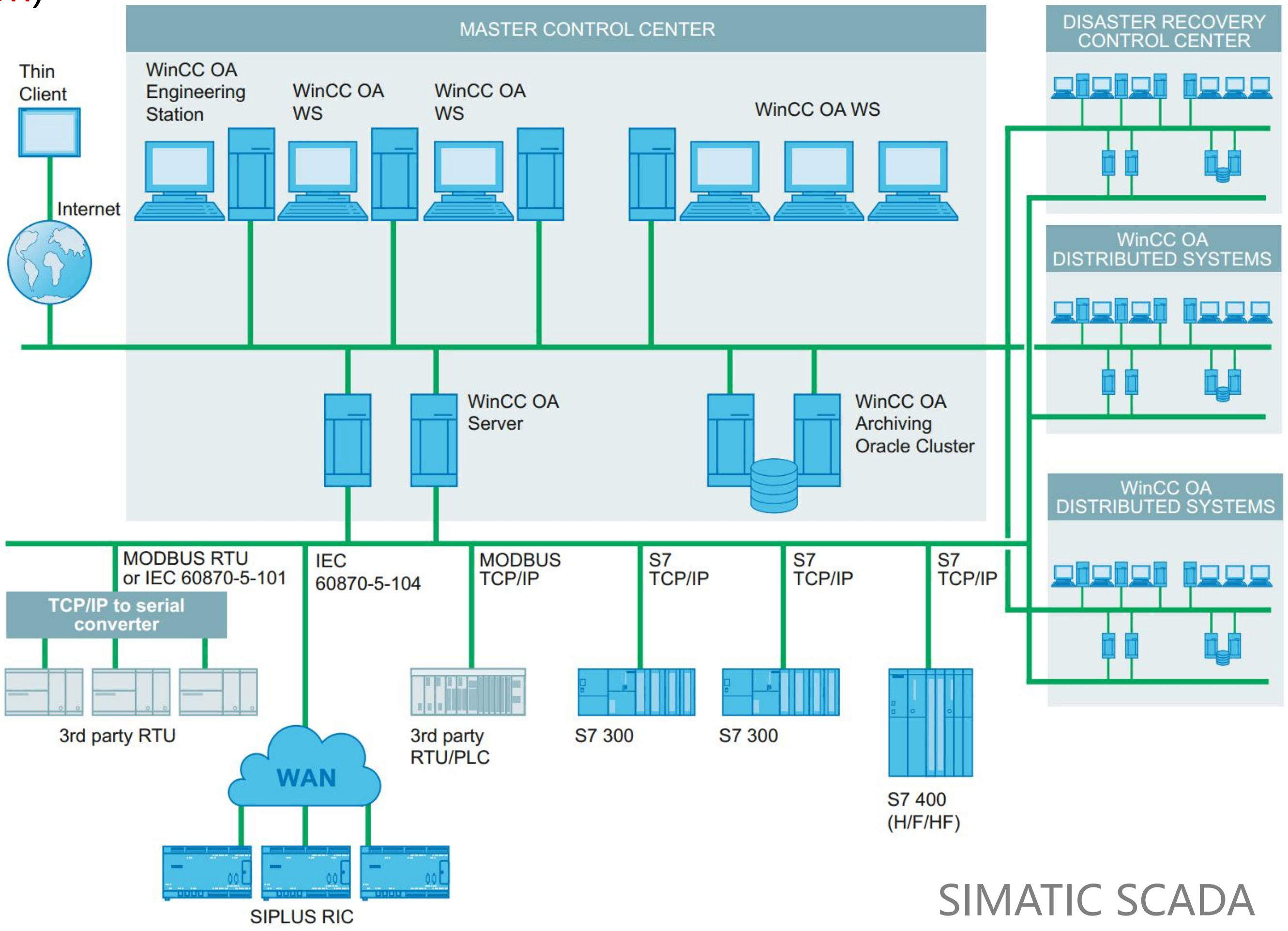




http://www.spring8.or.jp/en/about_us/manage_structure/jasri/control_system/madoca/

Commercial SCADA

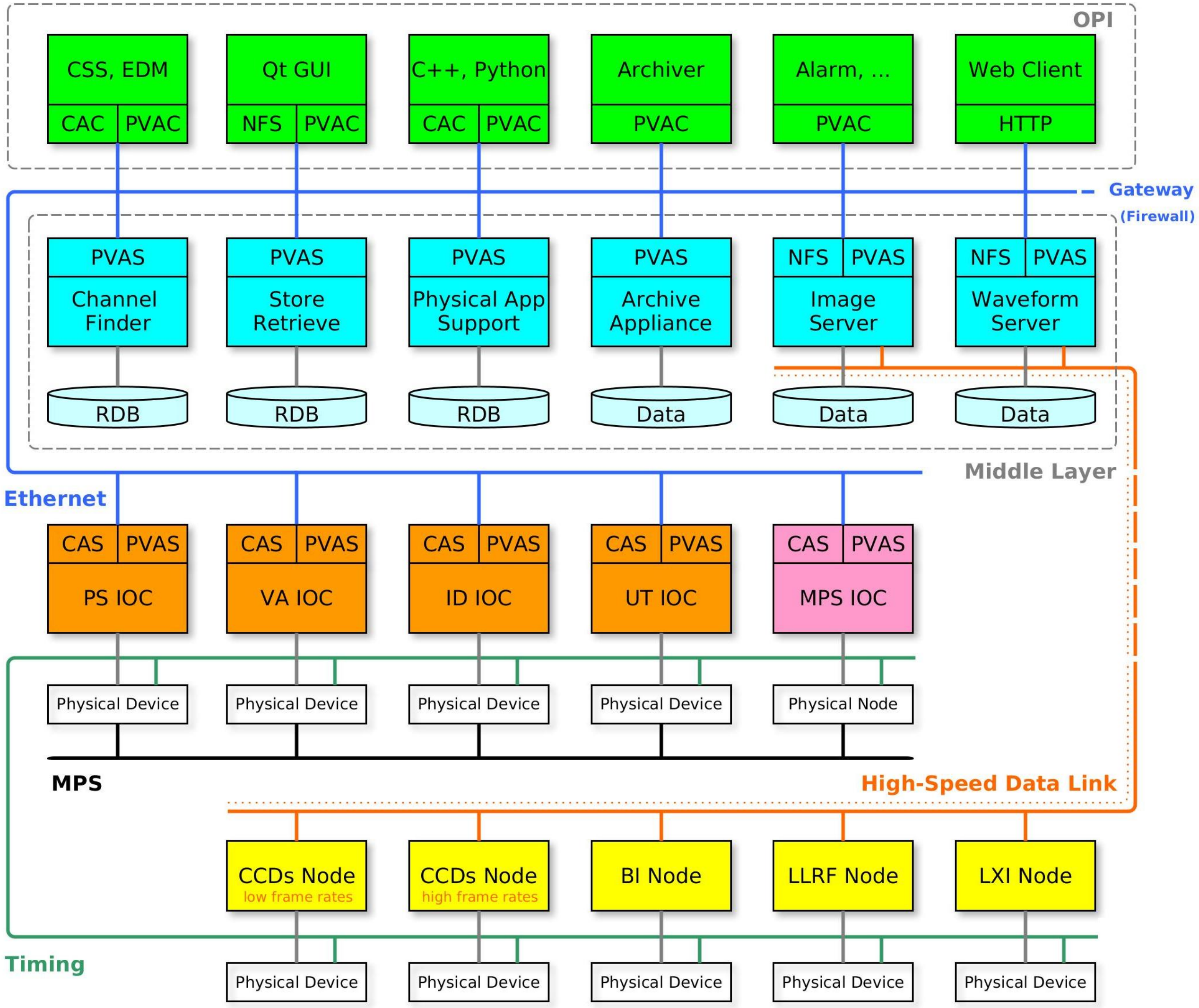
- SCADA (Supervisory Control and Data Acquisition) systems are essential for monitoring and controlling industrial processes across various sectors, including power, metallurgy, chemical industry, and railways.
- For the large accelerators, integration and management of SCADA systems can be challenging.



SIMATIC SCADA

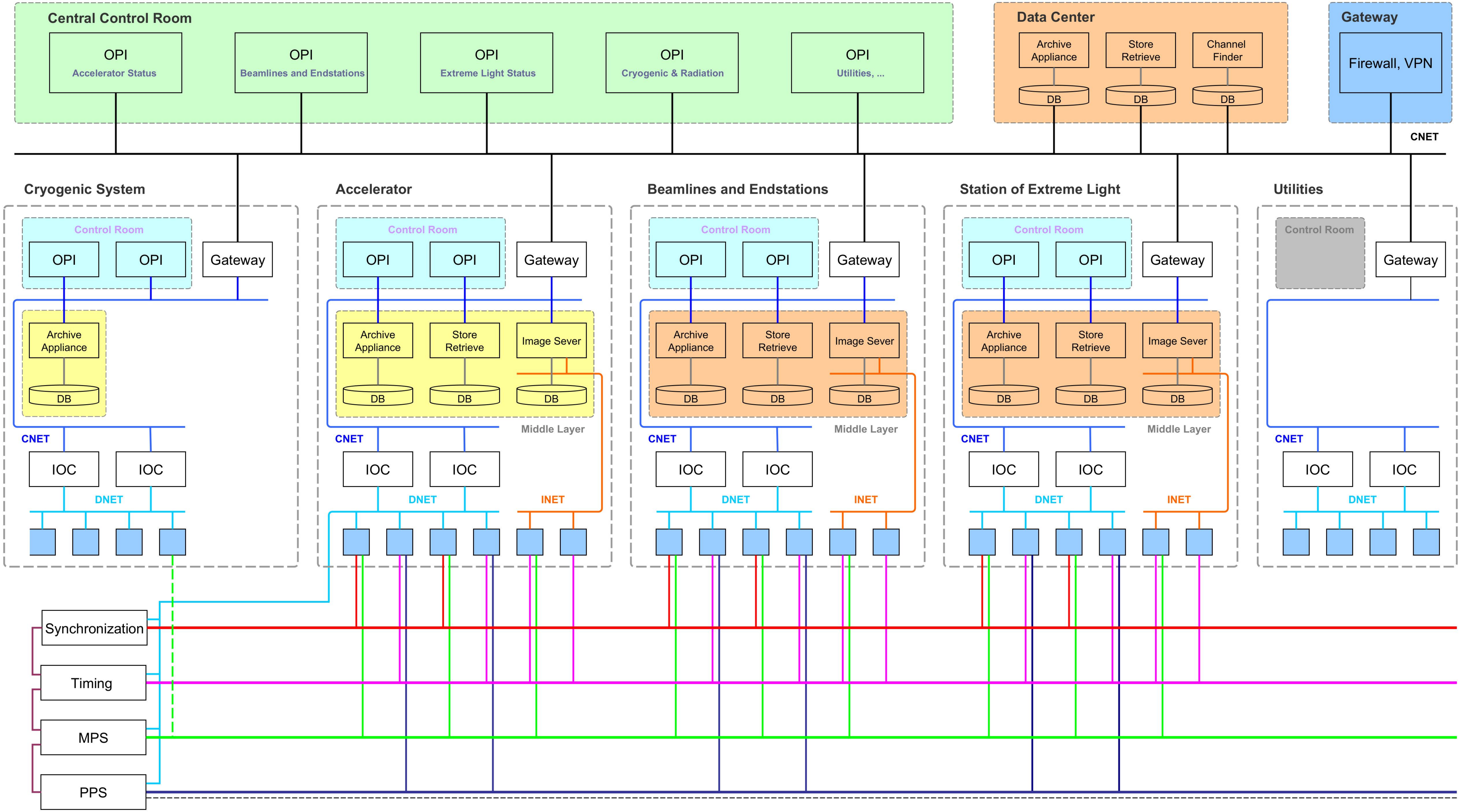
SHINE Accelerator Control System

- Network
- Control Platform
- Device Control
- Data Acquisition
- Machine Protection
- Timing System
- Feedback System
- Data Storage
- User Interface
- High Level Software
- Control Rooms
- ...



Open source large-scale distributed control system, EPICS V7 + White Rabbit

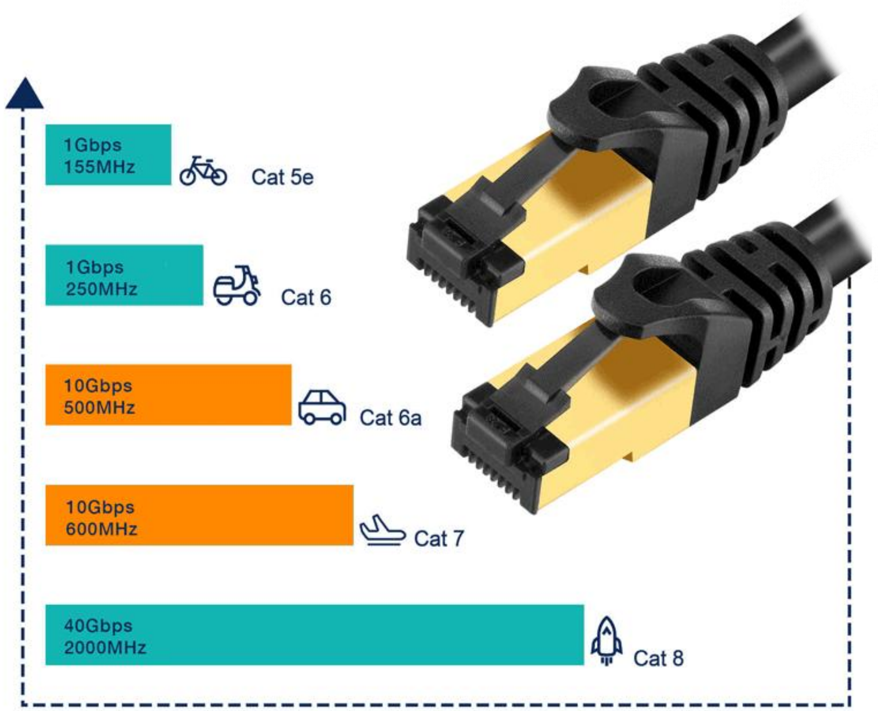
SHINE Control System



Interface & Protocol

Ethernet

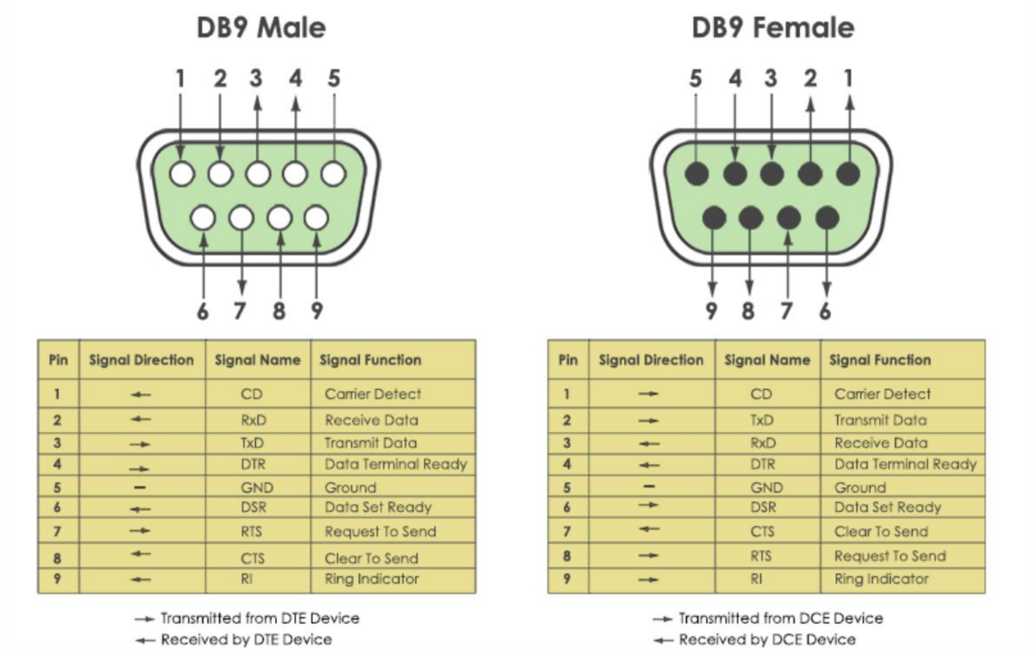
- Ethernet is a widely used wired networking technology that connects devices in a **Local Area Network (LAN)** or Wide Area Network (WAN).
- Physical Connection
  - Uses twisted-pair cables or fiber optics
  - Connects via **RJ45** ports or **SFP** ports
- Speed & Performance
  - Ranges from 10 Mbps to 400 Gbps (latest standards)
  - Common speeds: **1 Gbps**, **10 Gbps**, **25 Gbps**
- Topology
  - Traditionally used a bus topology (old coaxial cables)
  - Modern Ethernet uses **star topology** (central switch)
  - **Ring topology** is used by some small facilities



https://storage.googleapis.com/dufgkmmlknqvre/what-type-of-ethernet-cable-do-i-need-for-poe.html

Serial

- RS232 (**Recommended Standard**) is an old **serial communication protocol** developed by EIA (Electronics Industry Alliance) / TIA (Telecommunications Industry Association) in 1962.
- RS232 describes the common voltage levels, electrical standards, operation mode and number of bits to be transferred from transmitter to receiver.



Pin	Signal Direction	Signal Name	Signal Function
1	←	CD	Carrier Detect
2	←	RxD	Receive Data
3	→	TxD	Transmit Data
4	→	DTR	Data Terminal Ready
5	–	GND	Ground
6	←	DSR	Data Set Ready
7	→	RTS	Request To Send
8	←	CTS	Clear To Send
9	←	RI	Ring Indicator

→ Transmitted from DTE Device
← Received by DTE Device

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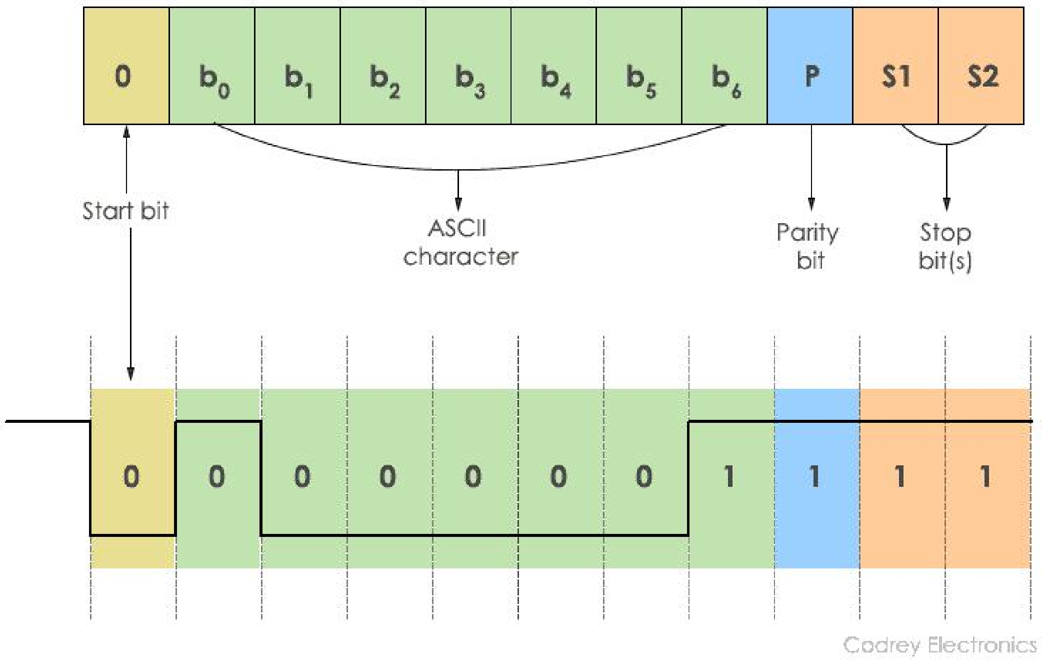
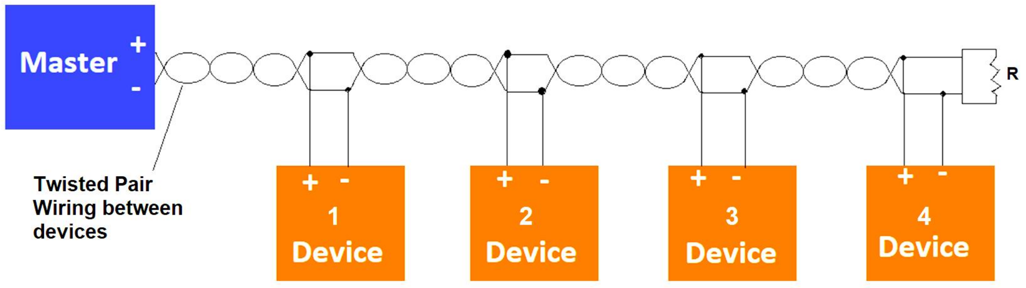


https://www.codrey.com/embedded-systems/rs232-serial-communication/

Serial

- **RS422** is designed for **faster** data transmission over **longer** distances compared to RS232.
- RS485 can be considered an upgraded version of RS422, allowing one device to control up to 32 devices. It became the **standard physical layer** for automation protocols such as **Modbus RTU** and **Profibus**.



RS 422 / RS 485 Multi Drop Network Connection

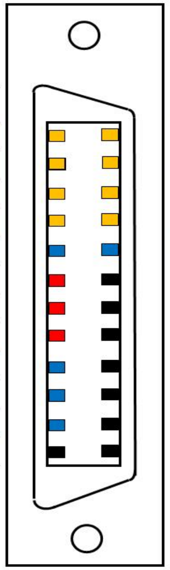
Port name	RS-232	RS-422	RS-485
Transfer type	Full duplex	Full duplex	Half duplex (2 wires), full duplex (4 wires)
Maximum distance	15 meters at 9600 bps	1200 meters at 9600 bps	1200 meters at 9600 bps
Contacts in use	TxD, RxD, RTS, CTS, DTR, DSR, DCD, GND*	TxA, TxB, RxA, RxB, GND	DataA, DataB, GND
Topology	Point-to-Point	Point-to-Point	Multi-point
Max. Number of connected devices	1	1 (10 devices in receive mode)	32 (with repeaters larger, usually up to 256)

https://ipc2u.com/articles/knowledge-base/the-main-differences-between-rs-232-rs-422-and-rs-485/

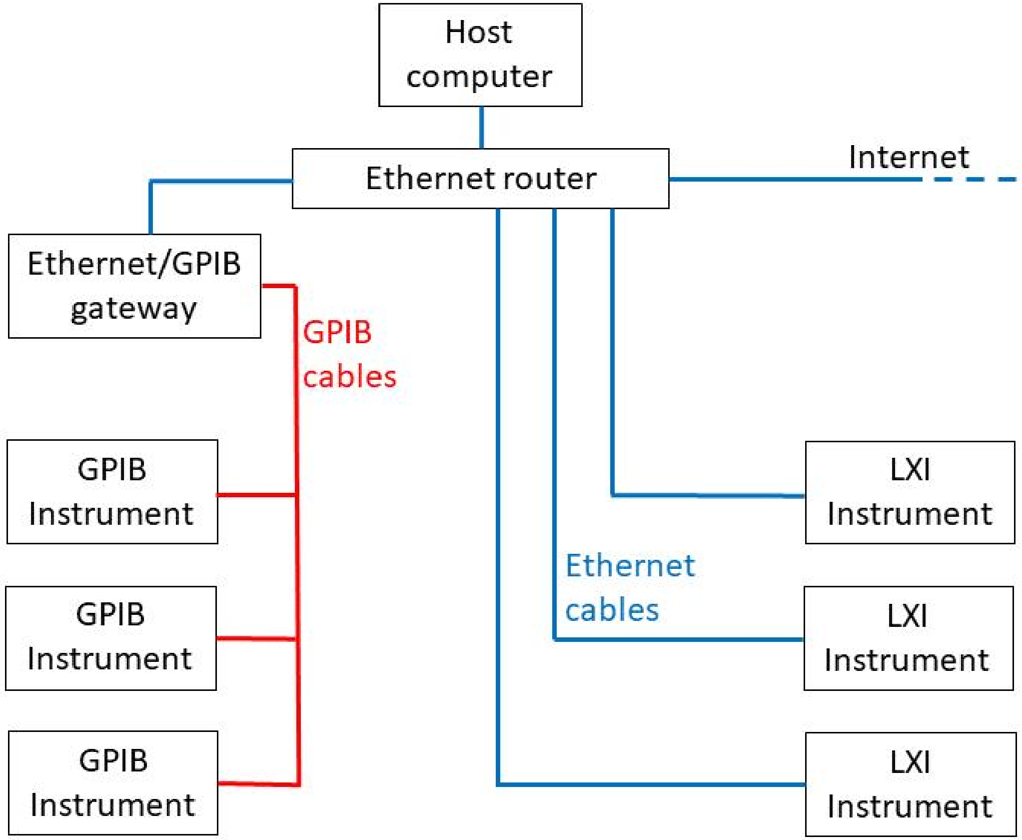
GPIB

- GPIB (General Purpose Interface Bus), also known as IEEE-488, is a digital communication standard developed in the 1960s for connecting and controlling test and measurement instruments (e.g., oscilloscopes, multimeters) to computers.
- It was the dominant interface for lab automation before Ethernet (LXI) and USB.

Description	Pin	No.
Data I/O	DIO1	1
Data I/O	DIO2	2
Data I/O	DIO3	3
Data I/O	DIO4	4
End-or-identify	EOI	5
Data valid	DAV	6
Not ready for data	NRFD	7
Not data accepted	NDAC	8
Interface clear	IFC	9
Service request	SRQ	10
Attention	ATN	11
Shield	SHIELD	12



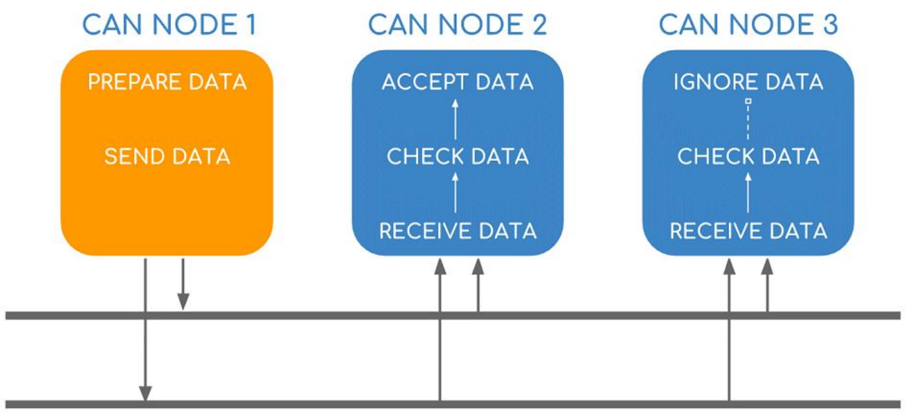
No.	Pin	Description
13	DIO5	Data I/O
14	DIO6	Data I/O
15	DIO7	Data I/O
16	DIO8	Data I/O
17	REN	Remote enable
18	GND	DAV ground
19	GND	NRFD ground
20	GND	NDAC ground
21	GND	IFC ground
22	GND	SRQ ground
23	GND	ATN ground
24	GND	Logic ground

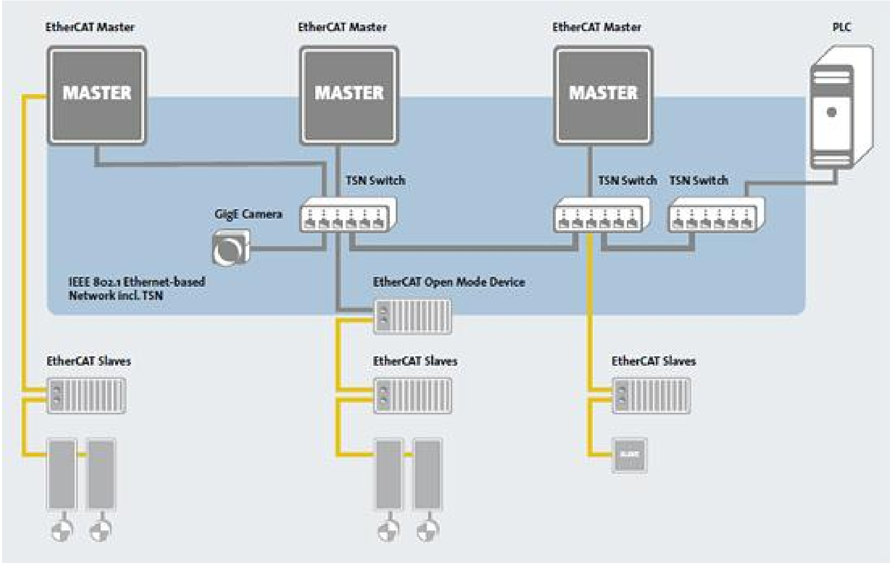


https://www.testandmeasurementtips.com/what-is-gpib-and-is-it-obsolete/

Fieldbus

- Fieldbus is a a member of a family of **industrial digital communication networks** used to connect automation devices (sensors, actuators, PLCs, controllers).
- **PROFIBUS** (Process Field Bus)
  - Developed by: Siemens
  - Speed: Up to 12 Mbps (PROFIBUS DP)
- **CAN** Bus (Controller Area Network)
  - Robust, low-cost, peer-to-peer communication
- **EtherCAT** (Ethernet for Control Automation Technology)
  - Ultra-Fast Industrial Ethernet
  - Speed: Up to 100 Mbps with real-time performance
- …

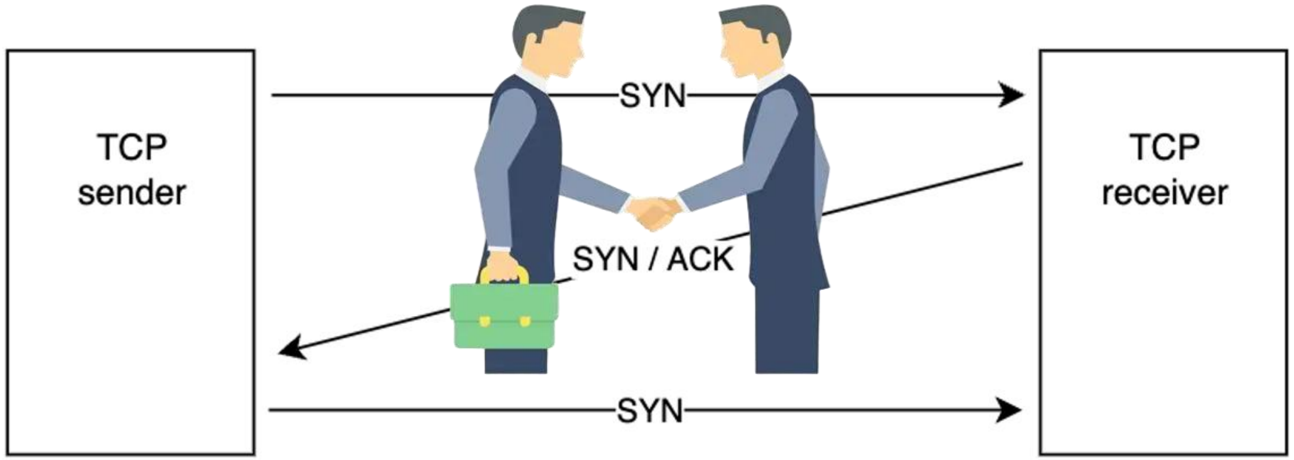




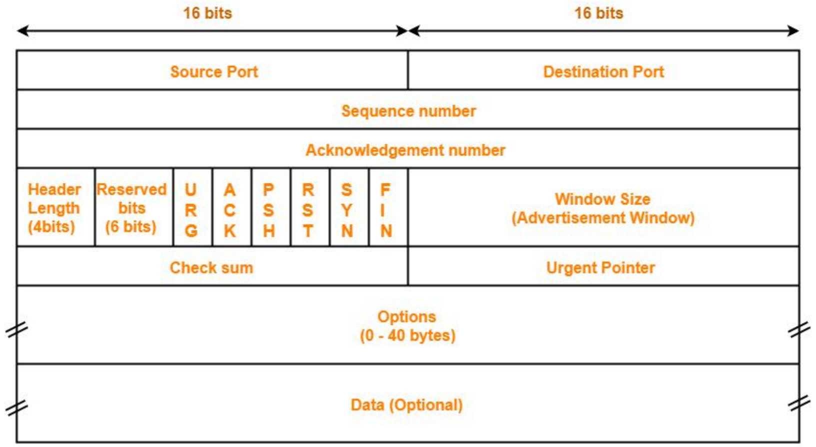
https://store.chipkin.com/articles/can-bus-protocol-10-minute-lesson
https://www.ethercat.org/en/ethercat_and_tsn.htm

TCP

- **Transmission Control Protocol** is one of the core protocols of the Internet Protocol Suite (TCP/IP).
- Connection-Oriented – Establishes a **handshake** before data transfer.
- Reliable Delivery – Uses acknowledgments (ACKs) and retransmissions if packets are lost.
- Flow Control – Prevents sender from overwhelming receiver (sliding window mechanism).
- Error Detection – Uses checksums to detect corrupted data.
- Ordered Data Transfer – Ensures packets arrive in the correct sequence.



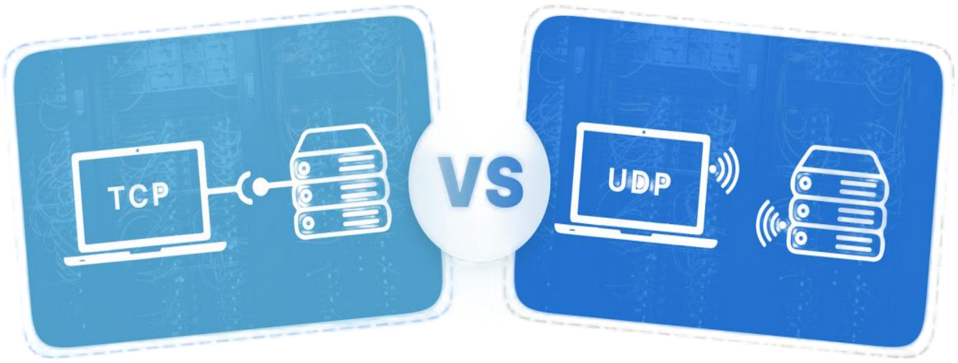
TCP 3 way handshake



TCP Header

UDP

- **User Datagram Protocol** doesn't establish a connection before sending data, **faster** but less reliable.
- Connectionless – No handshake (SYN/ACK), just sends data.
- Low Latency – Minimal overhead, ideal for real-time apps.
- No Guaranteed Delivery – No retransmissions if packets are lost.
- No Ordering – Packets may arrive out of sequence.
- Supports **Broadcast / Multicast** – Can send data to multiple devices at once.



Factor	TCP	UDP
Guarantees frame delivery	**Yes**	No
Acknowledgment used	Yes	No
Connectionless	No	Yes
Used when fast transmissions are required	No	Yes
Common TCP and UDP ports	DNS, HTTP, HTTPS, FTP, SMTP, Telnet	DNS, DHCP, TFTP, SNMP, RIP, VOIP

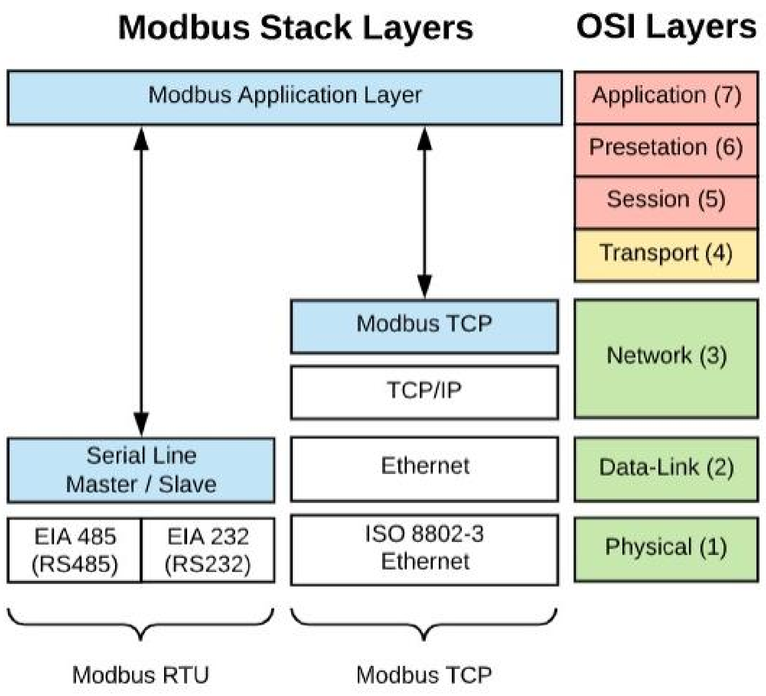
https://www.gumlet.com/learn/tcp-vs-udp/

https://www.netally.com/network-performance/tcp-vs-udp/

Modbus

- Modbus is a **serial communication protocol** developed for industrial automation in 1979.
- It enables communication between electronic devices over **RS-232**, **RS-485**, or **Ethernet** (TCP/IP).
- Open Standard – Free to use, **widely** adopted in industrial systems.
- Master-Slave Architecture – One master device controls multiple slaves.
- Supports Multiple Variants – **Modbus RTU**, **ASCII**, **TCP**, …
- Simple & Lightweight – Easy to implement.

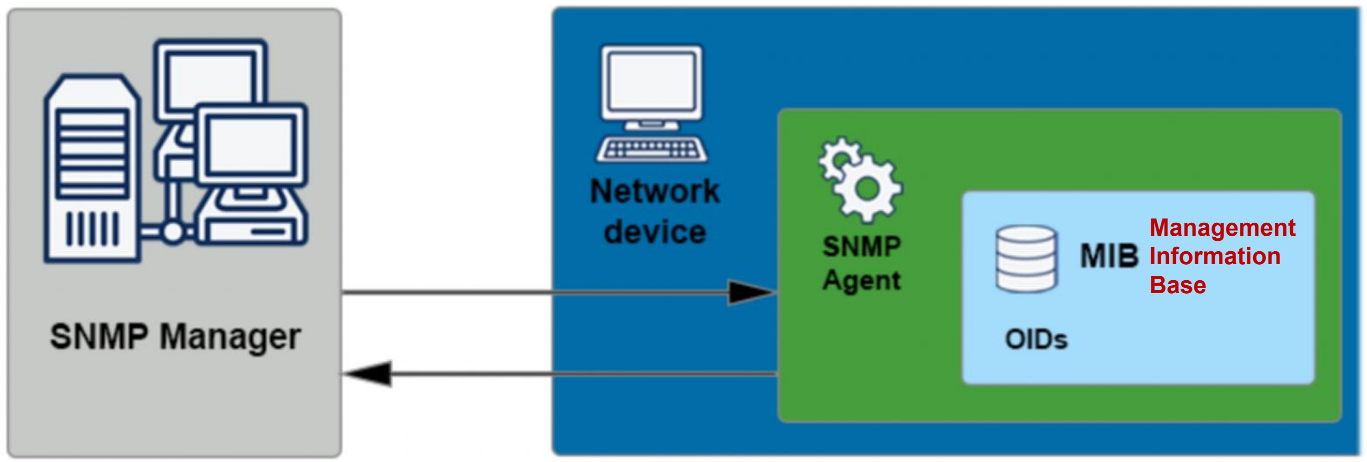
Type	Description	Physical Layer
Modbus RTU	Binary encoding, compact & fast	RS-485 / RS-232
Modbus ASCII	Human-readable (hexadecimal format).	RS-485 / RS-232
Modbus TCP	Runs over Ethernet (TCP/IP)	Ethernet (RFC 1006)
Modbus Plus (MB+)	Proprietary high-speed version.	Token-passing network

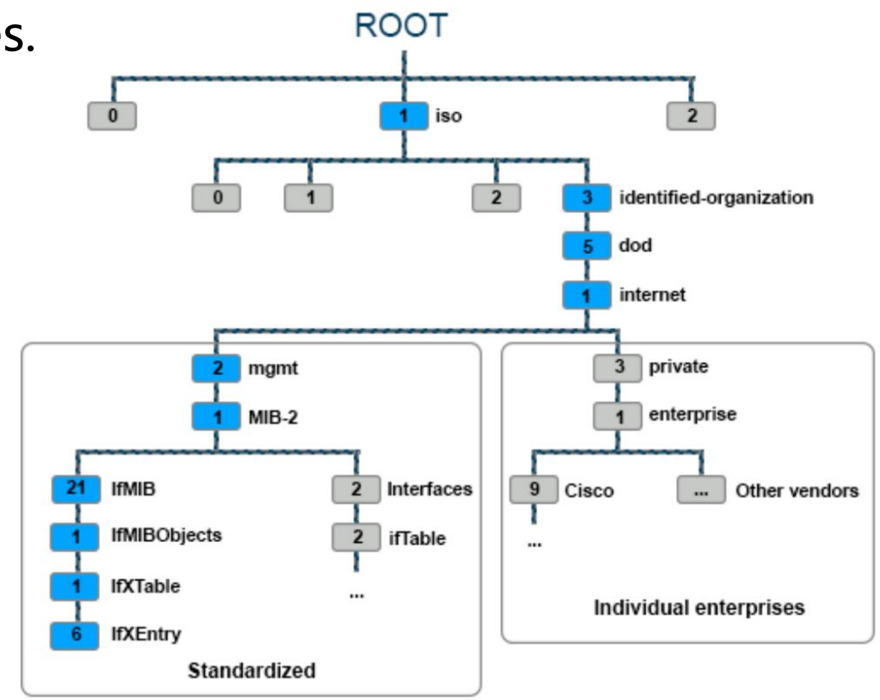


https://store.chipkin.com/articles/different-types-of-modbus-such-as-rtu-tcp-etc

SNMP

- SNMP (**Simple Network Management Protocol**) is a standardized **protocol** used to monitor and manage **network devices** (switches, routers, servers, IoT devices, etc).
- Device Monitoring – Tracks bandwidth, CPU usage, memory, etc.
- Fault Detection – Alerts when issues occur (e.g., high temperature, link down).
- Remote Configuration – Changes settings on network devices.
- Scalable – Works in small LANs or large enterprise networks.

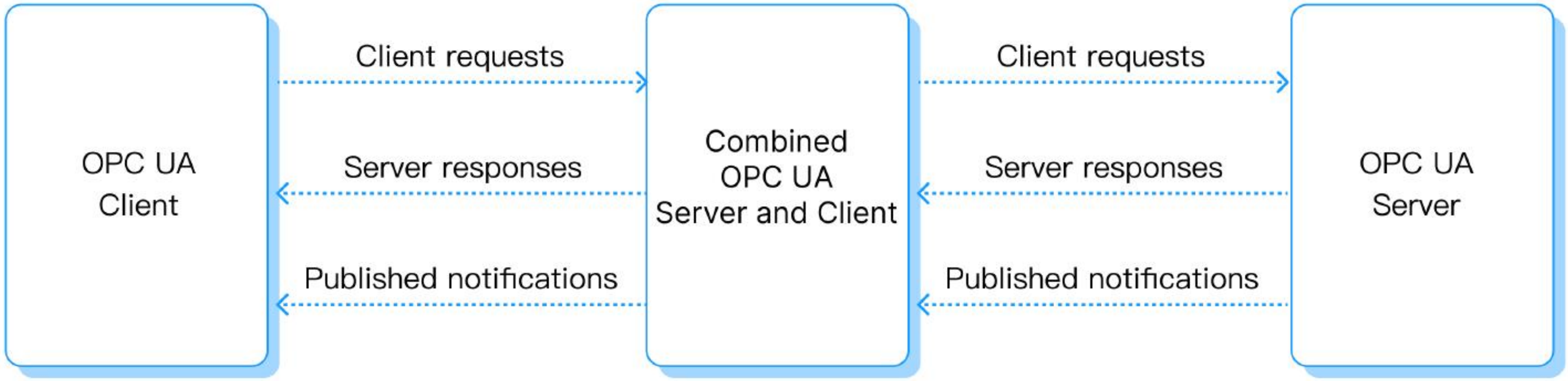




https://phoenixnap.com/kb/what-is-snmp

OPC UA

- OPC UA (**Open Platform Communications Unified Architecture**) is a communication **protocol** designed for industrial automation.
- Unlike traditional OPC which relied on Windows COM/DCOM, OPC UA is **platform-independent**, secure, and scalable, making it ideal for **Industry 4.0** and **IoT** applications.
- Platform-Independent – Runs on Windows, Linux, embedded systems, and cloud.
- Transport Protocols – **OPC UA TCP**, **HTTPS/WebSockets**, **MQTT** (For lightweight IoT scenarios)



OPC Unified Architecture

https://www.emqx.com/en/blog/opc-ua-protocol

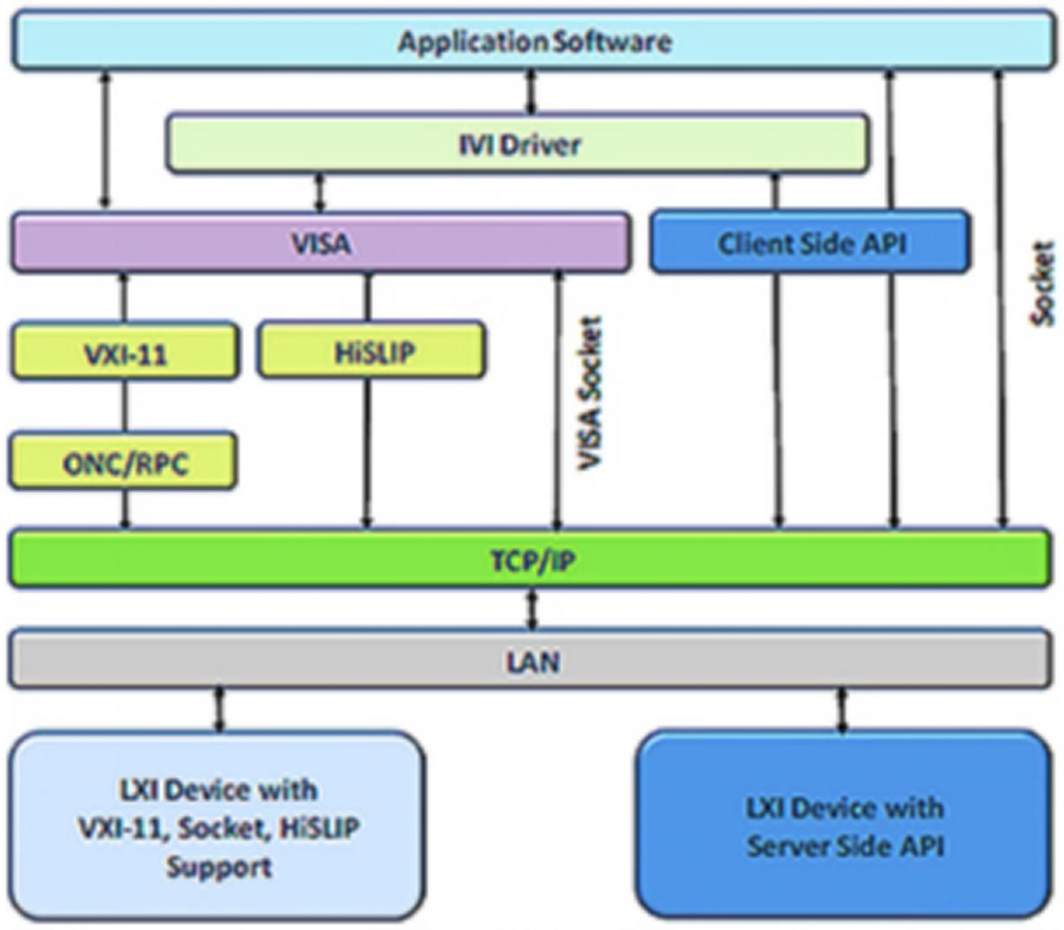
VXI-11

- VXI-11 is a standard **Ethernet-based** protocol for controlling test and **measurement instruments** (e.g., oscilloscopes, power supplies) over a LAN.
- It is part of the VXI (**VME eXtensions for Instrumentation**) standard and serves as an open, network-friendly alternative to GPIB (IEEE-488).

```python
import vxi11 # 导入vxi11包

def main():
    HOST = '192.168.0.100' # IP地址
    instr = vxi11.Instrument(HOST) # 连接仪器
    res = instr.ask('*idn?') # 发送询问指令
    print(res)

if __name__ == '__main__':
    main()
```

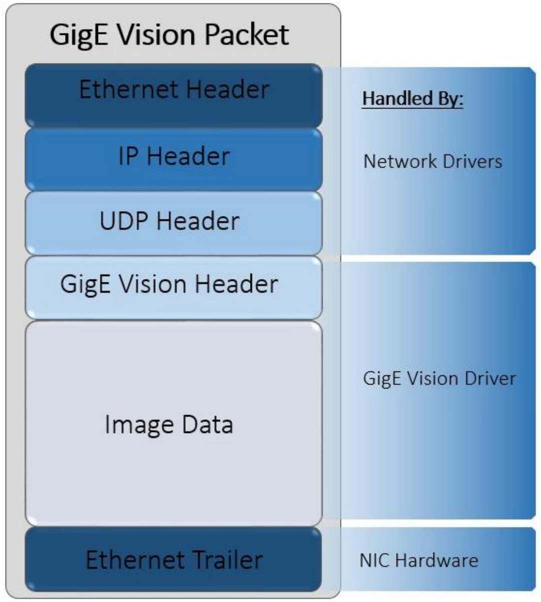


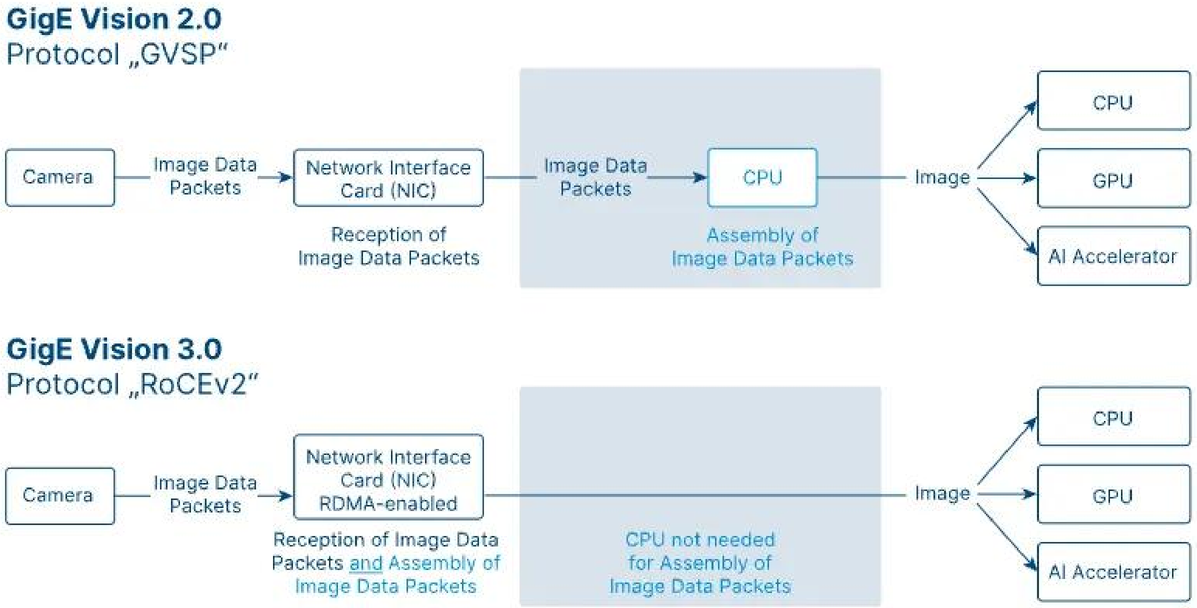
VISA：Virtual Instrument Software Architecture

https://lxistandard.org/

GigE Vision

- GigE Vision is a standardized protocol for **high-speed camera** communication over Gigabit Ethernet (**GigE**), widely used in industrial imaging, machine vision, and robotics.
- High Speed – Uses Gigabit Ethernet (**1 Gbps**) or 10 GigE (**10 Gbps**) for fast image transfer.
- Standardized – Managed by the Automated Imaging Association (AIA).
- **PoE** Support – **Power over Ethernet** (IEEE 802.3af/at) for single-cable operation.



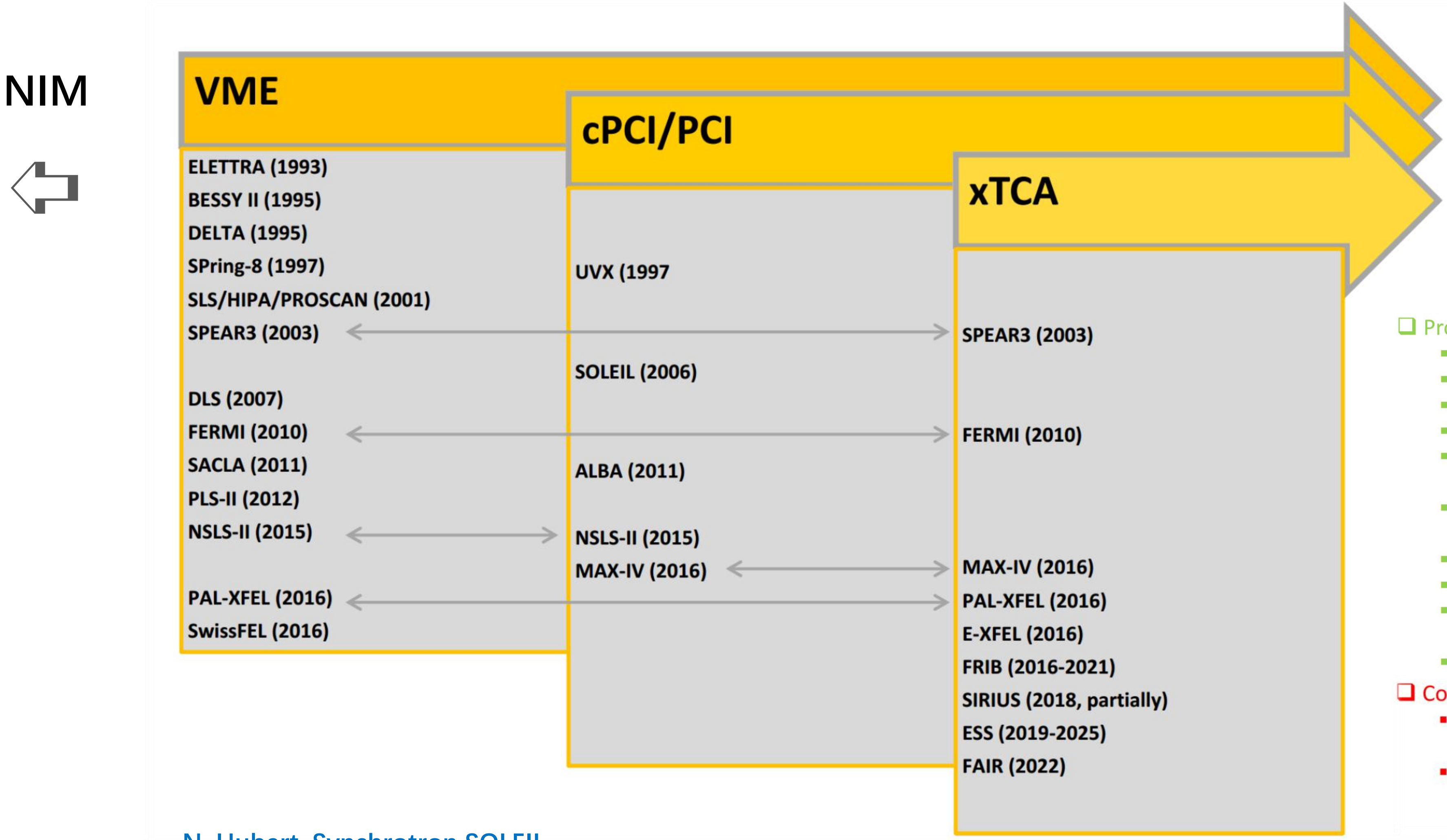


https://www.ni.com/

https://www.baslerweb.com/en/learning/gige-vision-3-0/

Hardware Platform

Hardware Platform

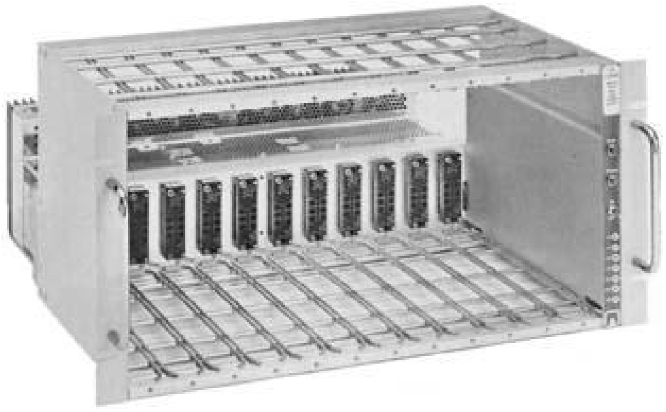


- Pros:
  - Integration
  - Maintenance and long term support
  - Management and control
  - Availability from industry
  - Standard boards: CPU, ADC, power supplies.
  - Wider user community (possible collaborations)
  - Reliability (if mature): long MTBF
  - Modularity: small MTTR
  - Redundancy (if supported by the standard)
  - Cost
- Cons:
  - Volume and cost for small application
  - Performances (bandwidth, bus speed sometimes limited for older standards)

N. Hubert, Synchrotron SOLEIL

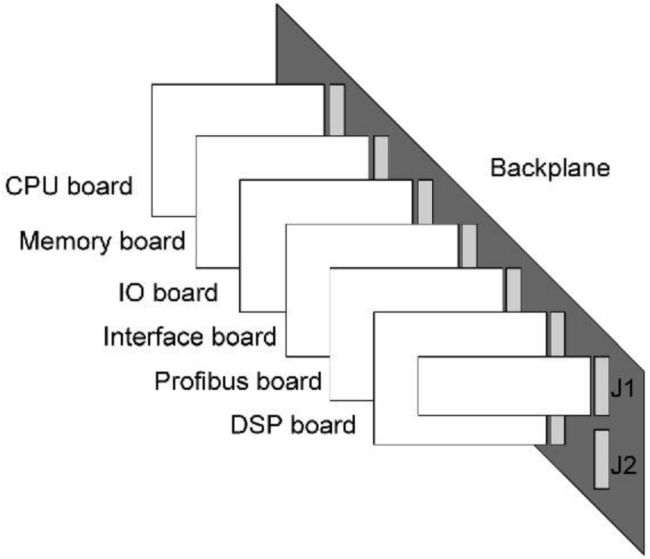
NIM

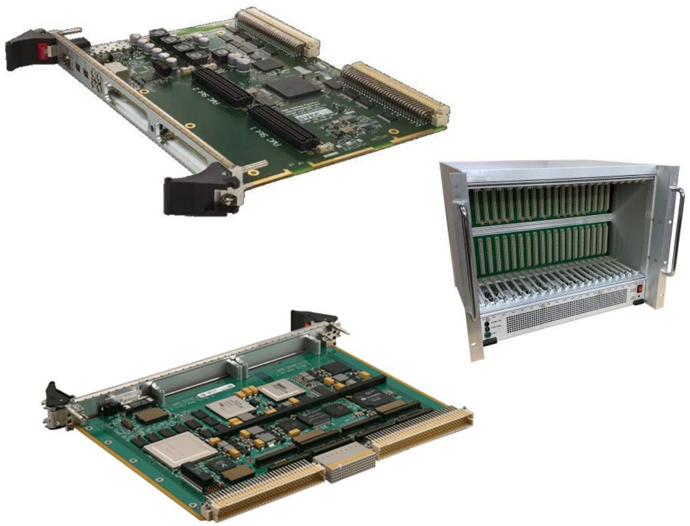
- NIM (**Nuclear Instrumentation Module**) is the oldest and simplest nuclear electronics standard.
- Standardized Mechanical & Electrical Specs
- Modular Design – Plug-in modules for signal processing (amplifiers, ADCs, etc.).
- Analog & Digital Signals – Supports both low-voltage analog and logic-level digital signals.
- Power Supply Standard – Provides ±12V, ±24V, and +6V DC to modules.
- Widely Used in Nuclear/Physics Labs – Found in radiation detectors, particle accelerators …

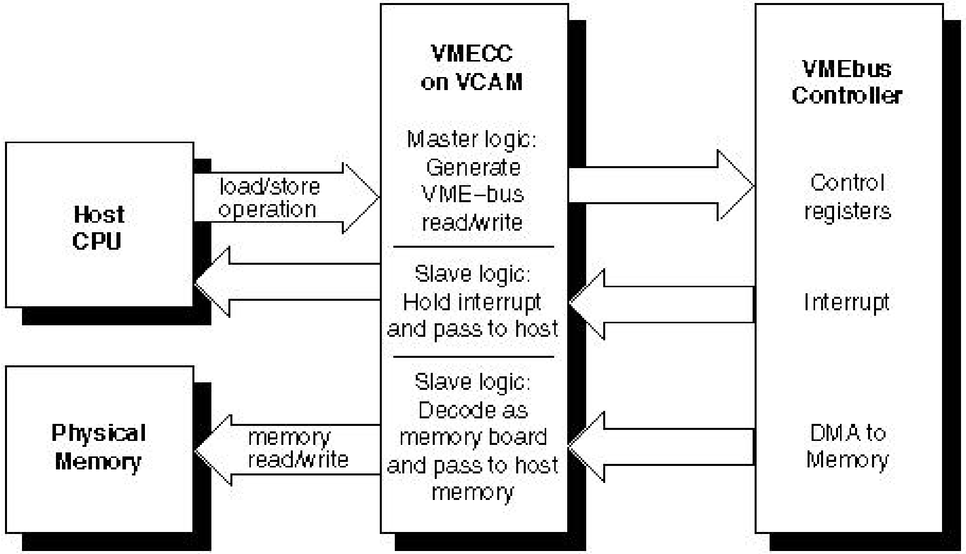


VME

- VME (**VERSA Module Eurocard**) initially developed starting in 1981, provides a **backplane-based** architecture for integrating processors and I/O modules, and instrumentation.
- High Reliability – Designed for industrial, aerospace, and defense use.
- Modular Design – Supports **6U** (160mm × 233mm) and **3U** (100mm × 160mm) Eurocard modules.
- **Parallel Bus Architecture** – 32-bit data/address bus (**VME32**) or 64-bit (**VME64x**).
- Standardized – IEEE 1014 (VME32), ANSI/VITA 1 (VME64x).

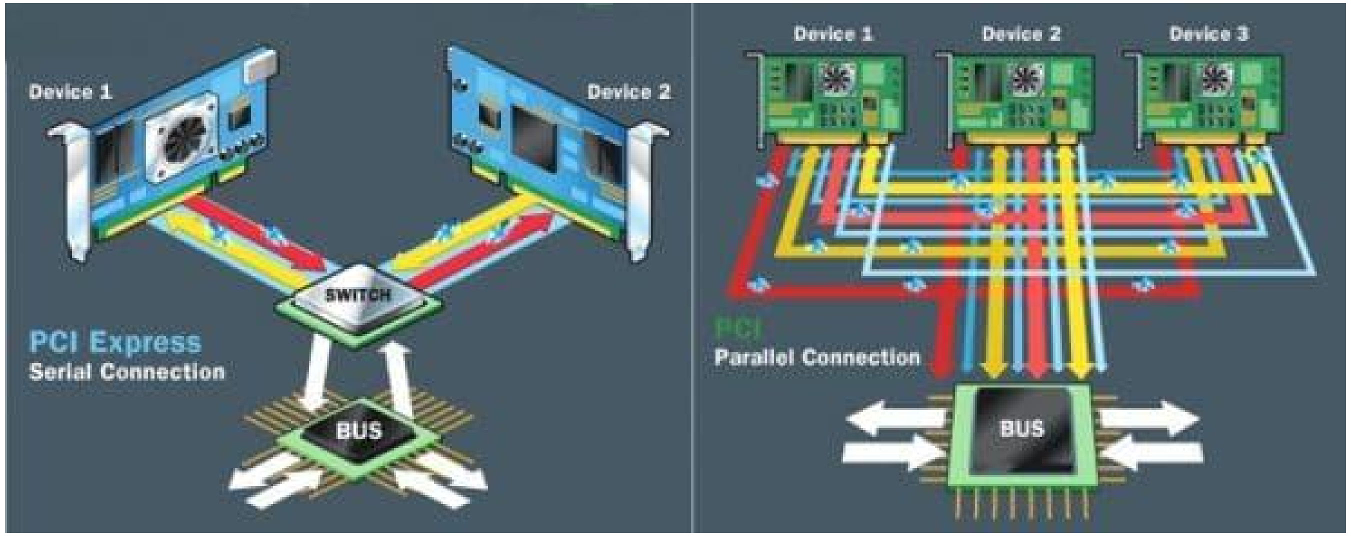


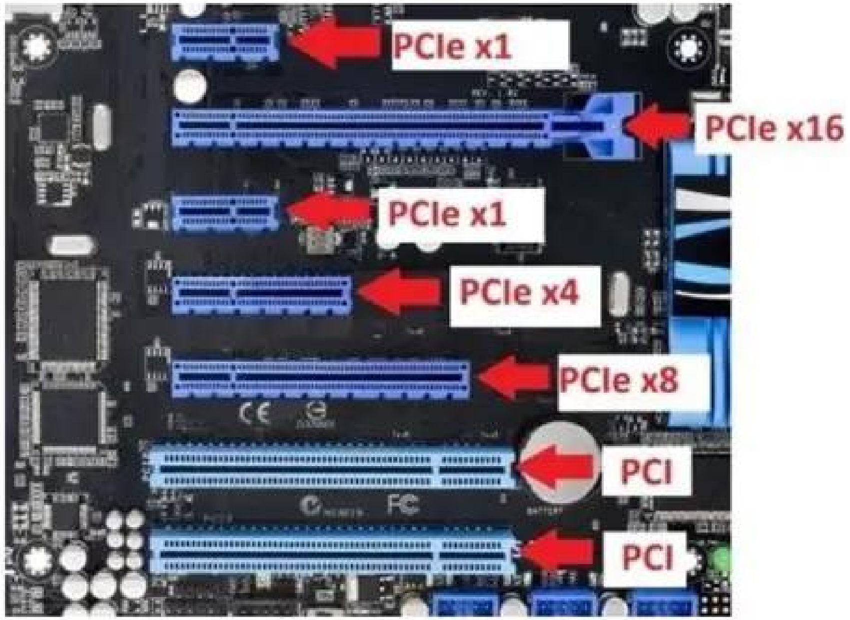




PCIe

- PCIe (**Peripheral Component Interconnect Express**) is a high-speed **serial bus standard** used to connect hardware devices (GPUs, SSDs, NICs) to a computer's motherboard.
- It replaced older **PCI** buses, offering higher bandwidth, lower latency, and scalability.
- High Speed – From 250 MB/s (Gen1 x1) to ~64 GB/s (Gen5 x16).
- **Serial** Point-to-Point – No bus contention (unlike **parallel PCI**).
- Scalable Lanes – x1, x4, x8, x16 configurations.

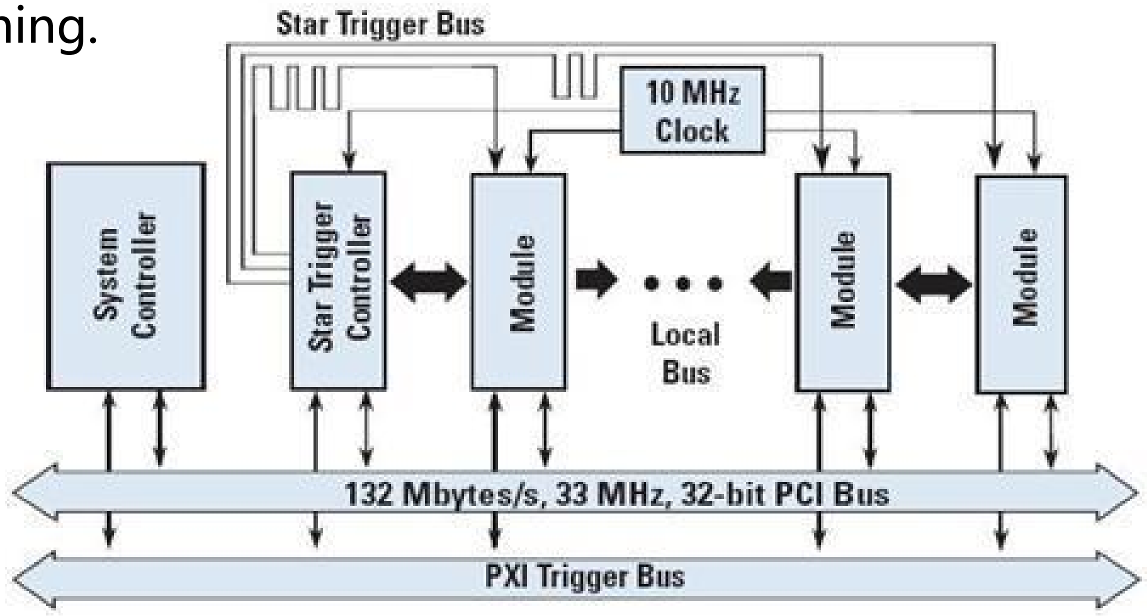




https://pcguide101.com/motherboard/what-are-pcie-slots/

PXI

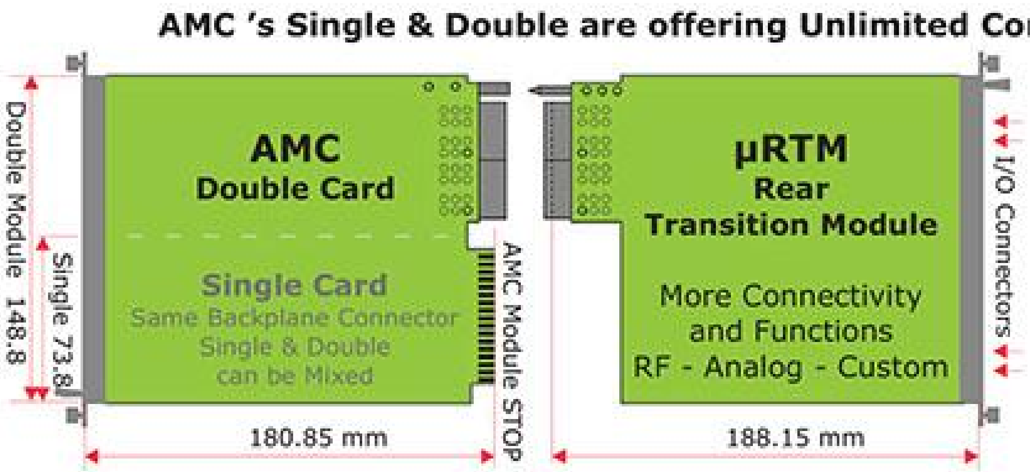
- PXI (**PCI eXtensions for Instrumentation**) is a rugged, modular bus standard for test, measurement, and automation systems.
- It is developed by NI in 1997, and widely used in Industrial Control, Data Acquisition (DAQ), ...
- Uses **PCI/PCIe** backbone (up to 24 GB/s with PCIe Gen3 x16).
- Modular – Hot-swappable **3U** or **6U** modules (similar to VME/VXI).
- Built-in **10 MHz clock & triggers** for precise timing.



https://www.marvintest.com

ATCA

- ATCA (**Advanced Telecommunications Computing Architecture**), also known as PICMG 3.x, is an open standard for high-performance, modular telecom and datacenter hardware.
- Carrier Card – FPGA, memory, backplane connections
- AMC (**Advanced Mezzanine Card**) – ADCs, DACs, high performance front end electronics
- RTM (**Rear Transition Module**) – General purpose IO,extra networks,miscellaneous

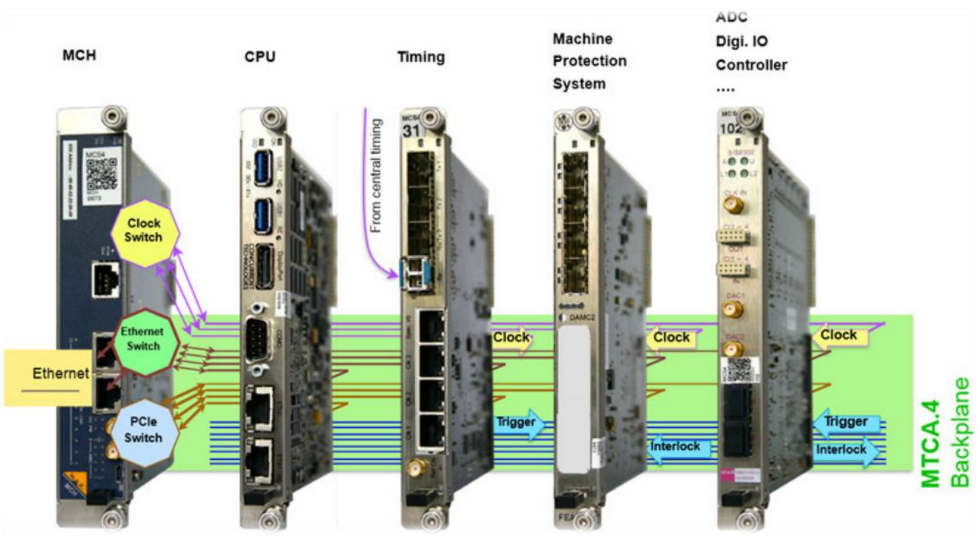


http://www.atcaworld.com/amc-overview.html

MicroTCA

- **MicroTCA** (**µTCA**) is a compact, modular version of the AdvancedTCA (ATCA) standard.
- It leverages AMCs as its core building blocks while eliminating the need for a full ATCA chassis.
- Cost-Effective – **Lower price** point than ATCA while maintaining reliability.
- Compact & Scalable – **Smaller** than ATCA (1U to 6U rack units).
- MicroTCA/ATCA Workshop for Large Scientific Facility Control (Sep 2025)

Feature	MicroTCA (µTCA)	ATCA
Form Factor	1U-6U rack	8U-14U rack
Core Block	AMC (Advanced Mezzanine Card)	Full-size ATCA Blades
Speed	PCIe Gen3/4, 10G/40G Ethernet	PCIe Gen4, 100G+ Ethernet
Target Market	Telecom edge, industrial	Telecom core, data centers
Cost	Medium	High

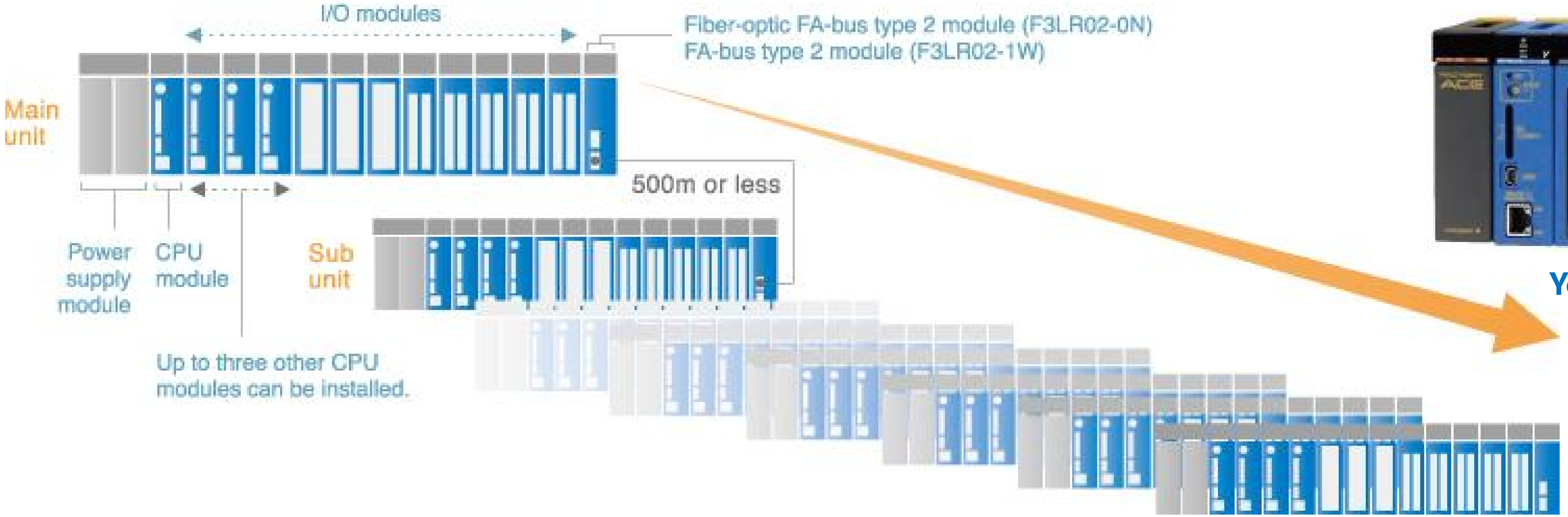


Hardware Bus

Feature	NIM	VME	PCIe	cPCI	PXI	ATCA	µTCA
Year Introduced	1960s	1981	2003	1994	1997	2002	2006
Primary Use	Nuclear Physics instruments	Military Telecom	Consumer Enterprise	Industrial Automation	Test Measurement	Telecom & Data Centers	Telecom Edge & Industrial
Bus Type	Analog + Digital Signals	Parallel (VME64x)	Serial (PCIe)	Parallel (PCI)	PCI/PCIe + Triggers	Serial (Ethernet/PCIe)	AMC-based (PCIe/Ethernet)
Speed	kHz-MHz	40 MB/s (VME32)	Up to 64 GB/s (PCIe Gen5)	133 MB/s (32-bit PCI)	24 GB/s (PCIe Gen3 x16)	100G+ (Fabric)	40G+ (PCIe Gen3)
Form Factor	Modular Bin	3U/6U Eurocard	Add-in Card	3U/6U Eurocard	3U/6U CompactPCI	8U-14U Chassis	1U-6U Chassis
Status	Legacy (niche use)	Replaced by VPX	Dominant in PCs/servers	Replaced by cPCI Serial	Active	Active	Active

PLC

- **Programmable Logic Controller** is an industrial computer with inputs and outputs used in the control and automation of industrial processes.
- Dual Redundancy – Supports hot-swappable CPUs & I/O modules for fault tolerance.
- Advanced Communication – Protocols like **Ethernet/IP**, **Modbus**, **PROFIBUS**, **OPC UA**.

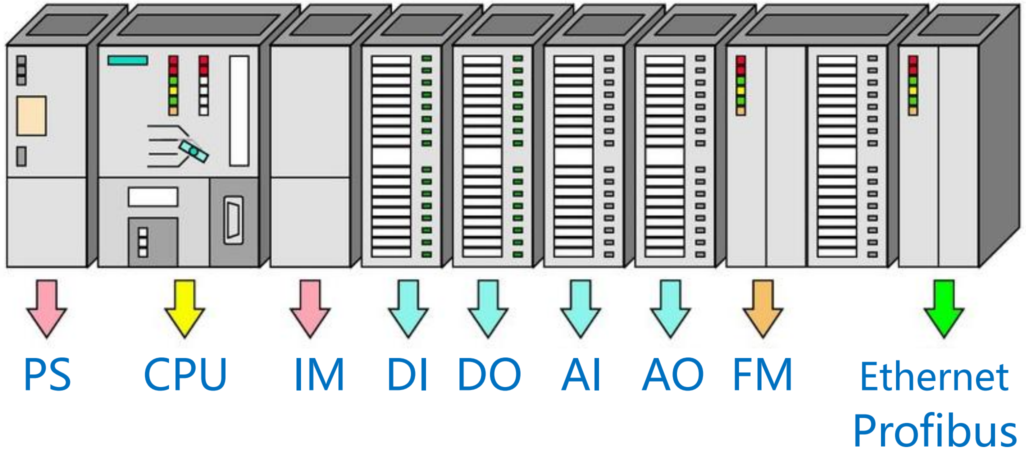


Yokogawa PLC

https://www.yokogawa.com/solutions/products-and-services

Siemens PLC

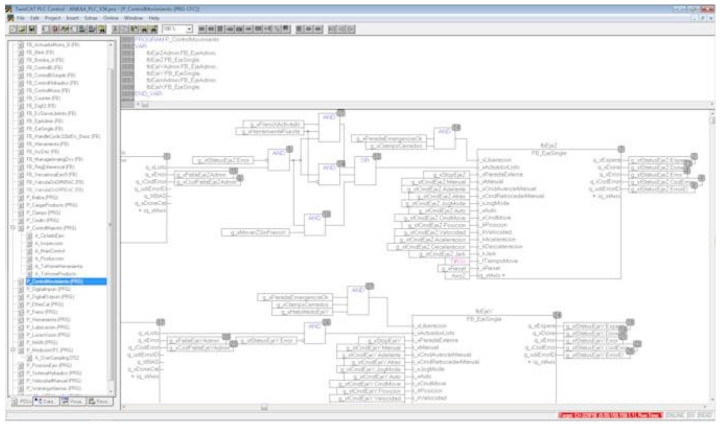
- **Siemens S7** refers to a family of programmable logic controllers (PLCs) and automation systems developed by Siemens AG for industrial control applications.
- Modular Design – Expandable I/O (digital, analog, specialty modules).
- Communication Protocols – PROFINET, Ethernet/IP, Modbus, OPC UA.
- **Motion Control** – Supports servo drives.



SIEMENS

Beckhoff PLC

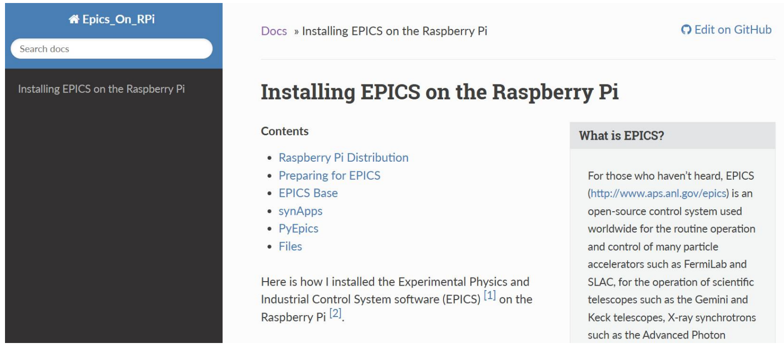
- **Beckhoff PLCs** are software-based and run on industrial PCs (IPCs) or embedded controllers, leveraging **TwinCAT** (The Windows Control and Automation Technology) for real-time control.
- **TwinCAT** Software – Integrates PLC, motion control, robotics, and IoT in one platform.
- **EtherCAT** – High-speed fieldbus (100 Mbps, <100 μs cycle times).
- Modular I/O – Supports E-bus (EtherCAT terminals) for flexible expansion.
- Scalability – From compact CX-series to high-performance C6xx industrial PCs.



Raspberry Pi

- Raspberry Pi is a low-cost, **credit-card-sized single-board computer** (SBC).
- It's designed to promote computer science education and DIY projects but is now widely used in embedded systems, IoT, robotics, and industrial applications.
- **Full Linux Computer** – Runs Raspberry Pi OS (Debian-based), Ubuntu, ...
- GPIO Pins – 40-pin header for sensors, motors, and peripherals.
- Networking – Wi-Fi, Bluetooth, Ethernet (varies by model).

Feature	Raspberry Pi	BeagleBone	NVIDIA Jetson
Core Purpose	General computing	Embedded Linux	AI/Edge Computing
OS Support	Linux, Windows IoT	Linux, Debian	Linux (JetPack)
GPIO	40 pins (3.3V)	65+ pins	40 pins
Power	5V USB-C (2.5W-12W)	5V DC (2W-5W)	5V-20V (10W-60W)
Price	$5-$75	$50-$150	$99-$2,000+



Epics_On_RPi

Search docs

Installing EPICS on the Raspberry Pi

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Edit on GitHub

Installing EPICS on the Raspberry Pi

Contents

- Raspberry Pi Distribution
- Preparing for EPICS
- EPICS Base
- synApps
- PyEpics
- Files

Here is how I installed the Experimental Physics and Industrial Control System software (EPICS) [1] on the Raspberry Pi [2].

What is EPICS?

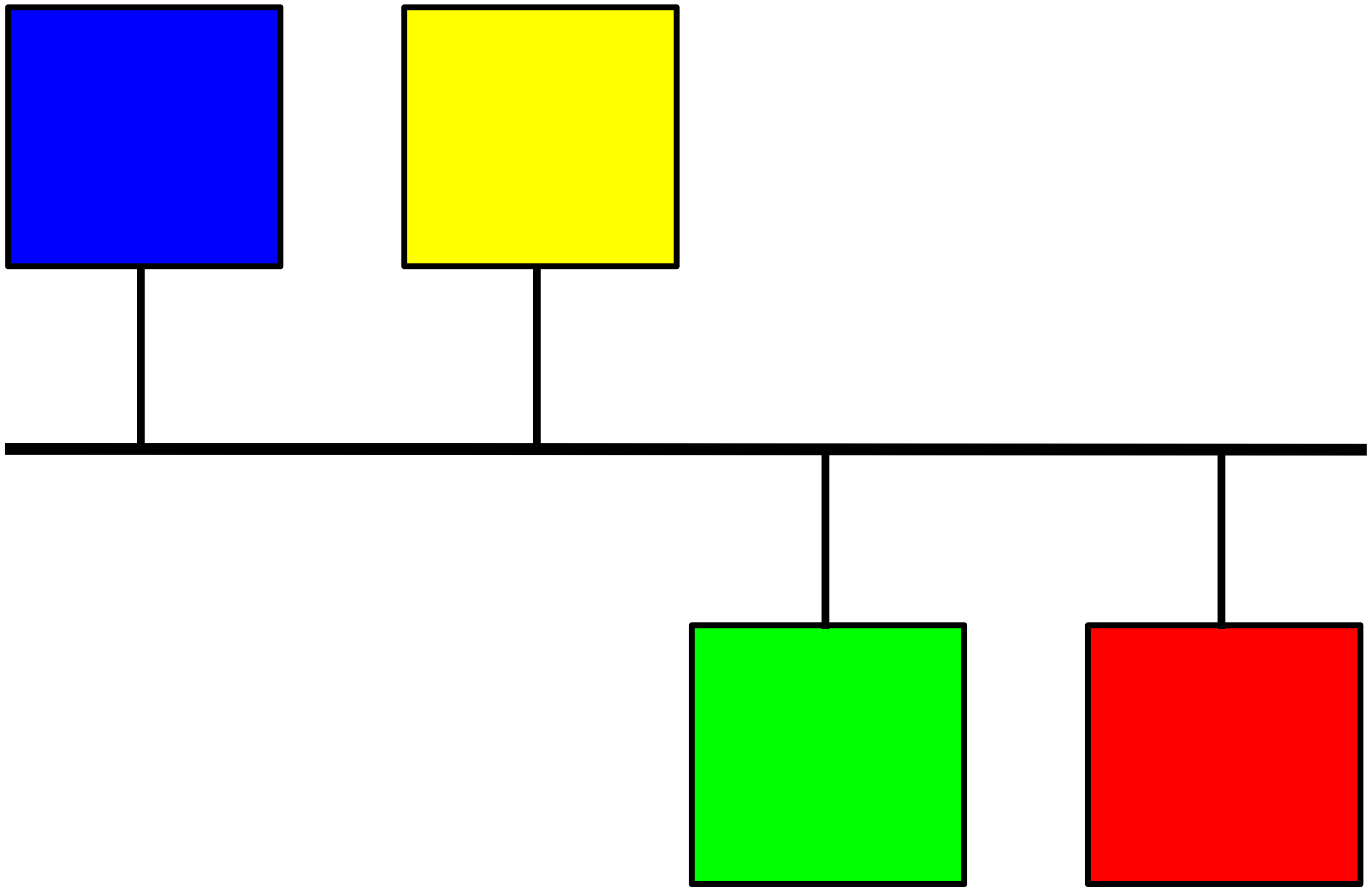
For those who haven't heard, EPICS (http://www.aps.anl.gov/epics) is an open-source control system used worldwide for the routine operation and control of many particle accelerators such as FermiLab and SLAC, for the operation of scientific telescopes such as the Gemini and Keck telescopes, X-ray synchrotrons such as the Advanced Photon

https://epicspi.readthedocs.io/en/latest/

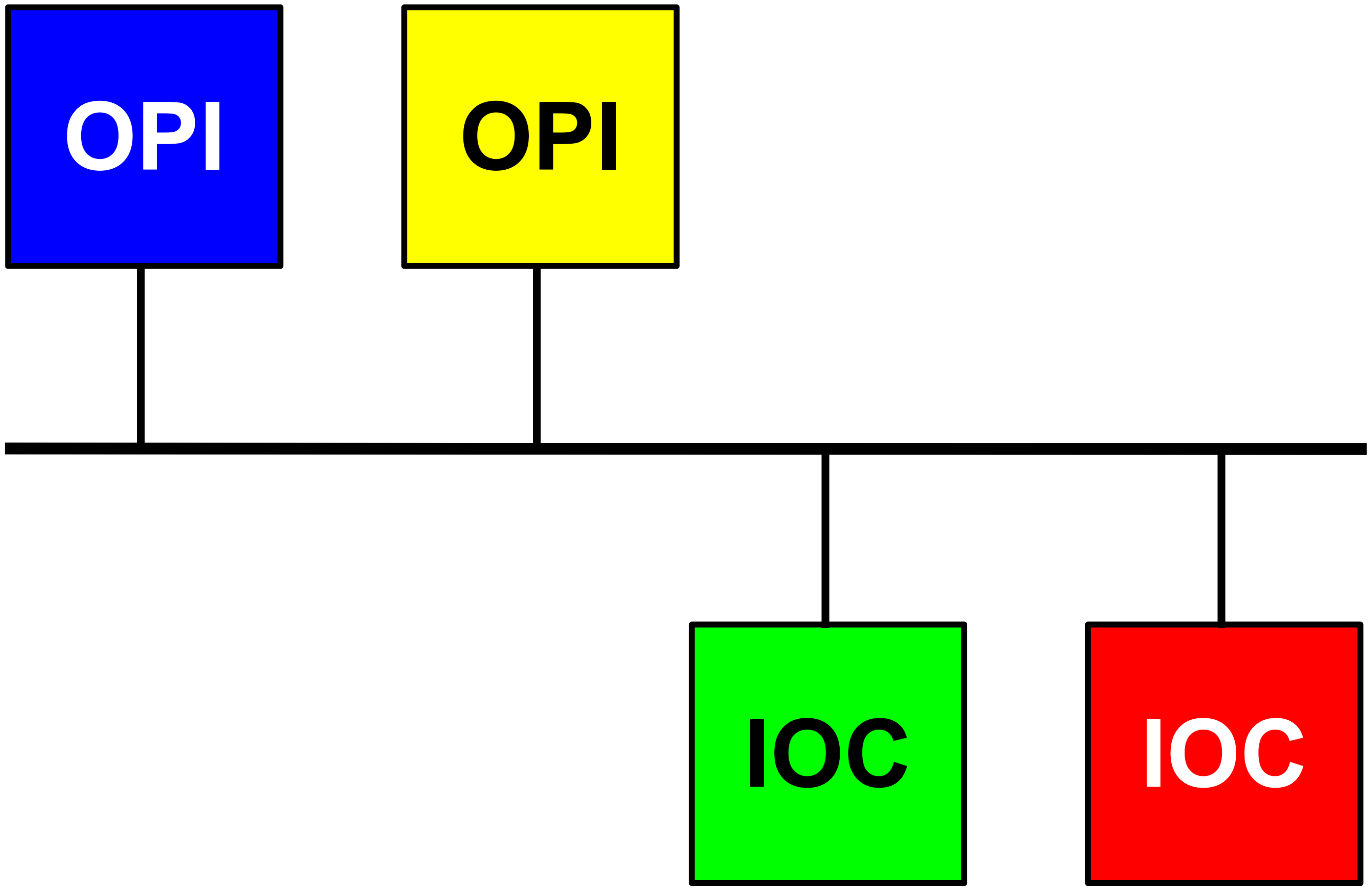
EPICS Basic & Modules

Some materials and ideas are copied from Ken Evans (APS) and EPICS website

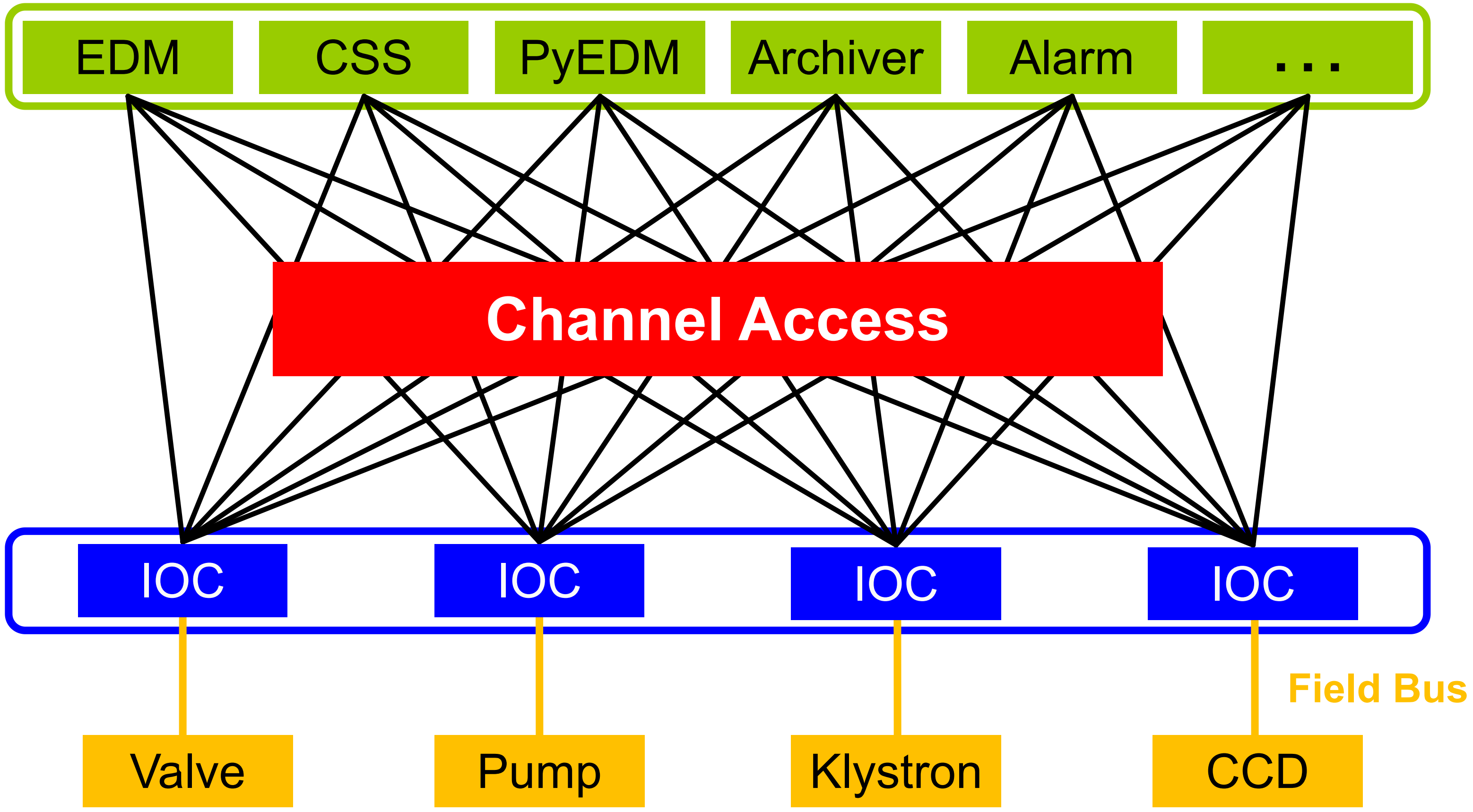
EPICS Overview



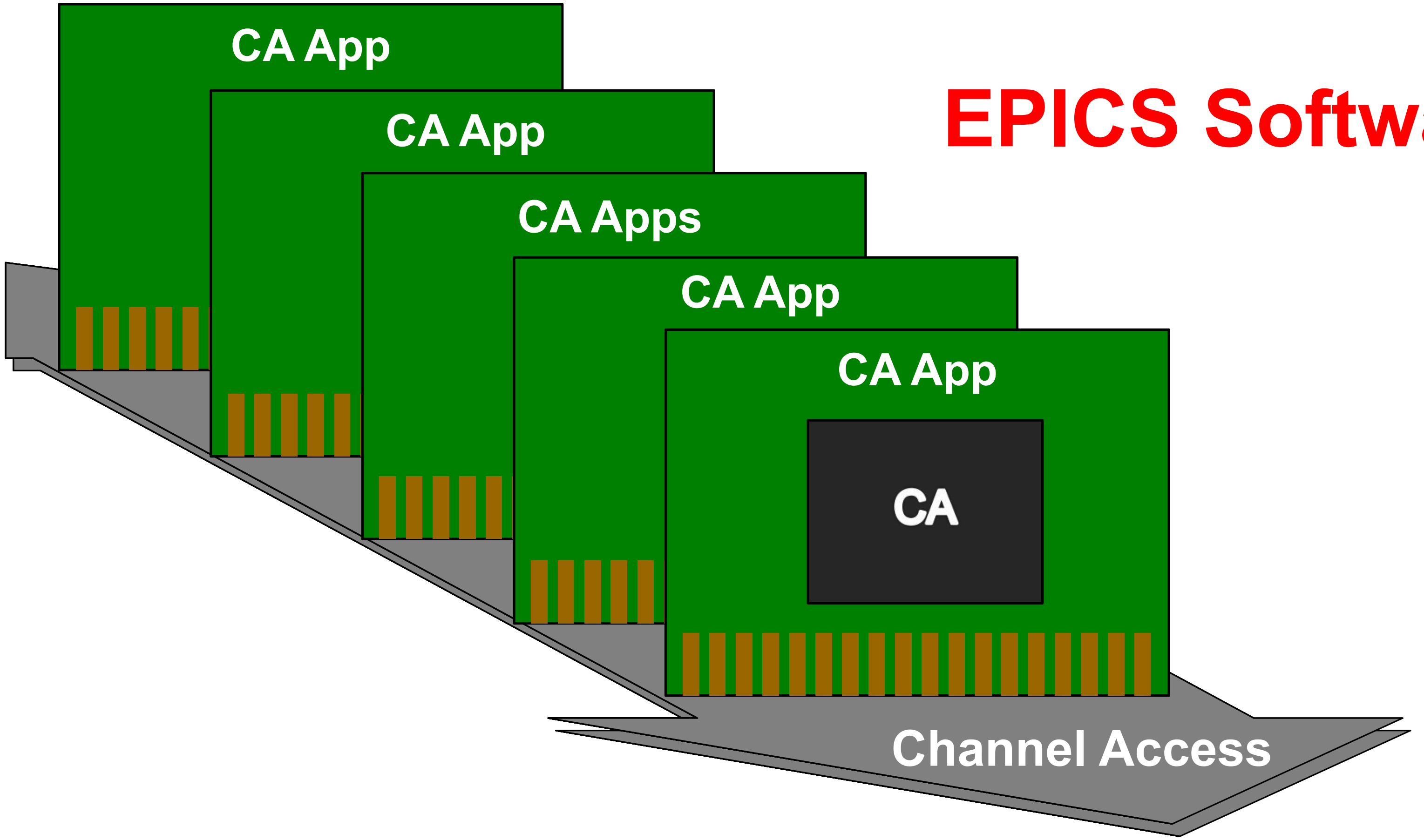
EPICS Overview



EPICS Overview



Channel Access



EPICS Software Bus

PV Access：Optimized for large data (arrays, structured data)

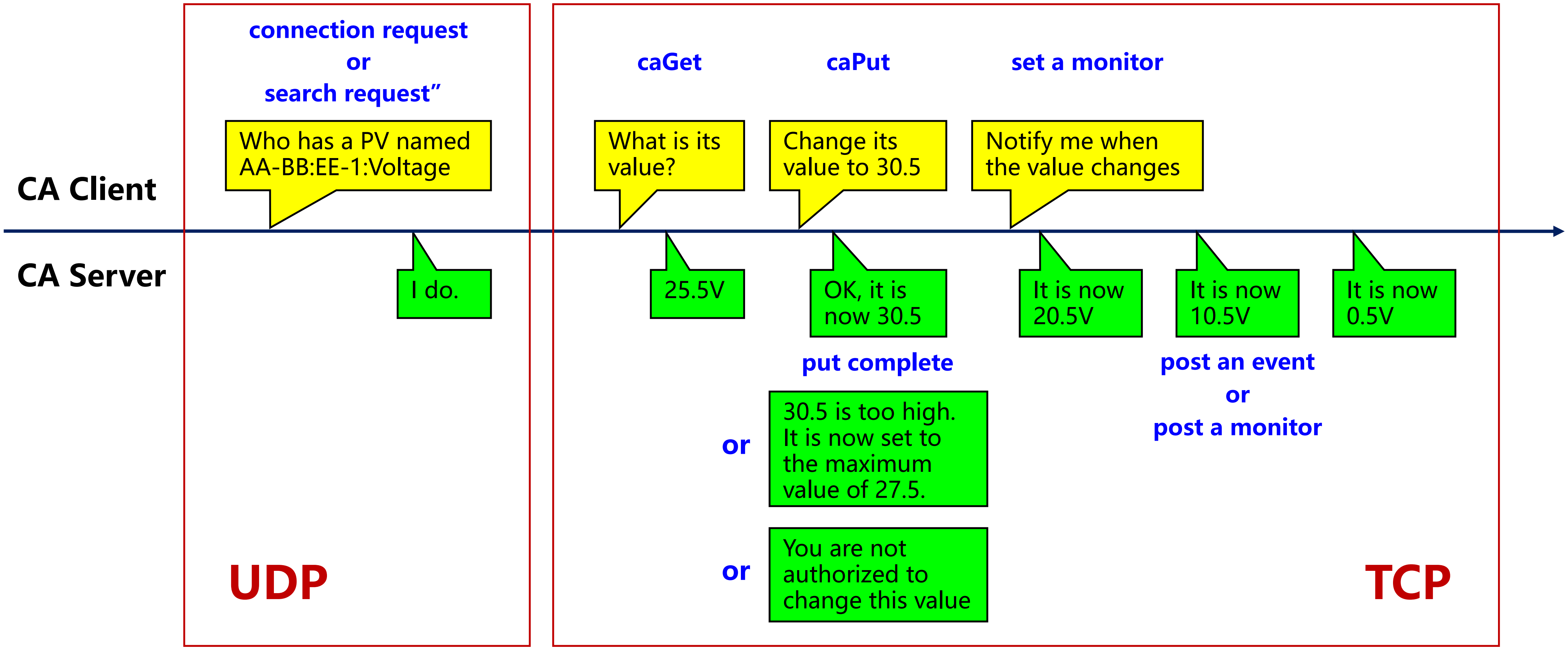
Process Variable

- **Process Variable** (PV) is a **named item of data resides in CA/PVA server**, with optional attributes.
- **Input/Output Controller** (IOC) is the server that **hosts** PVs and **interfaces** with hardware.
- Clients can read or write PVs using PV name, which must be **unique** in control system.
- Data Types – PVs can hold different data types (integers, floats, strings, arrays, etc.).
- Attributes – PVs often include additional information like units, alarm status, and timestamp.
- Access Control – Some PVs may have read/write permissions or security restrictions.

AC-UN-FEL1-VA:IPS-5:CURRENT-SP

AC-UN-FEL1-VA:IPS-5:OPEN-CMD

Channel Access



CA and PVA Command line Tools

- caget Reads the current value of one or more PVs.
- caput Writes a value to a PV.
- camonitor Monitors PV updates in real time.
- cainfo Displays detailed information about a PV (e.g., data type, host IOC).

- pvget Reads the value of one or more PVs (PVA alternative to caget).
- pvput Writes a value to a PV (PVA alternative to caput).
- pvmonitor Monitors PV changes (PVA alternative to camonitor).
- pvinfo Displays detailed PV metadata (PVA alternative to cainfo).
- pvcall Invokes a PVA RPC (Remote Procedure Call) service.
- pvlist Lists all PVs available on a network (PVA discovery).

…

CA and PVA Client Interfaces

- EZCA: Easy Channel Access interface library for C programs
- PVXS: A PVAccess protocol client+server library

C/C++

- CAJ/JCA: Channel Access client & server for Java
- CA: Another pure Java Channel Access client implementation

Java

- caffi: Channel Access Foreign Function Interface
- caproto: A pure-Python Channel Access protocol library
- Cothread: A CA interface to Python
- p4p: PVA Gateway and alternative pvAccess bindings for Python
- pvaPy: Official pvAccess bindings for Python and Conda
- PyEpics: EPICS Channel Access for Python

Python

- LabCA: Matlab & Scilab interface to Channel Access
- MatlabCA: Channel Access client library for Matlab and Octave

Matlab/Octave/Scilab

…

https://epics.anl.gov/extensions/index.php

CA Client Applications

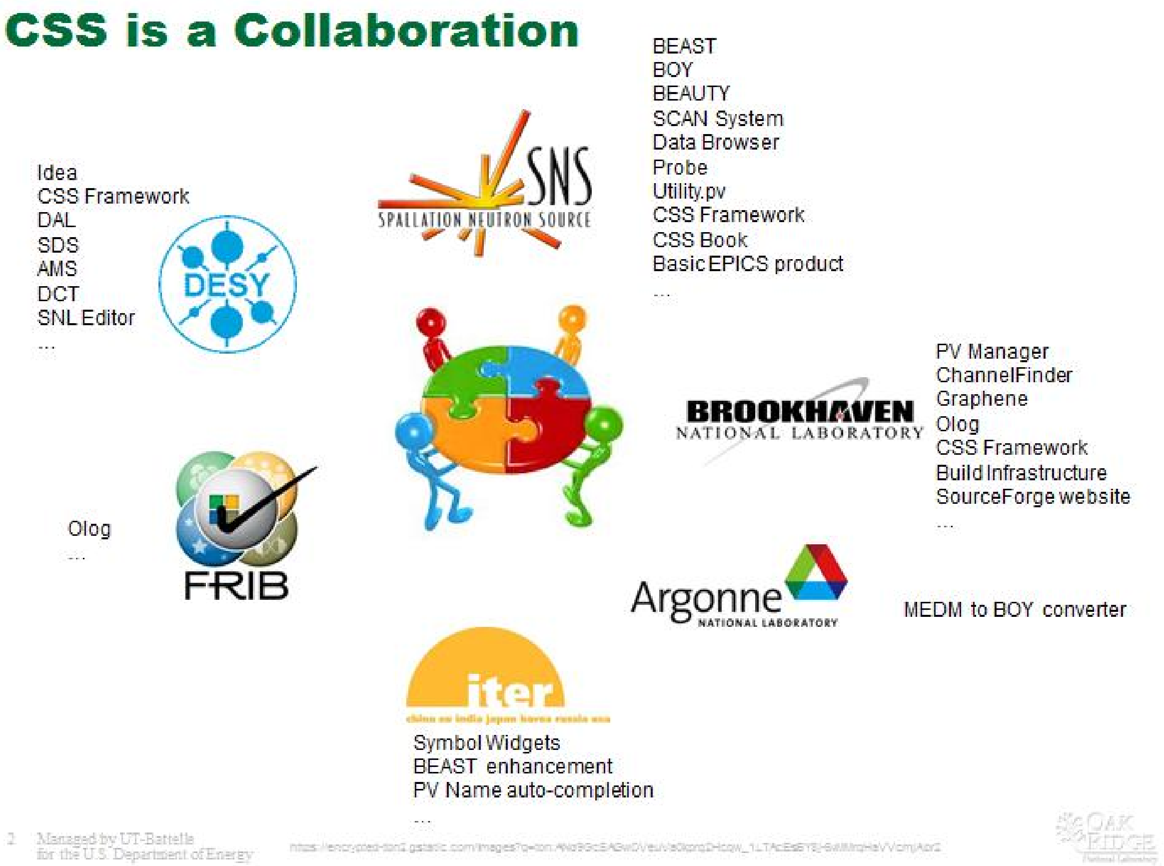
- ALH: Alarm Handler
- caQtDM: An MEDM replacement based on Qt
- CS-Studio: Control System Studio
- CS-Studio Phoebus
- EDM: Extensible Display Manager
- MEDM: Motif Editor and Display Manager
- Probe: Motif Channel Monitoring program
- PyDM: Python and PyQt-based Display Manager
- Sequencer: State Notation Compiler and Sequencer
- StripTool: Strip-chart plotting tool
- TimeChart: PyDM-based strip-chart application

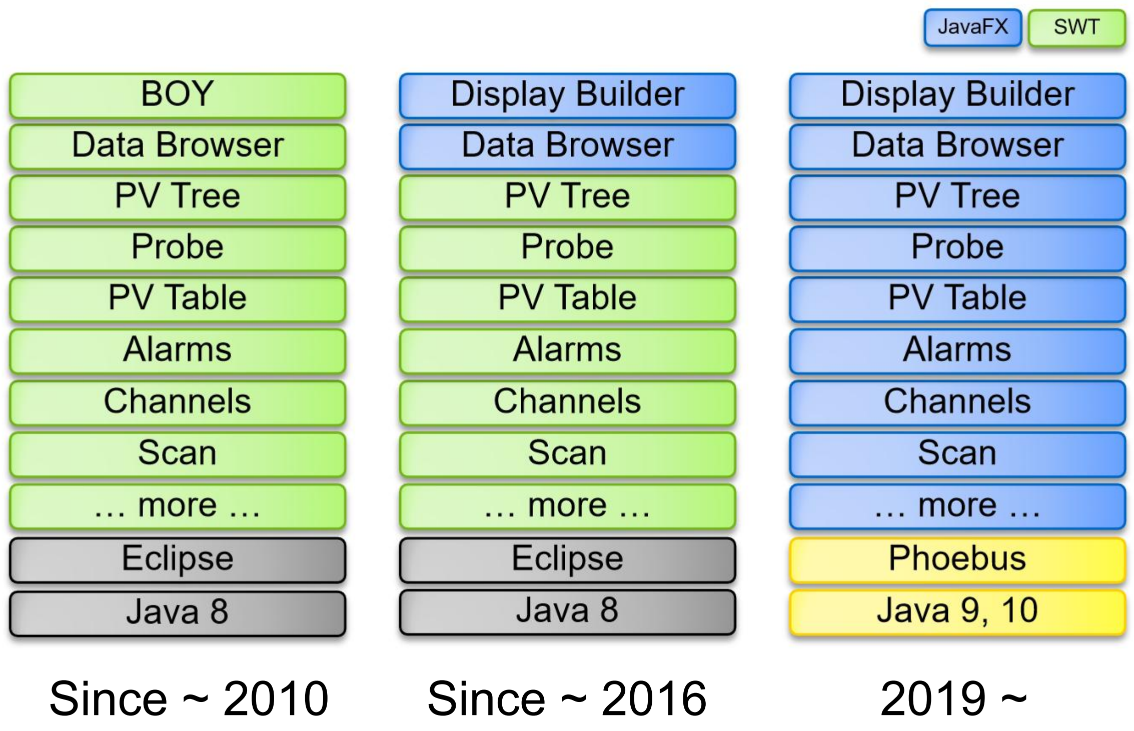
…

https://epics.anl.gov/extensions/index.php

Control System Studio

- CSS is an Eclipse-based **collection** of tools to monitor and operate large scale control system.
- It's a product of the colaboration between diferent laboratores and universities.





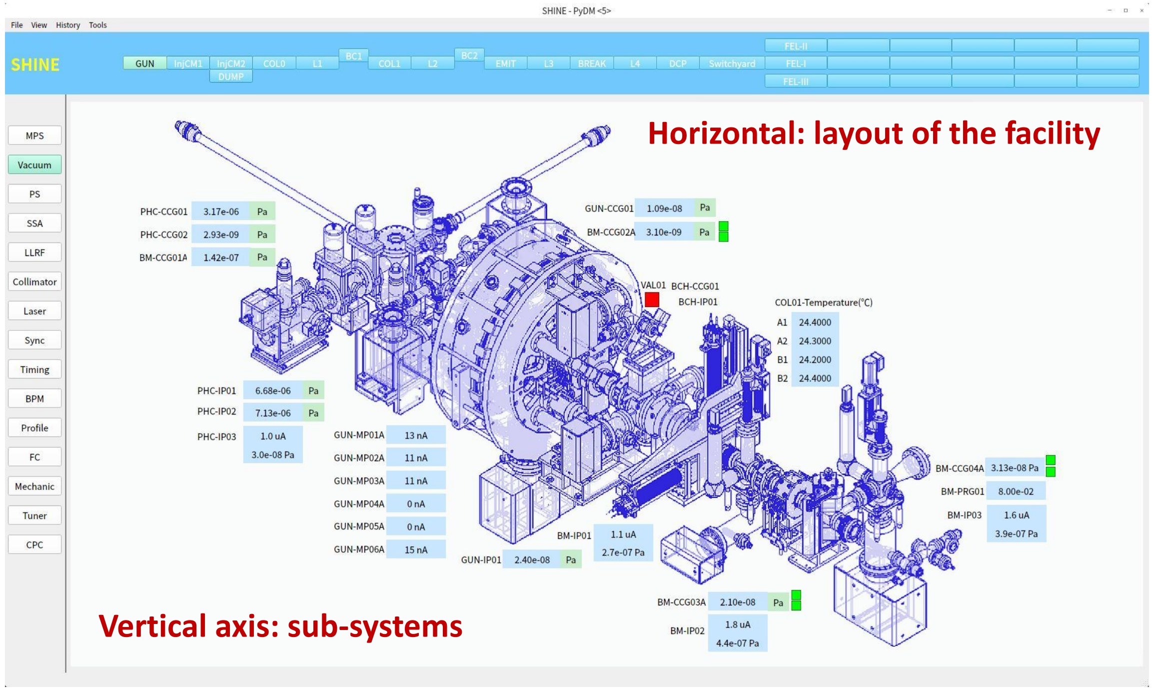
Kay Kasemir, Display Builder Tutorial

Python Display Manager

- PyDM is a **Python-based** graphical user interface (GUI) framework for control system.
- It provides a system for the drag-and-drop creation of user interfaces using **Qt Designer**.
- It also allows for the creation of displays driven by Python.

Widget Name	Function
PyDMPushButton	Add the toggle function
PyDMRelatedDisplayButton	Add the function of password authentication
PyDMShellCommand	Add the function of password authentication
PyDMPSReadbackButton	Password Button
ArchiverPlot	Retrieve the archiver data
…	

SHINE Customed PyDM Widgets

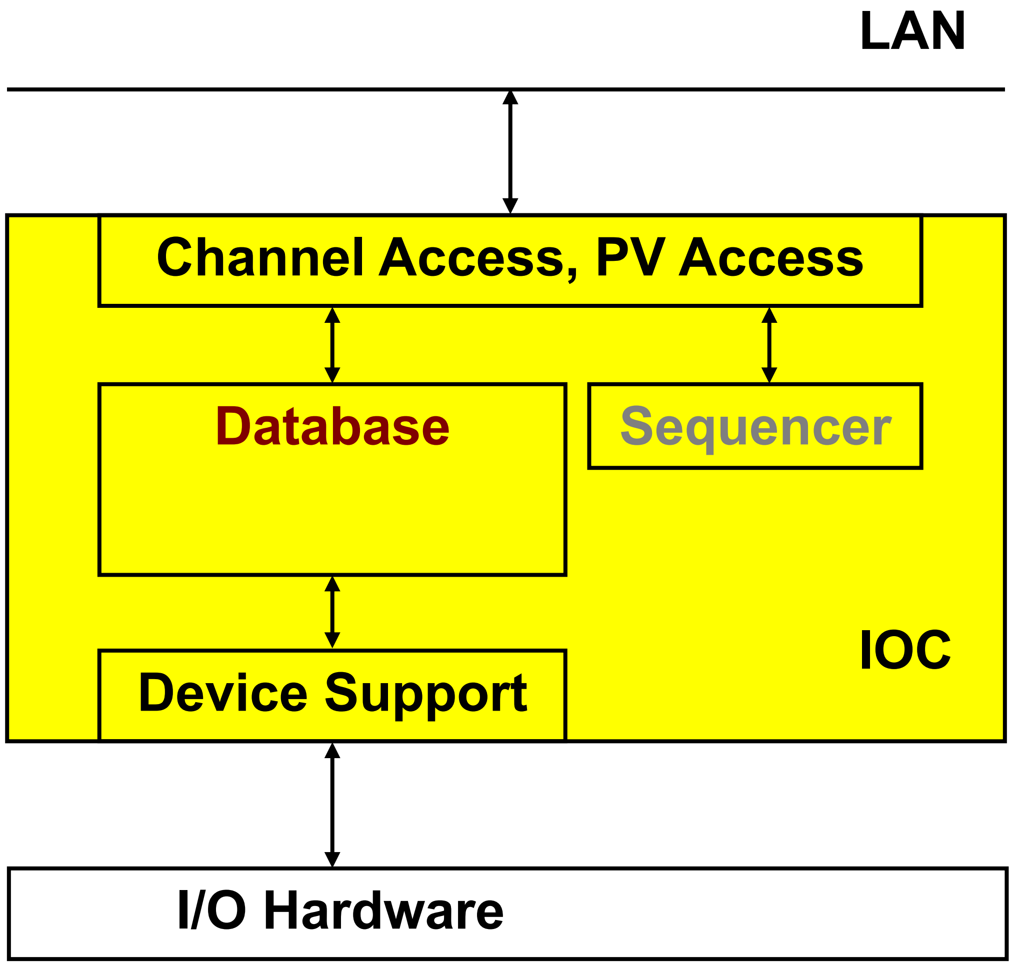


Display Manager

Feature	EDM	CSS	PyDM
Development Era	1990s	2006+	2016+
Language	C (X11)	Java (Eclipse)	Python (Qt/PyQt)
Performance	Very fast (C-based)	Moderate (Java)	Fast (Qt-based)
EPICS Support	CA (EPICS 3)	CA & PVA (EPICS 3/7)	CA & PVA (EPICS 3/7)
Widget Library	Basic (limited customization)	Advanced (Eclipse plugins)	Rich (Qt widgets + Python)
Scripting	EDL (limited)	JavaScript, Python	Python (full flexibility)
Styling	Minimal	CSS-like styling	Qt Stylesheets (CSS-like)
Cross-Platform	Linux (X11), Windows (limited)	Windows, Linux, macOS	Windows, Linux, macOS
Mobile/Web Support	No	RAP	PyDMWeb, …
Learning Curve	Low (simple but outdated)	Steep (Eclipse environment)	Moderate (Python/Qt knowledge helps)

Input/Output Controller (IOC)

- **Hardware Communication**
  - Interfaces with devices via protocols
  - Uses device support libraries (streamDevice, ...)
- **Database Processing**
  - 'iocCore' software loads and executes Records
- **Automation & Control Logic**
  - Supports sequencing (State Notation Language)
- **Process Variable (PV) Services**
  - Listens on CA or PVA for client requests.



- Database: **Records + Fields + Links**
- Sequencer: state machine, mostly on-demand

Record

- Each record has
  - Name – **unique** on the whole network
  - Type – determines fields and their functionality
  - Fields – properties, can be read, most also written at runtime
  - Often device support to interface to hardware
  - Links to other records
- Records process **periodically** or **triggered** by events / other records
  - Get data from other records or hardware
  - Perform calculations
  - Check value ranges, raise alarms
  - Write to other records or hardware

```
record ( ai," AA-BB:EE-FF:XX") {
    field ( DESC,   "Current Readback")
    field ( DTYP ,  "stream")
    field ( INP,    "@xxx.proto addr")
    field ( SCAN,   ".5 second")
    field ( EGU,    "Amps")
    field ( PREC,   "2")
    field ( HIHI,   "20")
    field ( HIGH,   "18")
    field ( LOW,    "1")
    field ( LOLO,   "0")
}
```

Record Types

Record Type	Description	Common Use Cases
Analog Input (ai)	Reads analog input values (eg., voltage, temperature)	Sensors (thermocouples, ADCs)
Analog Output (ao)	Writes analog output values (e.g., setpoints)	Control signals (DACs, power supplies)
Binary Input (bi)	Reads binary/digital input (0/1)	Limit switches, status bits
Binary Output (bo)	Writes binary/digital output	Relays, on/off controls
Multi-Bit Input (mbbi)	Reads multi-bit (enum) input	Device status (e.g., 3-bit encoded states)
Multi-Bit Output (mbbo)	Writes multi-bit (enum) output	Mode selection (e.g., START/STOP/RESET)
Long Input (longin)	Reads 32-bit integer values	Counters, encoder positions
Long Output (longout)	Writes 32-bit integer values	Stepper motor positions
String Input (stringin)	Reads text strings	Device firmware versions, messages
String Output (stringout)	Writes text strings	Command strings (e.g., RUN=1)
Waveform (waveform)	Handles arrays (numeric/string)	Data buffers (e.g., spectra, images)
Calc (calc)	Performs math on inputs	Derived values (e.g., A+B)
Calcout (calcout)	Math + conditional output	Alarm thresholds, feedback loops
Seq (seq)	State machine	Complex sequencing (e.g., device startup)

Common Fields

- **Initial**
  - NAME: Record name, unique on network!
  - DESC: Description
  - SCAN: Passivem, periodically, event or I/O Intr
  - PINI: Process once on initialization?
  - FLNK: Forward link
- **Runtime**
  - TIME: Time stamp
  - SEVR, STAT: Alarm Severity, Status
  - PACT: Process active
  - UDF: Undefined? Never processed?
  - PROC: Force processing

```
record ( ai," AA-BB:EE-FF:XX") {
    field ( DESC,  "Current Readback")
    field ( DTYP , "stream")
    field ( INP,   "@xxx.proto addr")
    field ( SCAN,  ".5 second")
    field ( EGU,   "Amps")
    field ( PREC,  "2")
    field ( HIHI,  "20")
    field ( HIGH,  "18")
    field ( LOW,   "1")
    field ( LOLO,  "0")
}
```

Common Fields

- Input/Output Record Fields
  - DTYP: Device type
  - INP/OUT: How to read/write, format depends on DTYP
  - RVAL: Raw value (e.g. 16 bit integer)
  - **VAL**: Engineering unit value (e.g. 64bit float)
- Output Record Fields
  - DOL: Desired Output Link.

    Output records read this link to get VAL, then write to OUT…
  - OMSL: .. if Output Mode SeLect = closed_loop
  - IVOA: Invalid Alarm Output Action
  - DRVL, DRVH: Drive limits

```
record ( ai," AA-BB:EE-FF:XX") {
    field ( DESC,  "Current Readback")
    field ( DTYP , "stream")
    field ( INP,   "@xxx.proto addr")
    field ( SCAN,  ".5 second")
    field ( EGU,   "Amps")
    field ( PREC,  "2")
    field ( HIHI,  "20")
    field ( HIGH,  "18")
    field ( LOW,   "1")
    field ( LOLO,  "0")
}
```

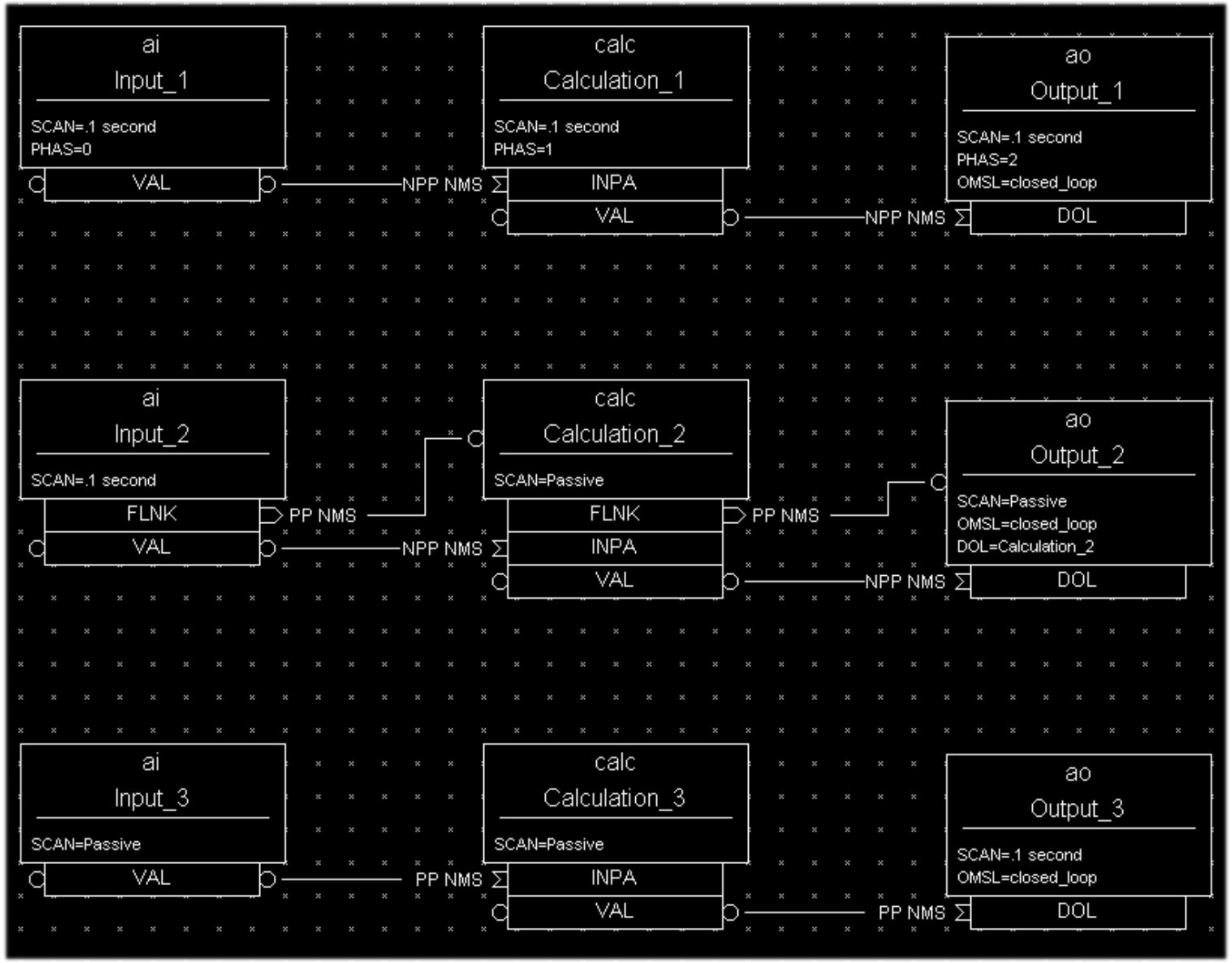
Common Fields

- Analog Record Fields
  - EGU: Engineering units name
  - LINR: Linearization (None, Slope, breakpoint table)
  - EGUL, EGUF, ESLO, EOFF: Parameters for LINR
  - LOLO, LOW, HIGH, HIHI: Alarm Limits
  - LLSV, LSV, HSV, HHSV: Alarm severities
- Binary Record Fields
  - ZNAM, ONAM: State name for zero and one
  - ZSV, OSV: Alarm severities

```
record ( ai," AA-BB:EE-FF:XX") {
    field ( DESC,   "Current Readback")
    field ( DTYP ,  "stream")
    field ( INP,    "@xxx.proto addr")
    field ( SCAN,   ".5 second")
    field ( EGU,    "Amps")
    field ( PREC,   "2")
    field ( HIHI,   "20")
    field ( HIGH,   "18")
    field ( LOW,    "1")
    field ( LOLO,   "0")
}
```

Database Links

- PP: Process a passive target record
  - INP, DOL: Before reading
  - OUT: After writing
- NPP: non-process-passive (**default**)
- MS: Maximize severity
- NMS: non-MS (default)
- MSS: Maximize Severity and Status
- MSI: .. when severity = INVALID



Access Security

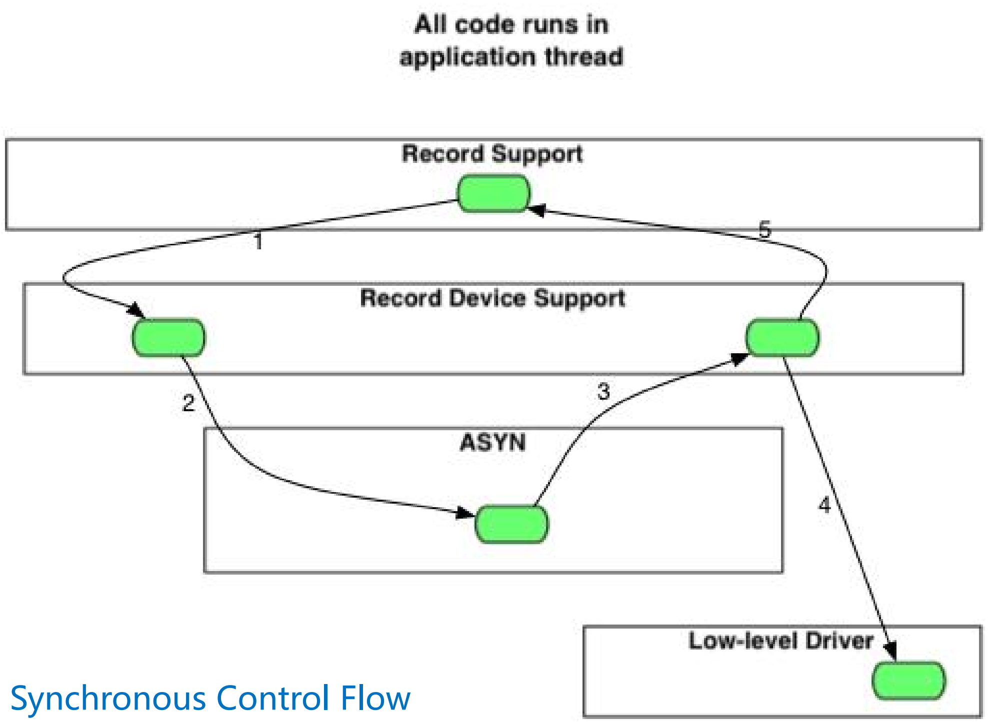
- A networked control system must have the ability to enforce **security rules**
  - Who can do what from where, and when?
- In EPICS, security is enforced by the **CA server** (the IOC or **gateway**)
- A record is placed in the **Access Security Group** named in its ASG field
  - DEFAULT is used if no group name is given
- Rules are specified for each group to determine whether a CA client can read or write to records in that group, based on
  - Client user ID
  - Client host-name or IP address
  - Access Security Level of the field addressed
  - Values read from the database

```
UAG(users) {user1, user2}
HAG(hosts) {host1, host2}
ASG(DEFAULT) {
    RULE(1, READ)
    RULE(1, WRITE) {
            UAG(users)
            HAG(hosts)
    }
}
```

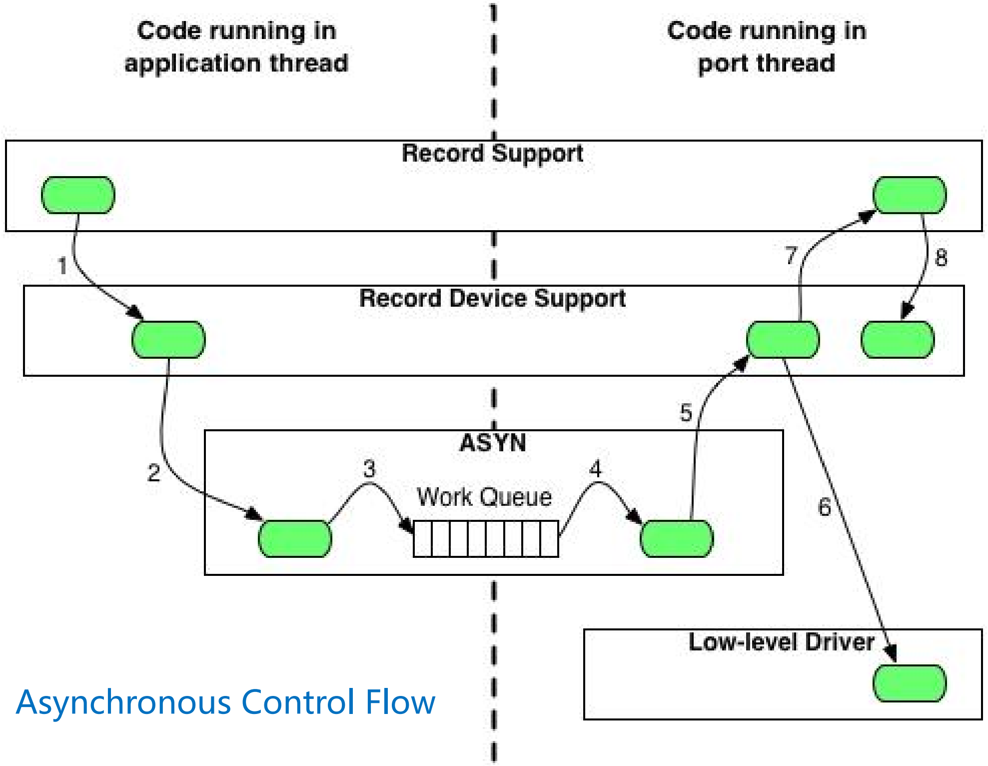
Access Security Configuration File

AsynDriver

- asynDriver is a **general purpose** facility for interfacing device specific code to low level drivers.
- It allows non-blocking device support that works with both **blocking** and **non-blocking** drivers.
- Provides consistent APIs for read/write, monitor and flow control.
- Uses **callback** mechanisms for efficient data handling.



Synchronous Control Flow



Asynchronous Control Flow

https://epics.anl.gov/modules/soft/asyn/R4-35/asynDriver.html

streamDevice

- streamDevice is a generic device support module that simplifies communication with devices using **text-based protocols** (e.g., SCPI, custom ASCII commands).
- Based on AsynDriver, it translates record operations into **device-specific command sequences**.
- **Serial** (RS-232, RS422, RS485), **Network** (TCP, UDP), **GPIB** (IEEE-488)

Protocol File

```
Terminator = CR LF;
InTerminator = LF;
ReplyTimeout = 10000;
ReadTimeout = 10000;
getTempA
{
    out "KRDG? A";
    in "%f";
}
```

DB File

```
record(ai, "Temp:A")
{
    field( DESC, "Temperature Readback")
    field(DTYP, "stream")
    field(INP, "demo.proto getTempA L0")
    field(SCAN,"5 second")
    field( EGU, "...")
    ...
}
```

IOC st.cmd

```
drvAsynSerialPortConfigure("L0","/dev/tty.X",0,0,0)
asynSetOption("L0", -1, "baud", "9600")
asynSetOption("L0", -1, "bits", "8")
asynSetOption("L0", -1, "parity", "none")
asynSetOption("L0", -1, "stop", "2")
asynSetOption("L0", -1, "clocal", "Y")
asynSetOption("L0", -1, "crtscts", "Y")
...
```

https://epics.web.psi.ch/software/streamdevice/

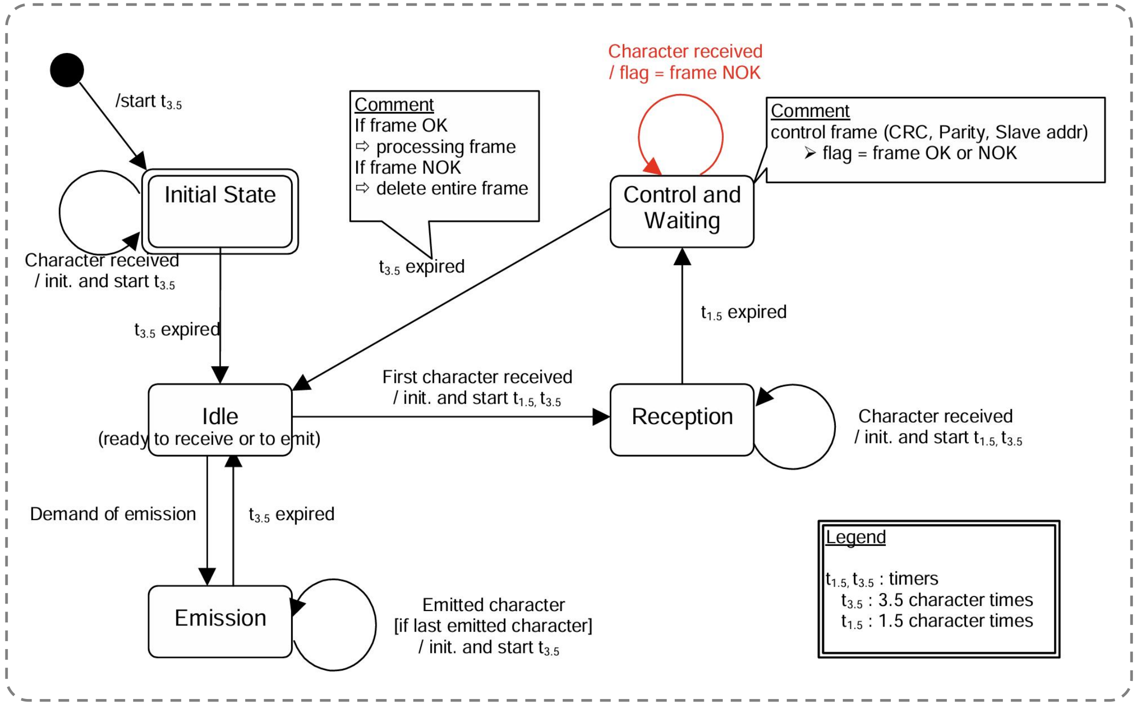
Modbus

- The Modbus module is a software component that allows the IOC to communicate with devices using the **Modbus protocol**, which is widely used in industrial automation systems.
- Supports 3 communication-link layers: **TCP**, **RTU** and **Serial ASCII**.
- Provides access to the following 4 types of data.

Primary tables	Object type	Access
Discrete Inputs	Single bit	Read-Only
Coils	Single bit	Read-Write
Input Registers	16-bit word	Read-Only
Holding Registers	16-bit word	Read-Write

Slave Address	Function Code	Data	CRC
1 byte	1 byte	0 up to 252 byte(s)	2 bytes CRC Low, CRC Hi

RTU Message Frame



RTU Transmission Mode State

S7nodave

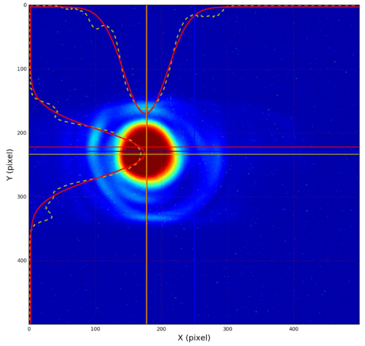
- S7nodave is a device support that communicates with **Siemens S7 PLCs** using ISO-TCP protocol.
- Unlike OPC-based solutions, It does **NOT** require SIMATIC NET or extra Siemens software licenses.
- It works with standard records, and **maps** PLC **memory areas** to **process variables**.
- S7nodave does **NOT** require any special programming on the PLC side.
- Compatible with S7-300, S7-400, S7-1200, and S7-1500 series.

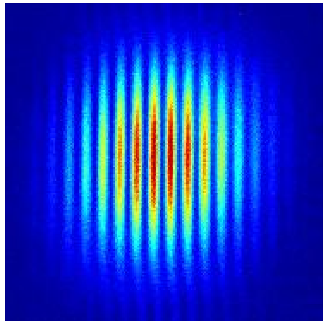
	bool	int8	uint8	int16	uint16	int32	uint32	float
STRING		X	o					
CHAR	X	X		X		X		o
UCHAR	X		X	o	X	o	X	o
SHORT	X			X		X		o
USHORT	X				X	o	X	o
LONG	X					X		o
ULONG	X						X	o
FLOAT	X	o	o	o	o	o	o	X
DOUBLE	X	o	o	o	o	o	o	X
ENUM	X				X	o	X	o
X = default for memory addresses of the corresponding width, o = supported, if specified explicitly								

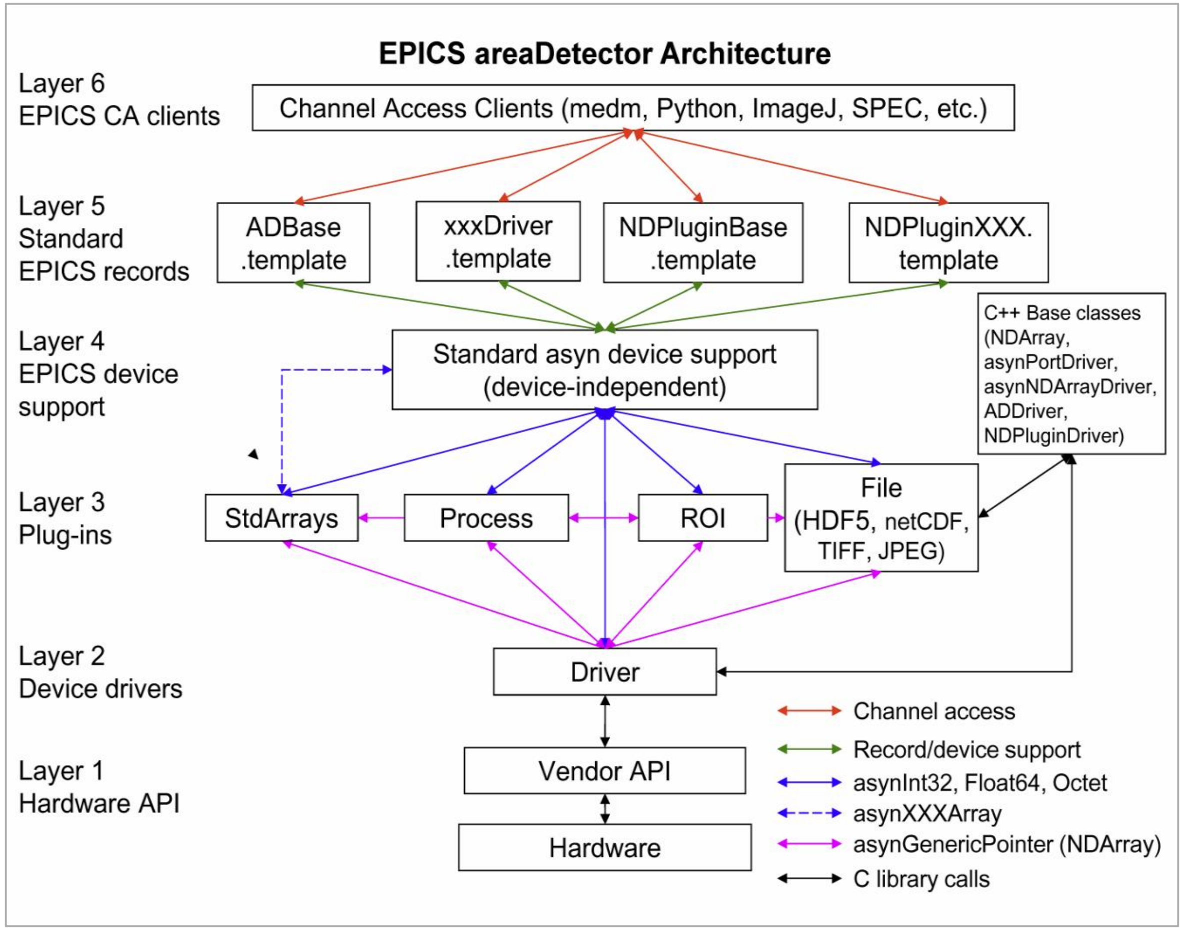
https://oss.aquenos.com/epics/s7nodave/docs/3.0.2/manual.html

areaDetector

- The areaDetector module provides a **general-purpose** interface for area (**2-D**) detectors.
- It is intended to be used with a wide variety of detectors and cameras, ranging from high frame rate CCD and CMOS cameras, pixel-array detectors such as the Pilatus, and large format detectors like the Perkin Elmer flat panels.







https://areadetector.github.io/areaDetector/

Hardware and Software Support

- A hardware support module provides software for use within an IOC to control a real-world commercial device.
- A soft support module may contain a new record type, software-only device support, or some other software that runs in the IOC but which is not readily identified with a particular piece of hardware.

Total Records Found: 676, showing 50 per page

Manufacturer	Bus	Module	Description	Contact	Link
	ARM IOC (Linux)	GPIO	/dev/class/gpio on BeagleBone Black, Raspberry Pi etc.	Florian Feldbauer	GH:devgpio
	Firewire (Asyn)	IIDC DCAM cameras	AreaDetector plug-in to control and read out IIDC DCAM compliant firewire cameras	Ulrik Pedersen	DLS:DCAM
	IEEE1394 (Asyn)	IIDC DCAM cameras	AreaDetector plug-in to control and read out IIDC DCAM compliant firewire cameras	Ulrik Pedersen	DLS:DCAM
	IOC-Arduino (Streams)		Raspberry Pi to Arduino via USB	Pete Jemian	GH:cmd_response
	Modbus (Asyn)	PLCs	Modbus TCP, serial RTU and serial ASCII	Mark Rivers	CARS:Modbus
	USB (Asyn)	TMC	Test and Measurement Class devices	Eric Norum	APS:asyn

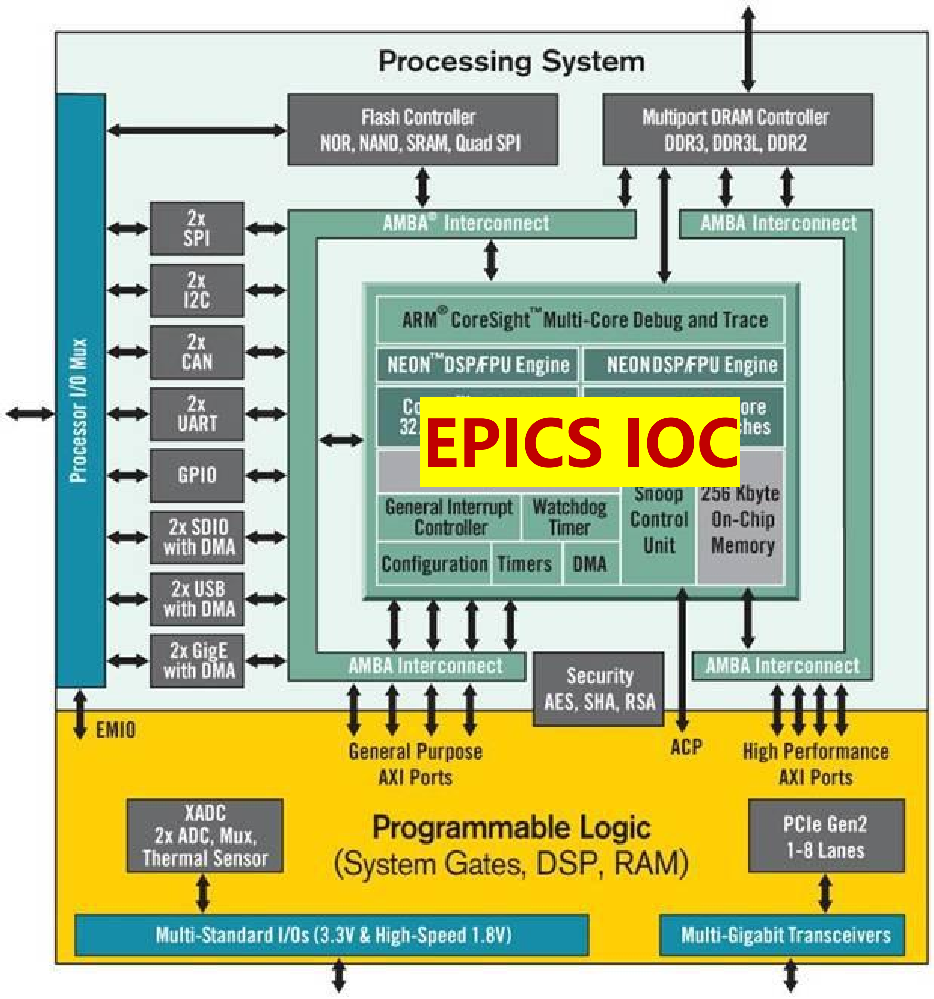
25 entries per page | Search:

Class	Name	Description	Contact	Link
Driver (Asyn)	iocshDev	iocsh command device support	Eric Norum (wenorum@lbl.gov)	APS:modules
embedded linux	Build rootfs	Scripts to build a minimal Linux rootfs	Michael Abbott (michael.abbott@diamond.ac.uk)	Diamond:Rootfs
facility	areaDetector	Support for cameras etc. Uses ASYN	Mark Rivers (rivers@cars.uchicago.edu)	GH:areaDetector
facility	ASYN	General-purpose device interface facility	Mark Rivers (rivers@cars.uchicago.edu)	APS:asyn
facility	asynPythonDriver	An asynPortDriver in Python	Wang Xiaoqiang (xiaoqiang.wang@psi.ch)	github:asynPythonDriver
facility	asynUSBTMC	ASYN support for USB Test & Measurement Class devices	Eric Norum (wenorum@lbl.gov)	SF:asynUSBTMC
facility	Autosave	Bumpless IOC Reboot support	Tim Mooney (mooney@aps.anl.gov)	APS:synApps/autosave
facility	caPutLog	Logging of CA puts to iocLogServer	Benjamin Franksen (benjamin.franksen@bessy.de)	BESSY:caPutLog

https://epics-controls.org/resources-and-support/modules/soft-support/

Embedded IOC

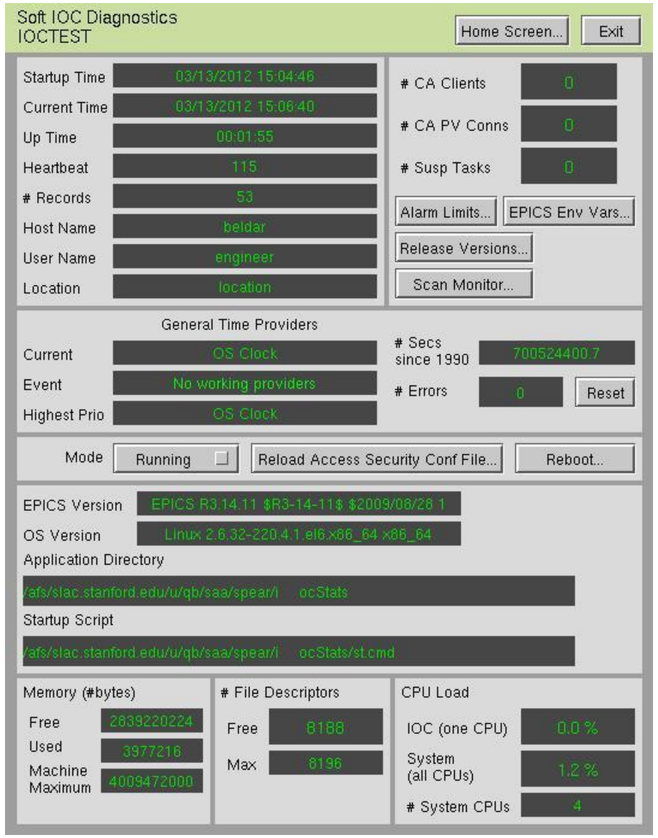
- ❑ Data Flow of BPM Electronics in a Synchrotron
- ❑ FPGA Side:
  - ADC samples beam position signals.
  - FPGA calculates beam position in real time.
  - Sends processed data to SoC via AXI bus (e.g., Zynq PS-PL interface).
- ❑ SoC Side (**EPICS IOC**):
  - Runs device support for beam diagnostics.
  - Publishes PVs via CA or PVA.
- ❑ Control Loop (Feedback):
  - EPICS sends corrections back to FPGA.
  - FPGA implements magnet control in hardware.

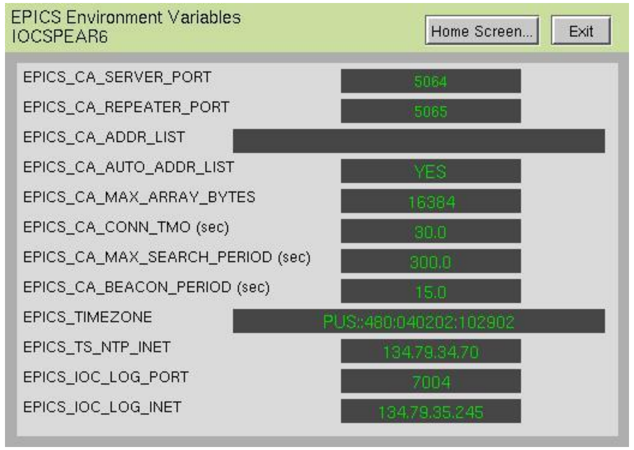


Zynq-7000 SoC (System-on-Chip)

iocStats

- The iocStats module provides support for records that show the **health** and **status** of an IOC.
- List of supported variables
  - number of file descriptors currently in use
  - size of largest free block
  - estimated percent CPU usage by tasks
  - number of suspended tasks
  - number of file descriptors currently in use
  - number of current CA clients
  - number of current CA connections
  - number of records on the IOC
  - EPICS environment variables
  - restart control
  - ...

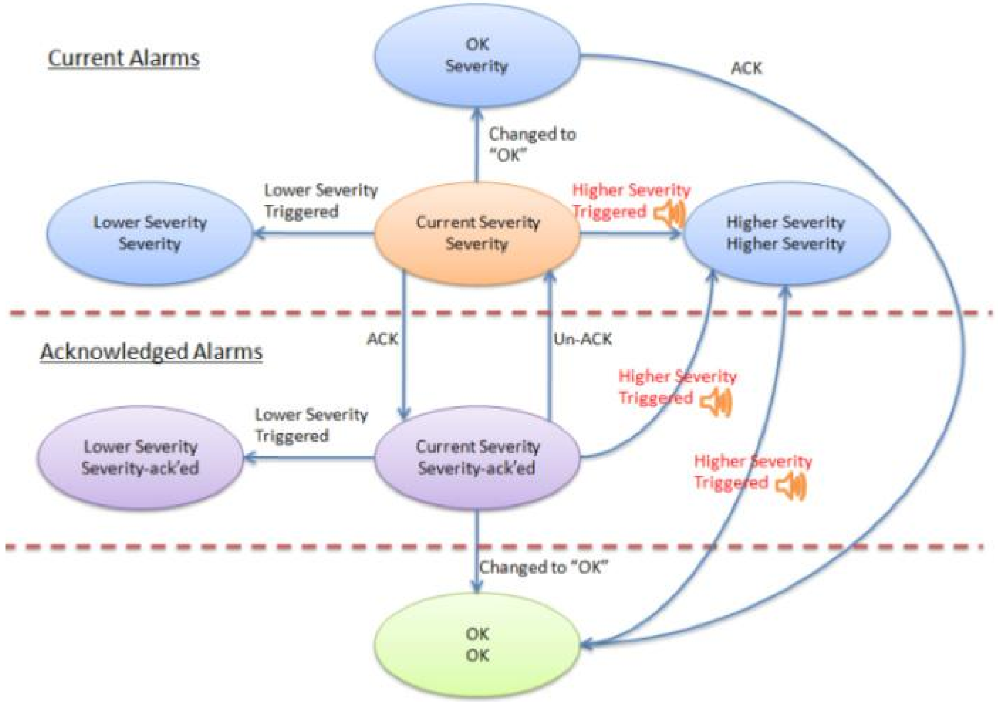




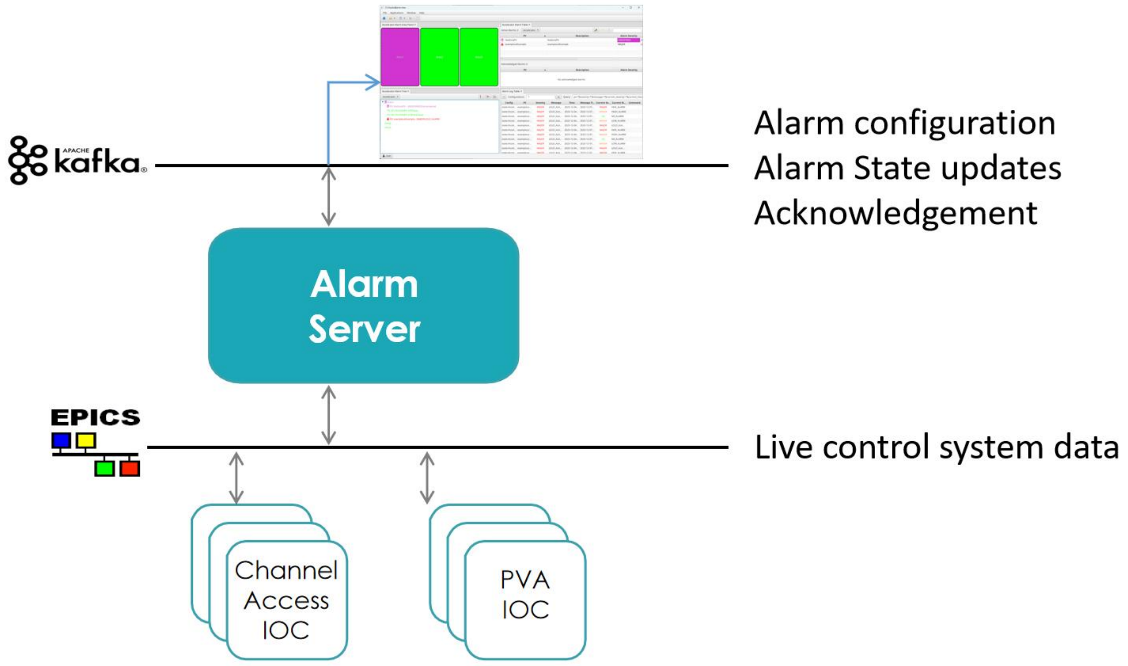
https://www.slac.stanford.edu/grp/ssrl/spear/epics/site/devIocStats/

Alarm

- The Alarm is a subsystem within EPICS that **monitors** and **manages** alarms for process variables.
- It helps operators detect and respond to abnormal conditions in the large-scale control system.
- Alarm conditions can be configured using **alarm thresholds** (e.g., HIHI, HIGH, LOW, LOLO).
- Alarm can trigger actions (e.g., notifications, logging, or automated responses).



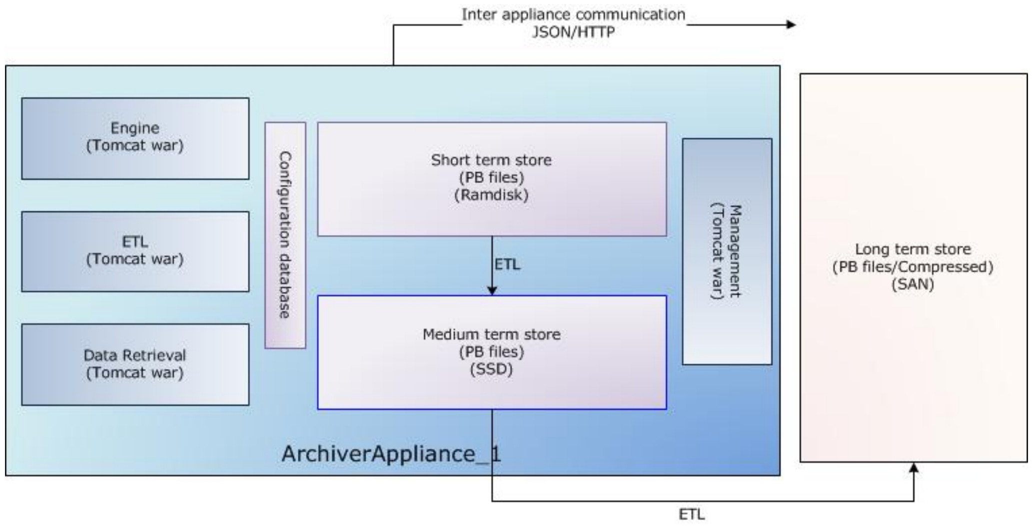
Kay Kasemir, The best ever alarm system toolkit, ICALEPCS 2009

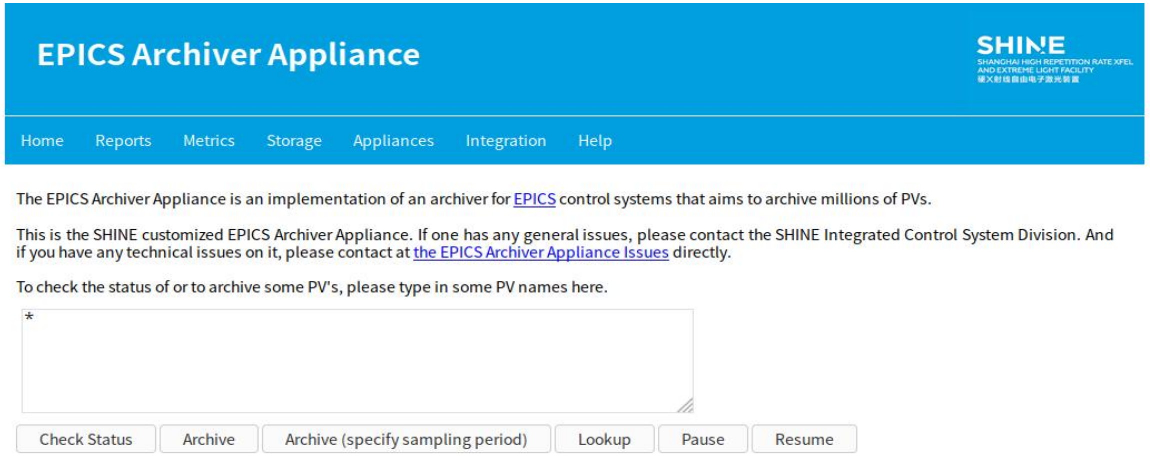


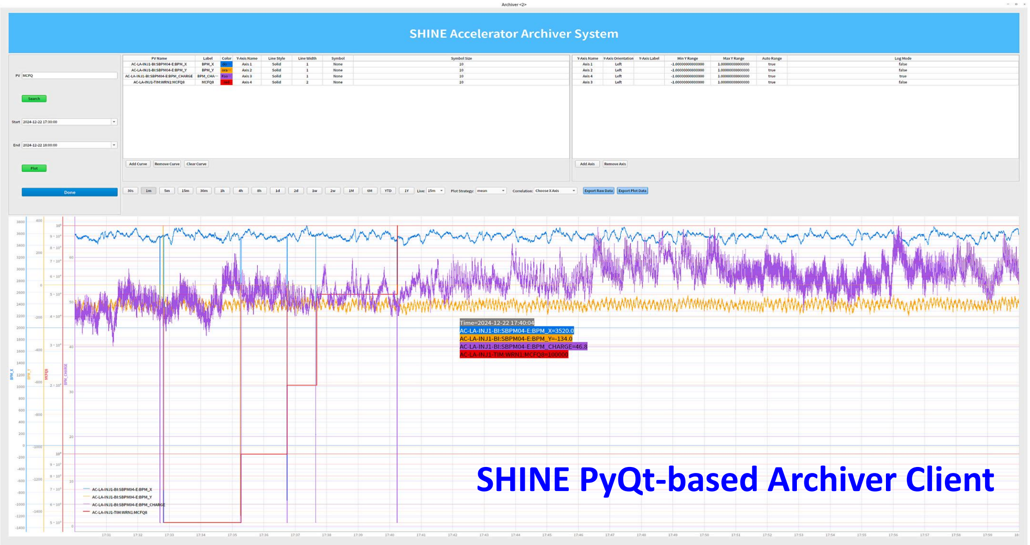
https://cs-studio.sourceforge.net/docbook/ch14.html

Archiver

- The **Archiver Appliance** is an implementation of an archiver that aims to archive millions of PVs.
- Ability to **cluster** appliances and to scale by adding appliances to the cluster.
- Multiple stages and an inbuilt process to move data between the stages.
- Focus on data retrieval performance.







SHINE PyQt-based Archiver Client

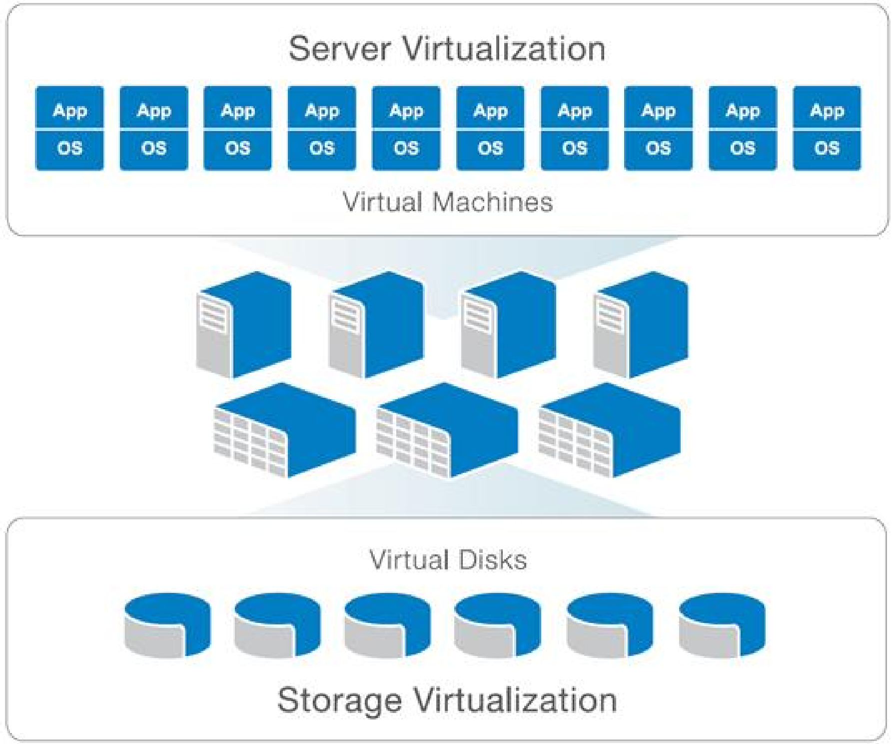
https://epicsarchiver.readthedocs.io/en/latest/

Infrastructure & Services

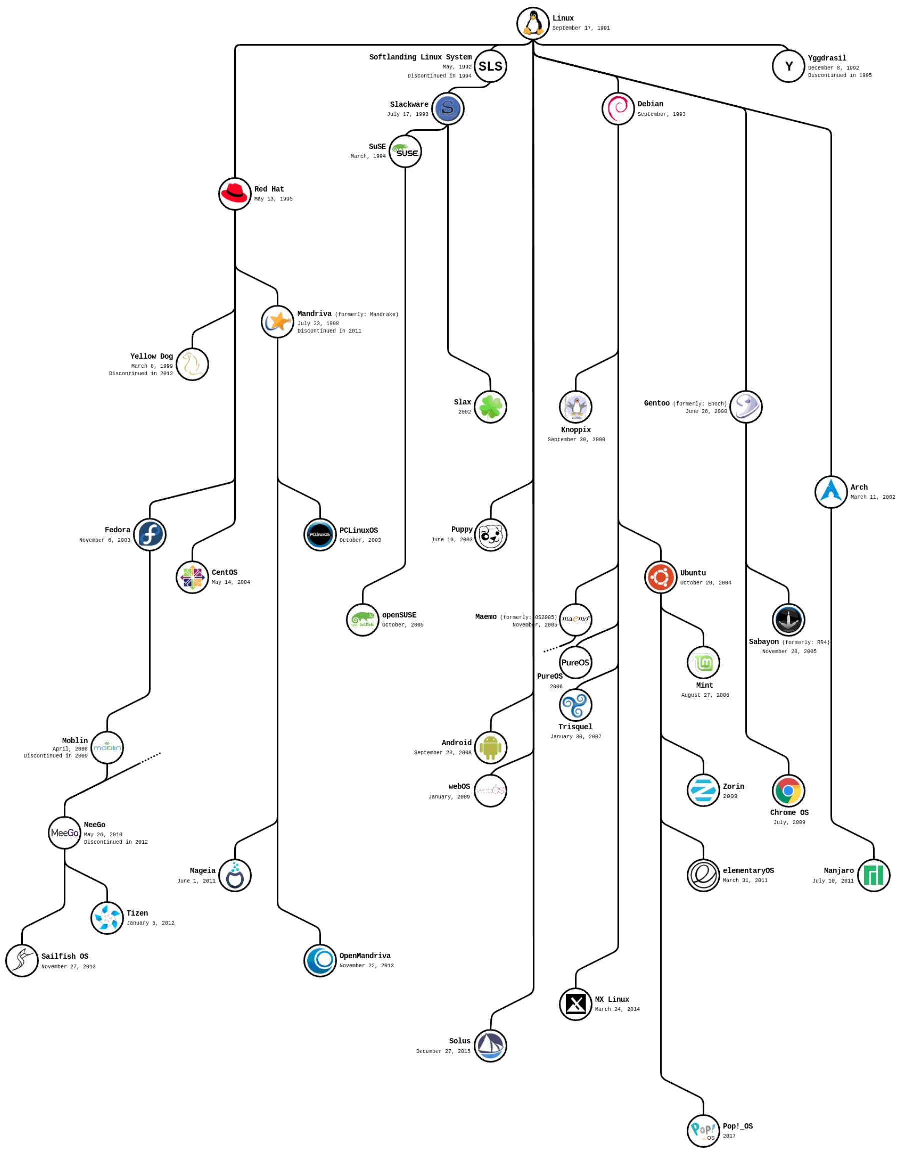
Virtualization Servers

- Virtualization servers use software (hypervisors) to create and manage **multiple virtual machines** (VMs) on the physical servers.
- Each VM runs its **own** OS and applications, sharing the host's CPU, memory, and storage.
- Maximizes HW utilization and improves system **stability**.
- KVM, VMware, Xen, Proxmox VE, Sangfor, …

Feature	Virtualization Server	Docker
Technology	Hypervisor-based	Container Engine
Isolation Level	OS-level isolation	Process-level isolation (shared OS kernel)
Performance	Higher overhead (runs full OS)	Near-native (lightweight)
Startup Time	Slow (seconds to minutes)	Fast (milliseconds)
Use Case	Running multiple OSes	Microservices, cloud-native apps
Networking	Complex (virtual switches, VLANs)	Simplified (Docker network bridges)
Orchestration	vSphere, Proxmox clusters	Kubernetes, Docker Swarm



Linux



- ❑ Linux is a **free**, **open-source** operating system based on UNIX.
- ❑ Code is freely available for modification (licensed under GPL).
- ❑ Supports **Multi-User** & **Multi-Tasking** simultaneously.
- ❑ 80,000+ free apps via package managers (apt, yum, pacman).
- ❑ Stability & Security – Rarely crashes; resistant to malware.

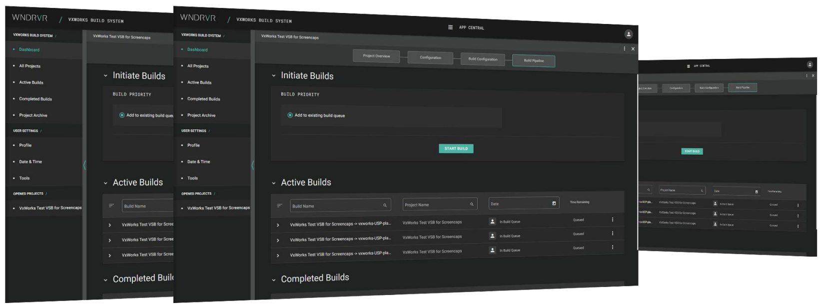
https://smarttech101.com/the-evolution-of-linux-a-journey-through-its-history-and-impact

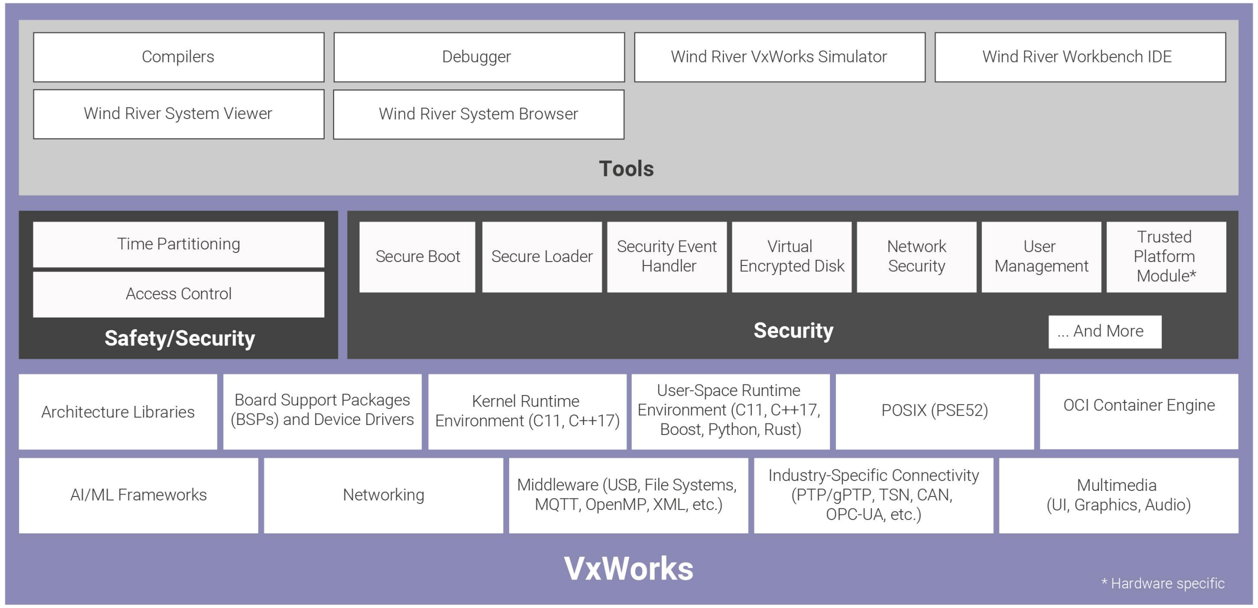
https://antix.mepis.org

VxWorks

- VxWorks is a **real-time** operating system (**RTOS**) developed by Wind River Systems, designed for mission-critical embedded systems where reliability, determinism, and low latency are essential.
- Hard Real-Time Performance – Guaranteed **microsecond-level** response times.
- Deterministic Scheduling – Tasks execute predictably (critical for safety systems).
- Certifications – DO-178C (avionics), IEC 61508 (industrial), ISO 26262 (automotive).
- Isolates processes to prevent crashes.

VxWorks





RTOS

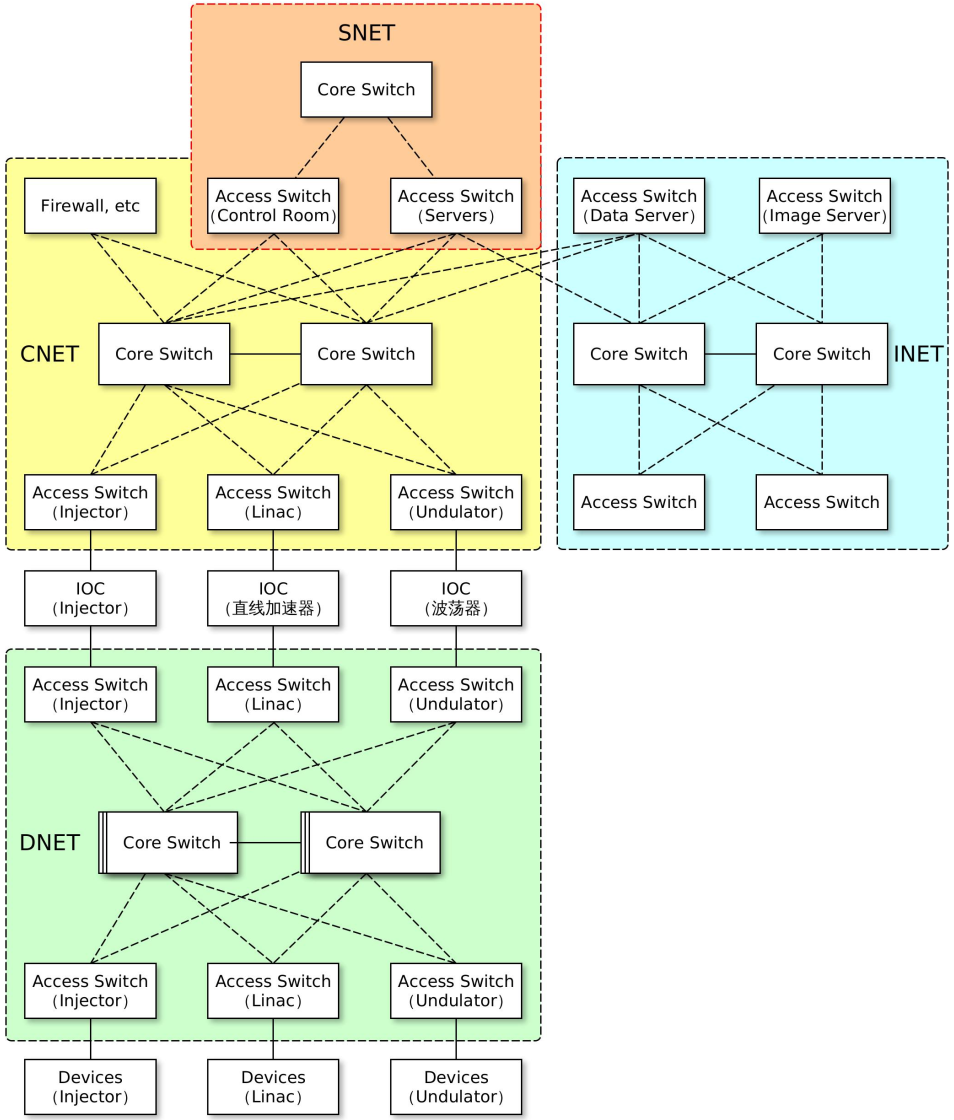
Feature	VxWorks	RTERM	QNX	FreeRTOS	Linux (RT-Preempt)
Real-Time Type	Hard RT	Hard RT	Hard RT	Soft/Hard RT	Soft RT
Determinism	Fully deterministic	Fully deterministic	Fully deterministic	Semi-deterministic	Non-deterministic (best-effort)
Multi-Core Support	Yes (SMP/AMP)	Yes (SMP/AMP)	Yes (SMP)	Limited	Yes (SMP)
Max Latency	<10 μs	<10 μs	<10 μs	~50 μs	~100 μs (with RT patches)
Safety Certifications	DO-178C, IEC 61508	DO-178C, IEC 61508, ISO 26262	ISO 26262, IEC 61508	None	None (non-safety use)
Memory Footprint	100 KB – 10 MB	50 KB – 10 MB	500 KB – 50 MB	5–20 KB	50 MB+
License	Proprietary	Proprietary	Proprietary	Open-source (MIT)	Open-source (GPL)
Use Cases	Aerospace, medical, automotive	Defense, aerospace, automotive	Automotive, medical	IoT, microcontrollers	Industrial PCs, robotics
Networking	Full networking stack	Custom TCP/IP stack	Full networking stack	Limited (lwIP)	Full networking stack

SHINE Control Network

- **CNET** : Control NETwork for OPIs, IOCs and servers.
- **DNET** : Device dedicated NETwork for IOCs and devices.
- **INET** : Image dedicated NETwork for CCDs and servers.
- **SNET** : Storage and console dedicated NETwork.

- All networks are physically isolated.
- Redundant network of double core fiber switches.
- Subnet managed by **VLAN**.
- 100Gigabit backbone, Gigabit to access equipment.

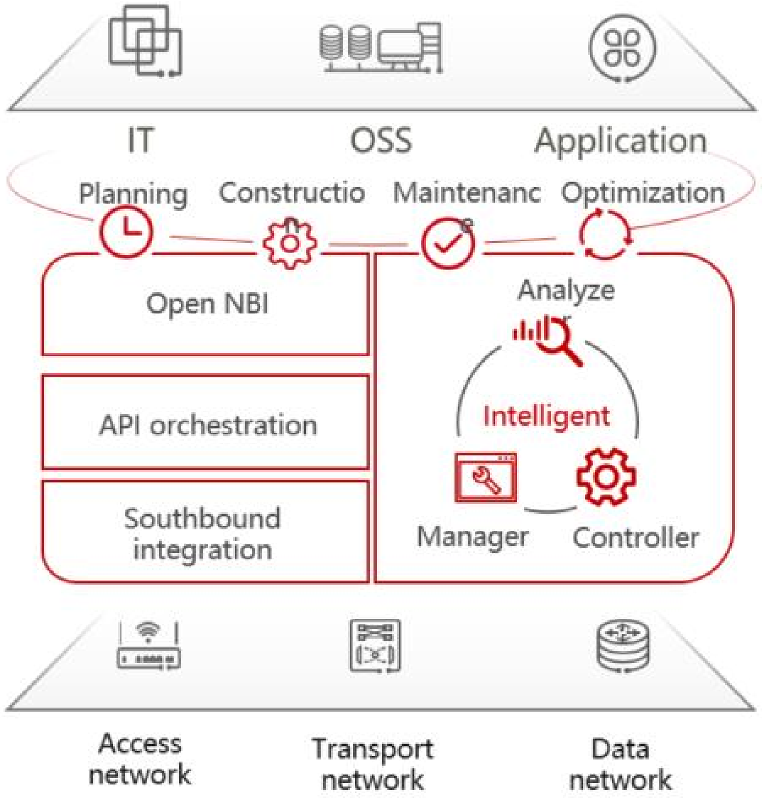
- Core Switch : HUAWEI S12700E-8
- Access Switch : HUAWEI S5736-S4874XC ~ 300

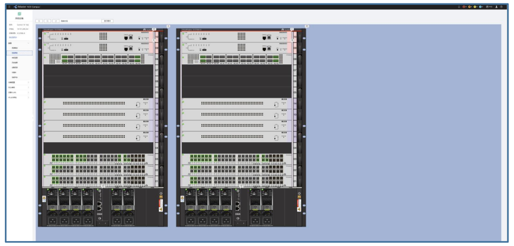


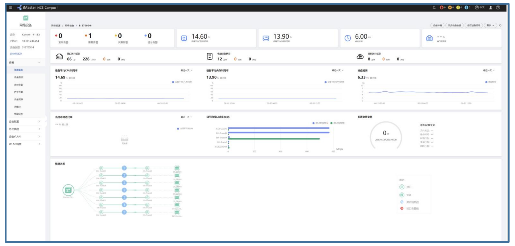
Network Management

- **Network Management System** (NMS) is a set of applications designed to **monitor**, **analyze**, and **manage** the network infrastructure (switches, routers, IoT devices,

Name	Vendor	License
iMaster NCE	Huawei	Commercial
SolarWinds NPM	SolarWinds	Commercial
Cisco DNA Center	Cisco	Commercial
PRTG Network Monitor	Paessler	Freemium (100 free)
Zabbix	-	Open-source
Nagios Core	-	Open-source
Prometheus + Grafana	-	Open-source
	…	

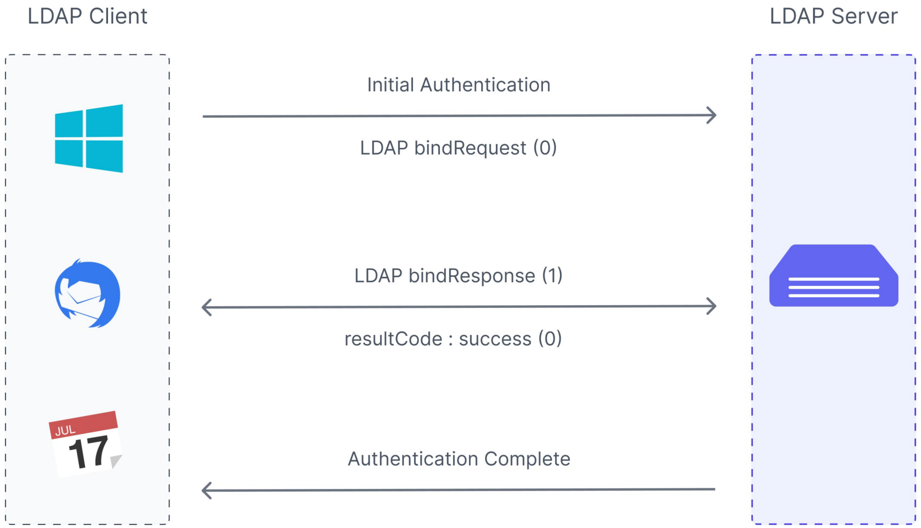






LDAP

- LDAP (**Lightweight Directory Access Protocol**) is an **open-source** application protocol that allows applications to access and **authenticate** specific user information across directory services.



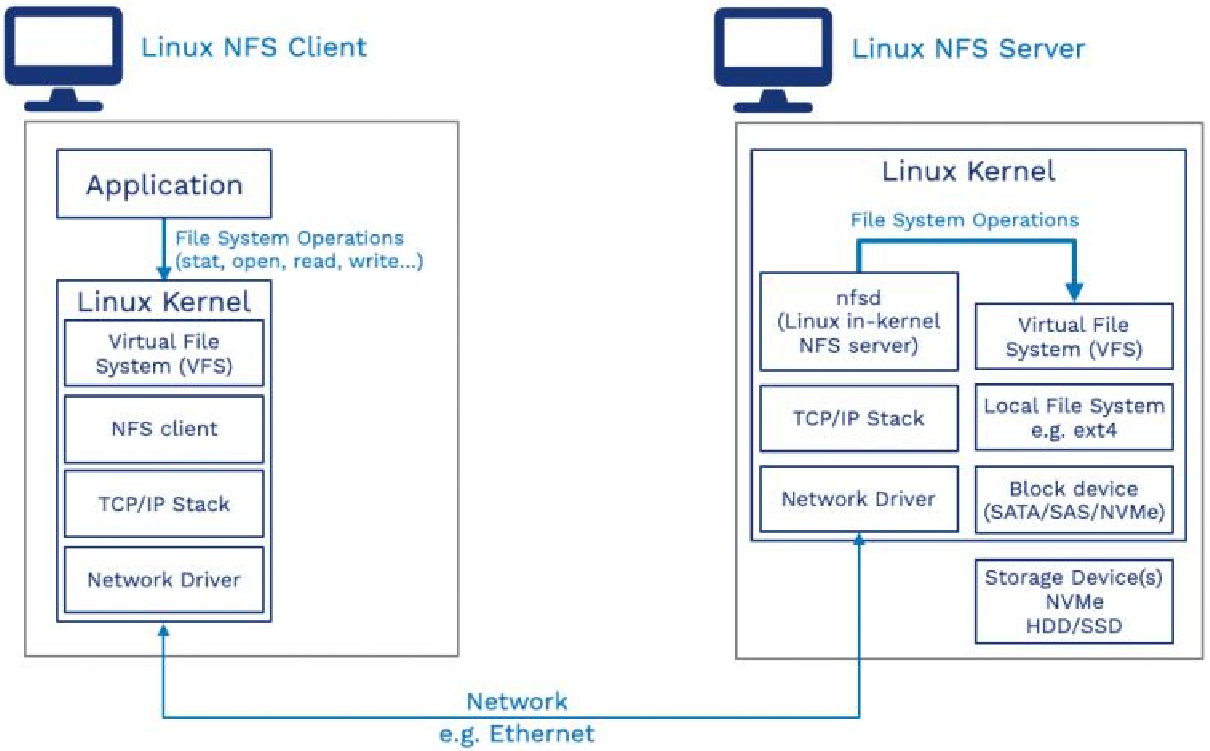
https://adaptive.live/blog/authentication-protocols-types-and-uses

Feature	LDAP Lightweight Directory Access Protocol	NIS+ Network Information Service Plus
Architecture	Hierarchical (tree-based, flexible schema)	Tabular (with improved structure over NIS)
Protocol	TCP/IP (LDAP on 389, LDAPS on 636)	RPC (with encryption support, port 111)
Security	Strong (TLS/SSL, Kerberos, SASL, ACLs)	Better than NIS (DES encryption, secure RPC) but weaker than LDAP
Scalability	Highly scalable (supports millions of entries)	Limited (better than NIS but not enterprise-grade)
Authentication	Modern (PAM, SSO, Active Directory integration)	Unix-centric (improved over NIS but still niche)
Flexibility	Highly flexible (custom schemas, multi-vendor support)	Fixed schema (but more structured than NIS)
Performance	Optimized for reads/writes in distributed systems	Faster than LDAP in small networks but less efficient at scale

NFS

- NFS (**Network File System**) is a distributed file system protocol that allows users to access and share files over a network as if they were stored locally.
- It is widely used in Unix/Linux environments for seamless file sharing between servers and clients.

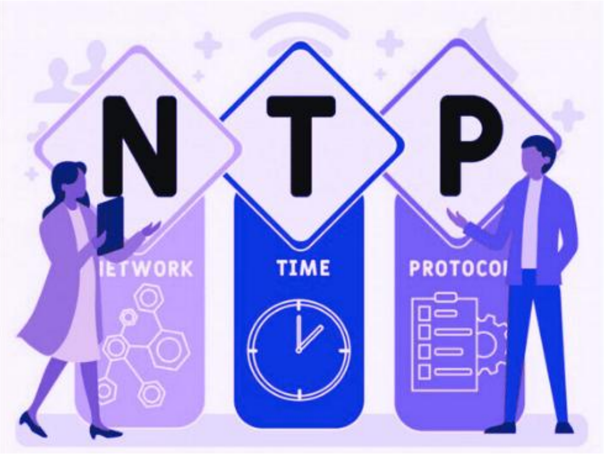
Feature	NFS	SMB/CIFS (Windows)	GlusterFS (Distributed)
Protocol	RPC (UDP/TCP)	SMB (TCP)	Custom (TCP)
Security	IP-based (v3) Kerberos (v4)	NTLM Kerberos	SSL POSIX ACLs
Performance	Good for Unix workloads	Optimized for Windows	Scalable for large data
Use Case	Linux/Unix environments	Windows networks	Cloud/ container storage

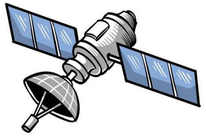


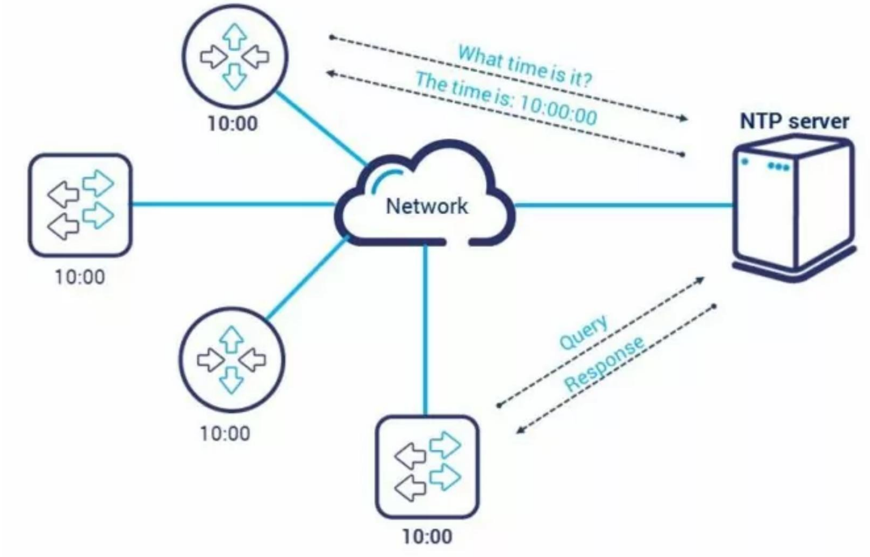
https://www.quobyte.com/storage-explained/what-is-network-filesystem/

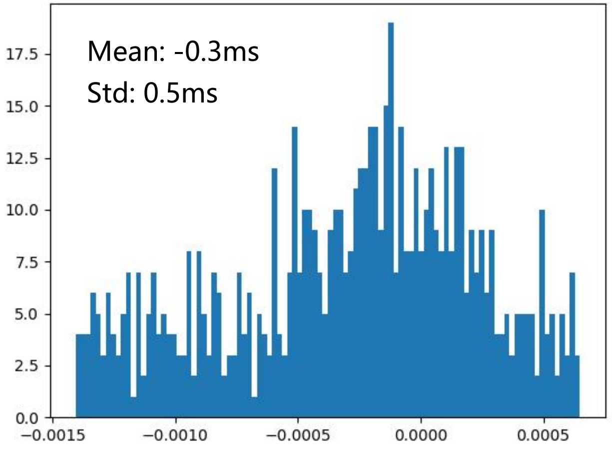
NTP

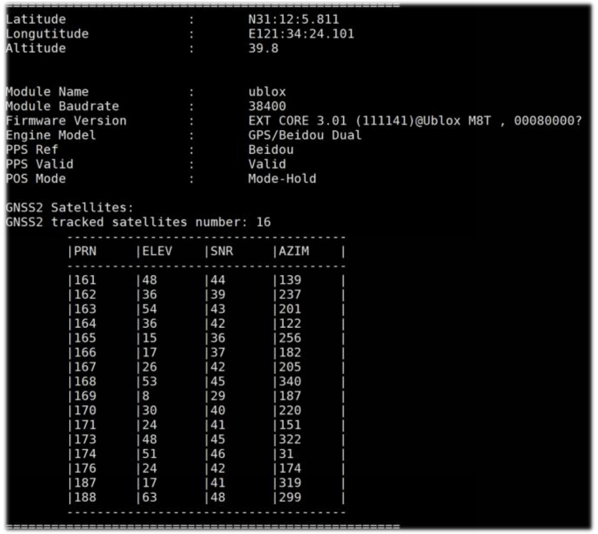
- NTP (**Network Time Protocol**) is a networking protocol used to synchronize the **clocks** of computers and devices over a network.
- Chrony is a modern time synchronization **tool** designed as an alternative to the traditional NTP daemon (ntpd).









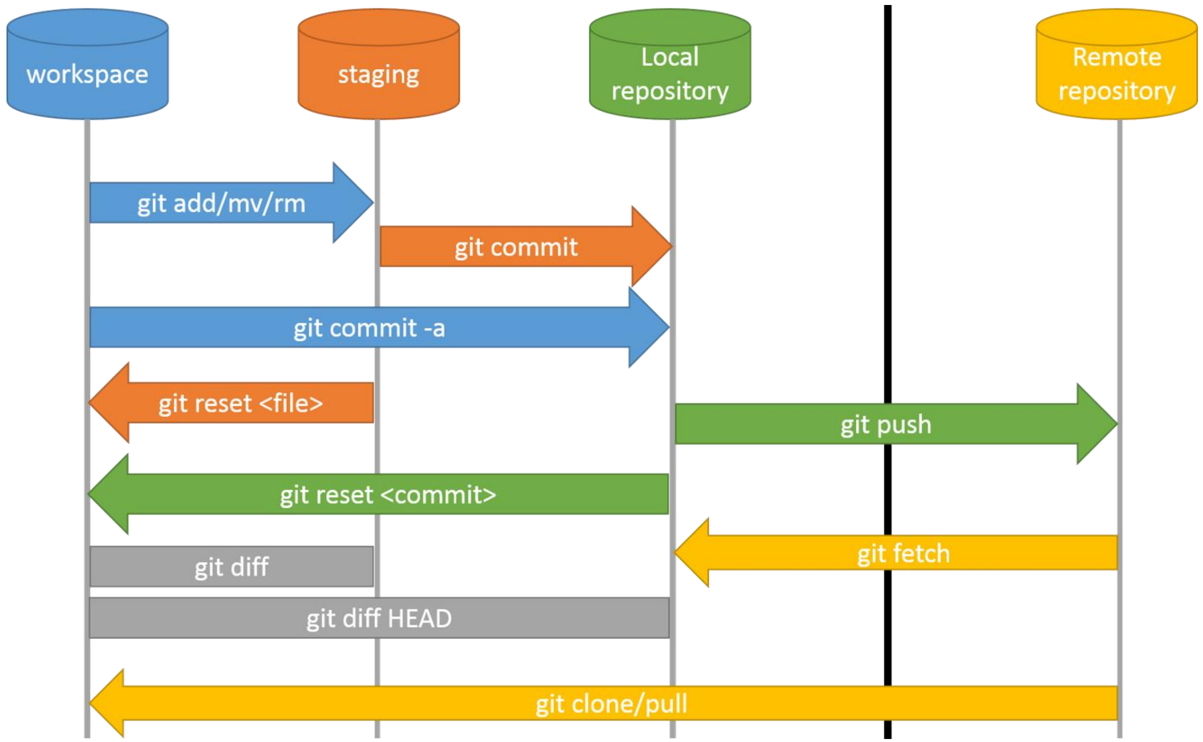


```
Latitude              :      N31:12:5.811
Longutitude           :      E121:34:24.101
Altitude              :      39.8

Module Name           :      ublox
Module Baudrate       :      38400
Firmware Version      :      EXT CORE 3.01 (111141)@Ublox M8T , 00080000?
Engine Model          :      GPS/Beidou Dual
PPS Ref               :      Beidou
PPS Valid             :      Valid
POS Mode              :      Mode-Hold

GNSS2 Satellites:
GNSS2 tracked satellites number: 16
        -------------------------------------
        |PRN     |ELEV    |SNR     |AZIM    |
        -------------------------------------
        |161     |48      |44      |139     |
        |162     |36      |39      |237     |
        |163     |54      |43      |201     |
        |164     |36      |42      |122     |
        |165     |15      |36      |256     |
        |166     |17      |37      |182     |
        |167     |26      |42      |205     |
        |168     |53      |45      |340     |
        |169     |8       |29      |187     |
        |170     |30      |40      |220     |
        |171     |24      |41      |151     |
        |173     |48      |45      |322     |
        |174     |51      |46      |31      |
        |176     |24      |42      |174     |
        |187     |17      |41      |319     |
        |188     |63      |48      |299     |
        -------------------------------------
```

https://chrony-project.org/ https://engineeringfactsz.com/what-is-ntp/

VCS

- **Git** is a distributed **version control system** (**VCS**). It helps you keep track of code changes, collaborate with other developers, and manage different versions of your codebase.
- **GitLab** is a platform that enhances Git with collaboration, automation, and DevOps features.



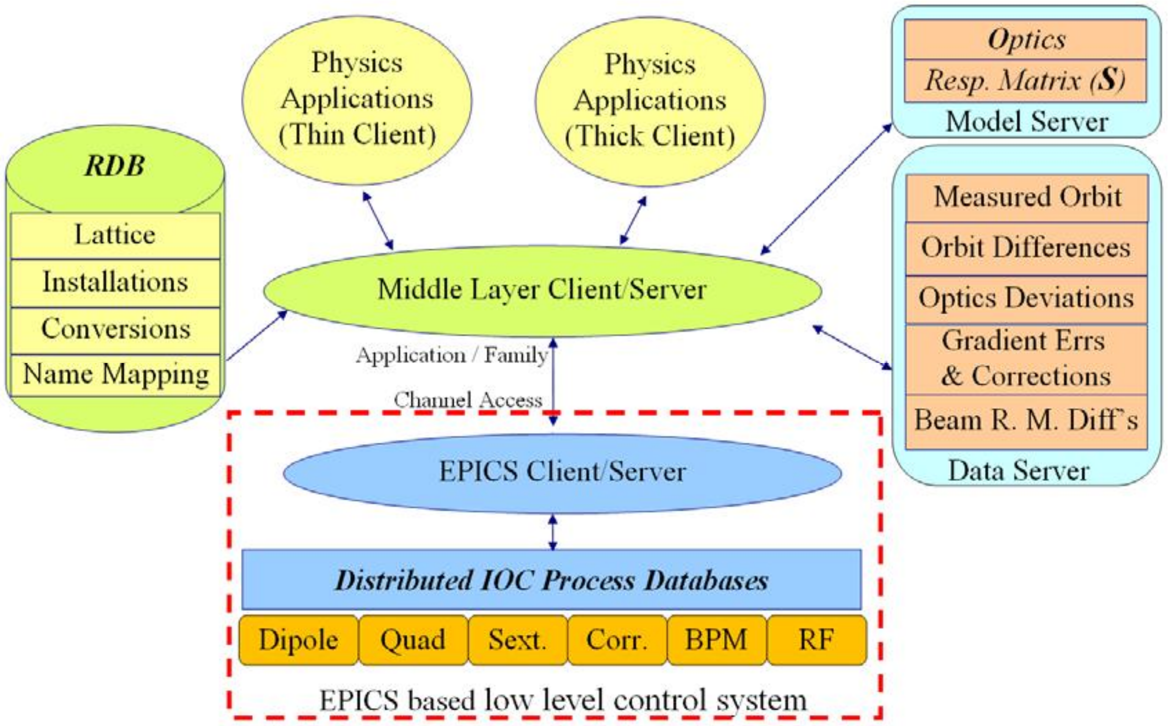
Feature	GitLab	GitHub
Free Private Repos	☑	☑ (now)
CI/CD Built-in	☑	☒
Self-Hosting	☑	☒ (except GitHub Enterprise)
Community Size	Smaller	Larger

git GitLab GitHub

High-Level Applications

- HLAs are software tools used for beam optimization, control, and physics modeling.
- **AT (Accelerator Toolbox)**
  - Matlab-based library for accelerator physics modeling and beam dynamics simulations.
  - Developed by ESRF, now widely used.
- **Open XAL**
  - Java/Python framework for online accelerator physics applications developed by ORNL.
- **LOCO** (Linear Optics from Closed Orbits)
  - Correct accelerator optics using BPM data.
  - Used at LCLS, NSLS-II, DLS, SSRF, ...

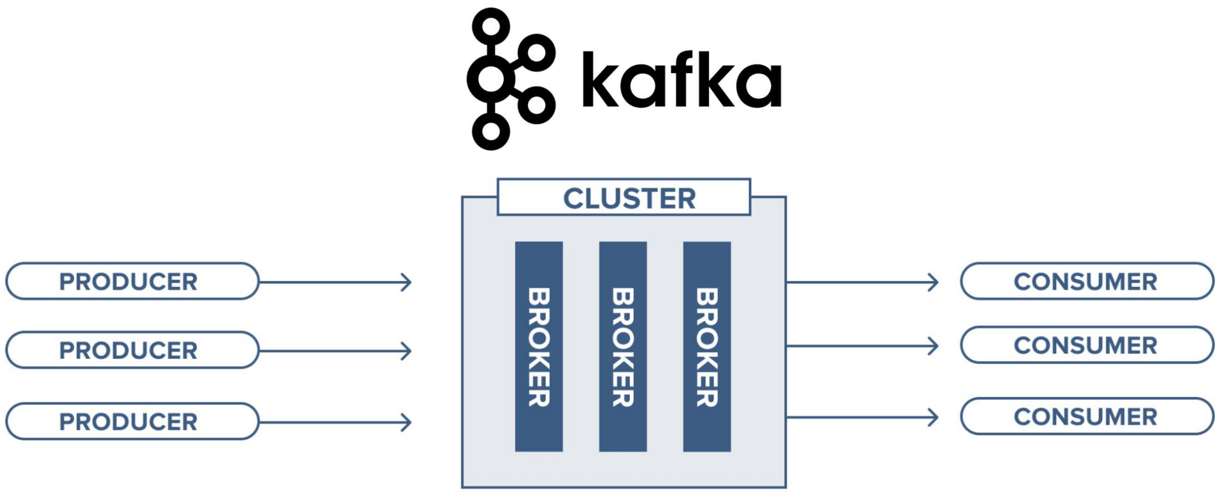
...

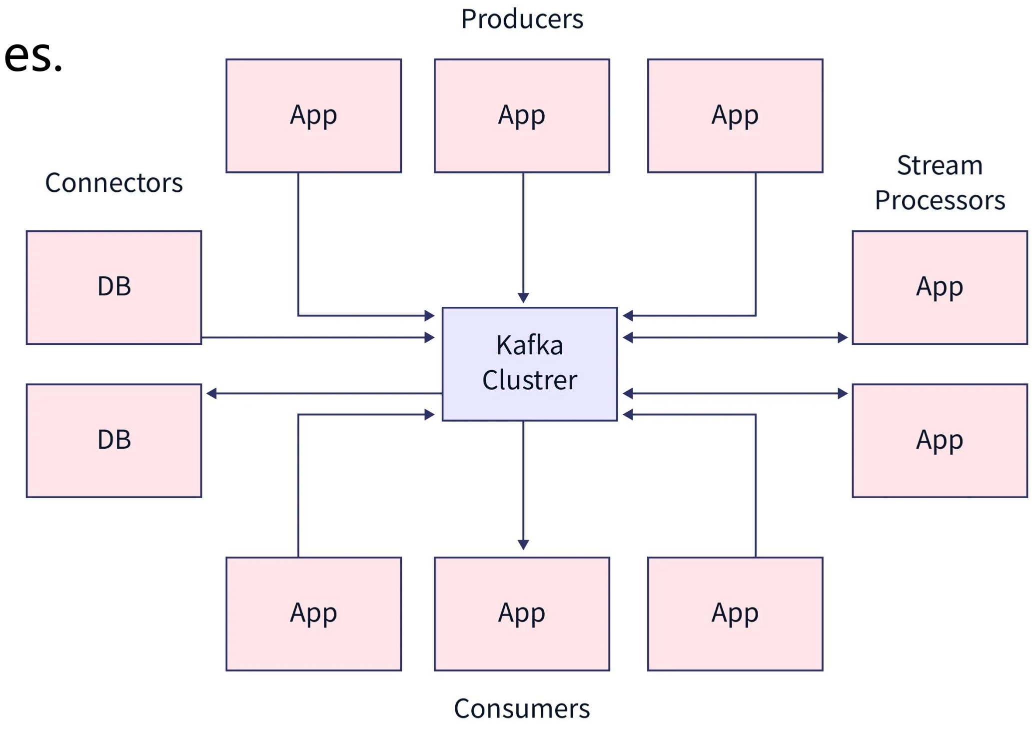


NSLS-II High Level Application Architecture (G.B. Shen)

Kafka

- Apache Kafka is an **open-source**, distributed data store optimized for ingesting and processing **streaming data** in real-time.
- It was originally developed by LinkedIn and later donated to the Apache Software Foundation.
- High Throughput – Handles millions of messages per second.
- Fault Tolerance – Replicates data across multiple nodes.
- Low Latency – Delivers messages in milliseconds.





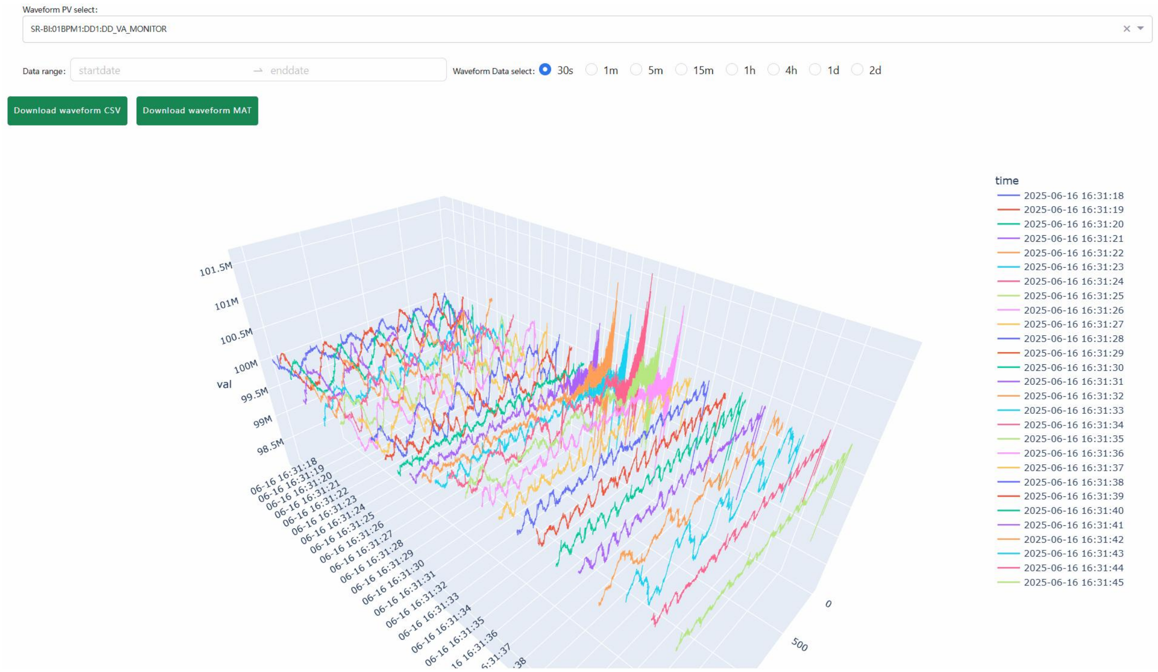
ZeroMQ

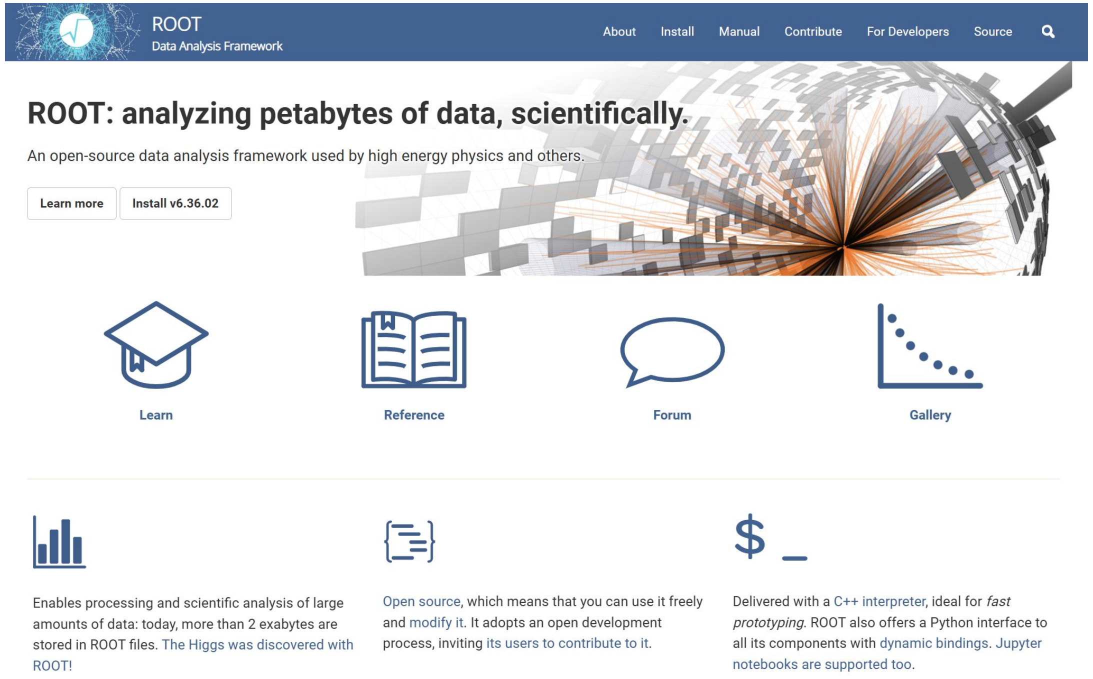
- **ZeroMQ (ZMQ)** is a high-performance, **asynchronous messaging library** designed for distributed and concurrent applications.
- Brokerless Architecture – Direct peer-to-peer communication.
- Multiple Transport Protocols – Supports TCP, IPC, WebSocket, multicast.
- Flexible Messaging Patterns – Pub/Sub, Request/Reply, Pipeline, etc.
- Lightweight – Tiny footprint (~50KB core library).

Feature	Apache Kafka	ZeroMQ	RabbitMQ	ActiveMQ
Architecture	Distributed log (brokered)	Brokerless (P2P sockets)	Centralized broker	Centralized broker
Messaging Model	Pub/Sub + Stream Processing	Pub/Sub, Req/Rep, Pipeline, etc.	Pub/Sub, Queues (AMQP)	Pub/Sub, Queues (JMS/AMQP)
Latency	ms to sec (batch optimized)	µs to ms (lowest)	ms	ms
Use Cases	Event streaming, log aggregation	Microservices, HFT, IoT	Task queues, workflows	Enterprise messaging

Data Storage and Analysis

- Accelerators generate **massive volumes of data** from control systems, beam diagnostics and detectors.
- Efficient data storage and analysis require specialized architectures and tools.
- Data Storage: Archiver Appliance, HDB++, HDF5, ROOT, MongoDB, ...
- Data Analysis: JupyterHub, MadAnalysis5, Psana, TensorFlow, PyTorch, ...

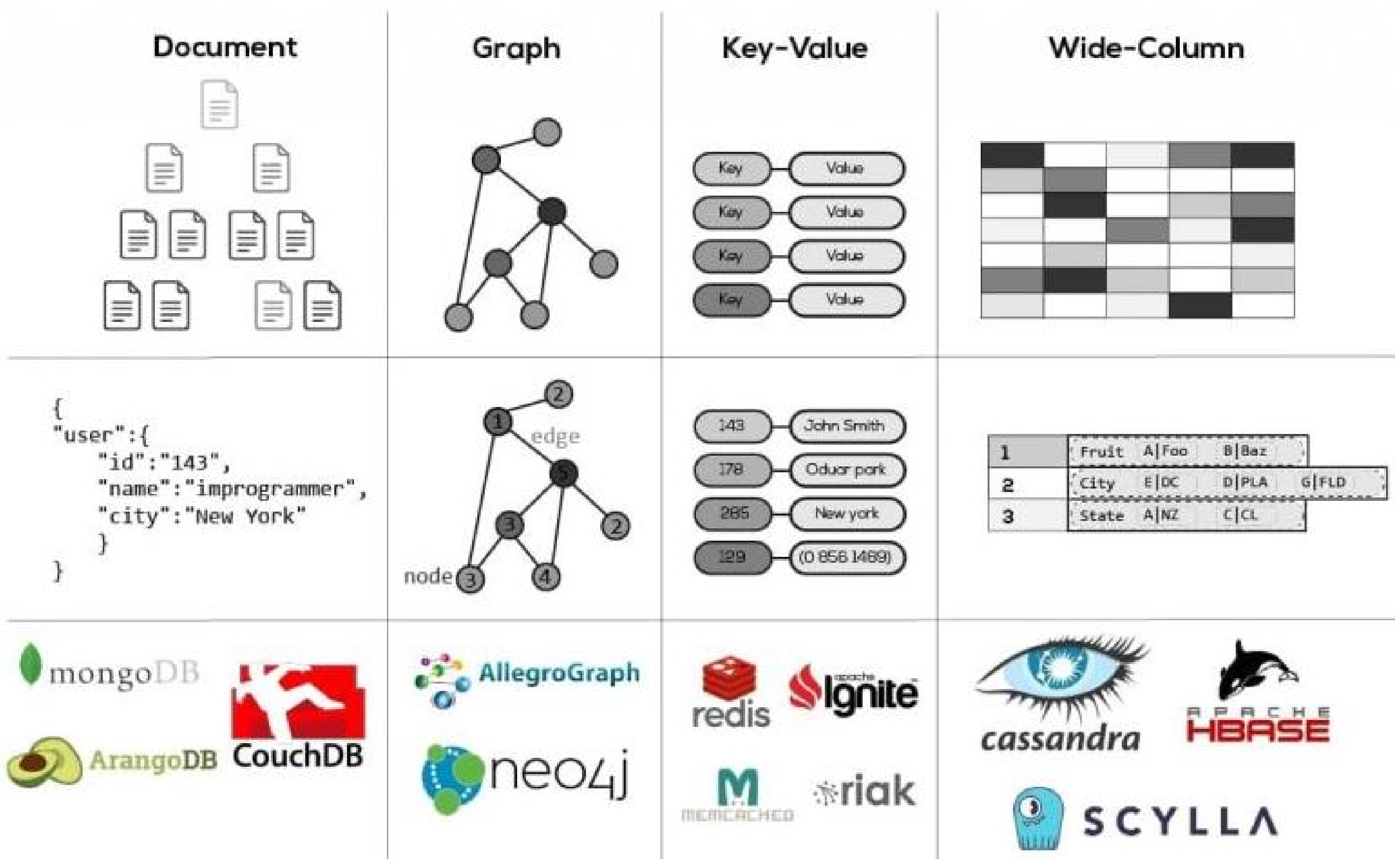




https://root.cern.ch/

NoSQL Database

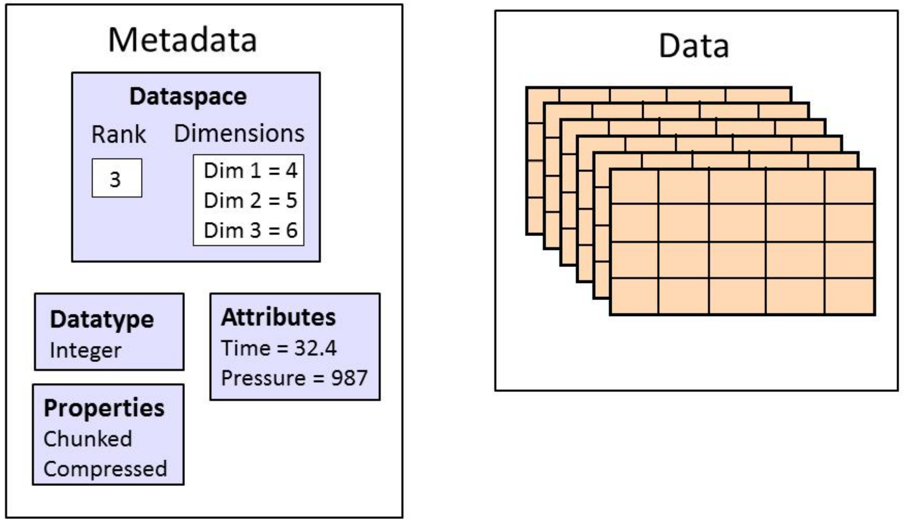
- NoSQL (**Not Only SQL**) is a type of database management system designed to handle and store large volumes of **unstructured** and **semi-structured** data.
- Unlike traditional relational databases that use tables with pre-defined schemas, NoSQL databases use **flexible data models** that can adapt to changes in data structures and scale horizontally to handle growing amounts of data.

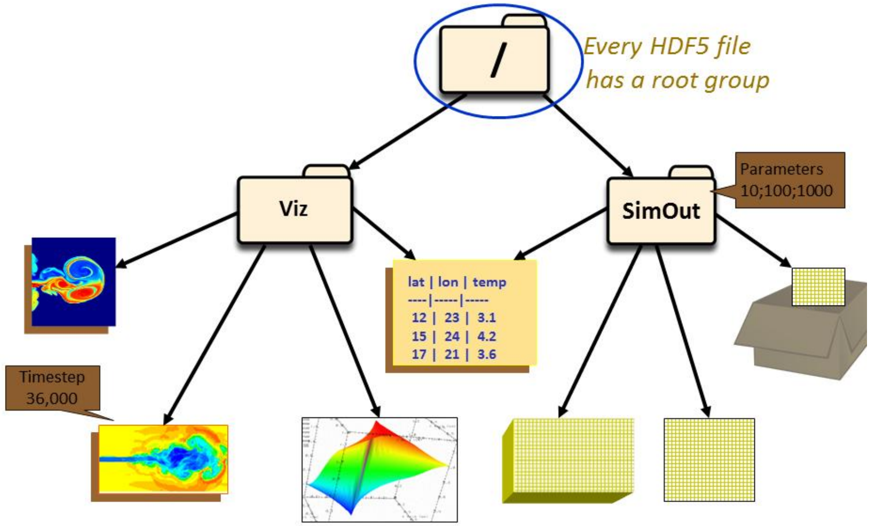


https://miska.co.in/how-do-nosql-databases-work/

HDF5

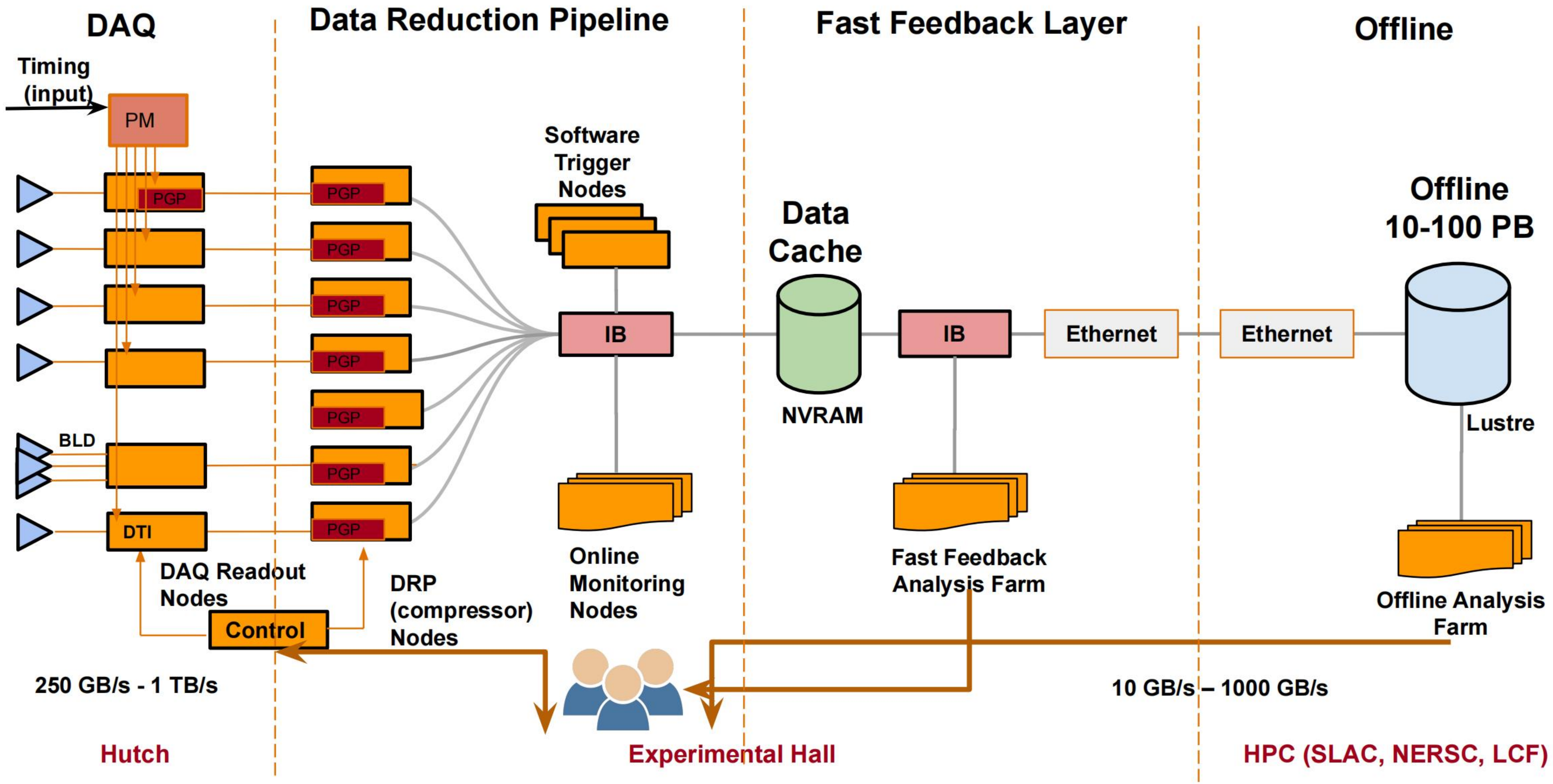
- HDF5 (**Hierarchical Data Format version 5**) is an **open-source** file format and data model designed for storing and managing large, complex datasets efficiently.
- It is widely used in scientific computing, big data analytics, and high-performance computing due to its flexibility, scalability, and support for heterogeneous data.
- HDF5 file can be thought of as a **container** that holds a variety of heterogeneous data **objects** (or **datasets**).
- A dataset consists of **metadata** that describes the data, in addition to the data itself.





https://support.hdfgroup.org/documentation/hdf5/latest/_intro_h_d_f5.html

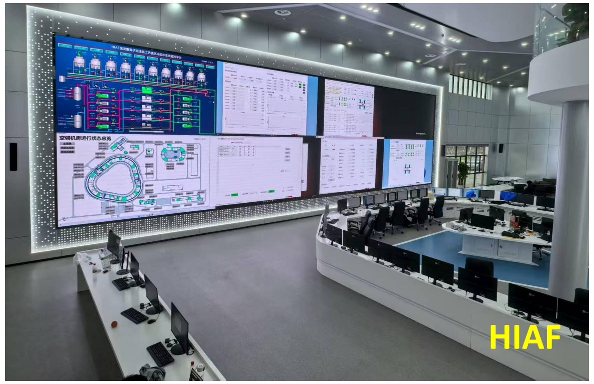
Data Acquisition and Analysis

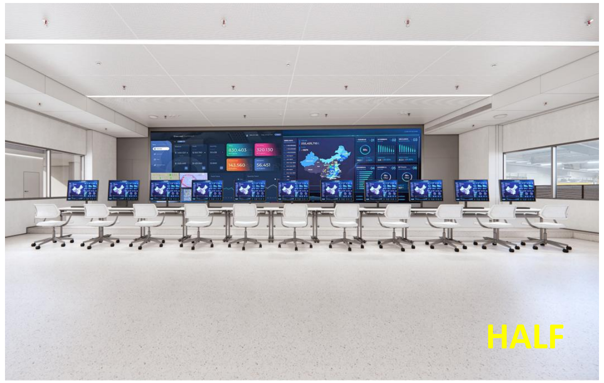


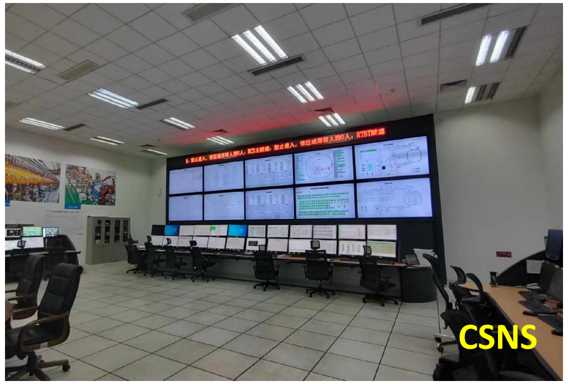
Christopher O'Grady, 1MHz 20GB/s Data Acquisition and Analysis at LCLS-II

Control Center

- It is the central hub where operators, physicists and engineers monitor and control the accelerator.
- It is also an important external interface for large-scale scientific facilities.
- Terminals, large screen, network, interlock(emergency stop, modes) , audio & video system.







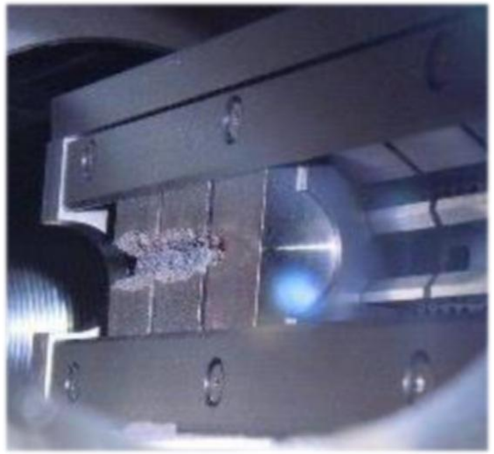
Machine Protection

Some materials and ideas are copied from Jörg Wenninger and Markus Zerlauth (CERN)

Definition

Accelerators, as all other technical systems, must respect some general principles with respect to safety.

- Protect the people (legal requirements).
- Protect the environment (legal requirements).
- Protect the equipment (asset management).
    - Without beam : superconducting magnets, RF systems, etc.
    - **With beam: damage caused by beams.**
- Those 3 aspects may be coupled in some circumstances!



Machine Protection is focused on equipment protection from damage caused by beams.

Risks and Protection

- Protection is required since there is some risk.

Risk = **Probability** of an accident

x **Consequences** (money, downtime, radiation doses)

- Probability of an uncontrolled beam loss:
  - What are the failures that lead to beam loss into equipment?
  - What is the probability for the failure modes?
- Consequences:
  - Damage to equipment.
  - Downtime of the accelerator for repair.
  - Activation of material, dose to personne.

5 Catastrophic	1	2	3	4	5
4 Major	0	1	2	3	4
3 Severe	0	0	1	2	3
2 Minor	0	0	0	1	2
1 Slight	0	0	0	0	1
	A 1/10000 Years	B 1/1000 Years	C 1/100 Years	D 1/10 Years	E 1/1 Year

The higher the risk, the more protection becomes important !

Objectives (P^3)

- **Protect the machine**
  - Highest priority is to avoid damage of the accelerator.
- **Protect the beam**
  - Complex protection systems reduce the availability of the accelerator, the number of 'false' interlocks stopping operation must be minimized.
  - Trade-off between protection and operation.
- **Provide the evidence**
  - Clear (post-mortem) diagnostics must be provided when:
    - the protection systems stop operation,
    - something goes wrong (failure, damage, but also 'near miss')

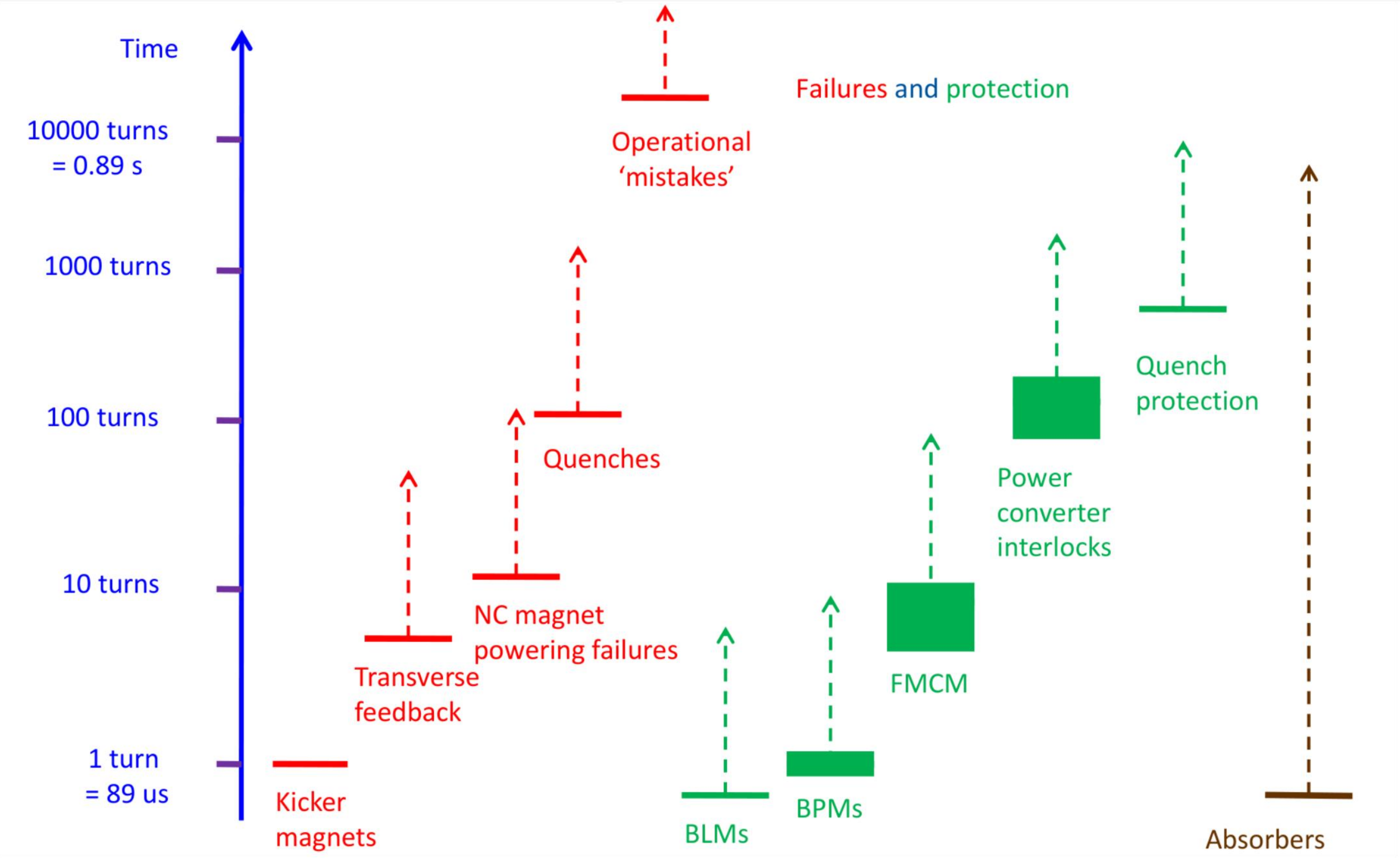
Failure Classification

- Failure type:
  - **Hardware failure** (AC distribution failure, vacuum leak, RF trip, ...).
  - **Controls failure** (wrong data, trigger problem, feedback failure, ...).
  - **Operational failure** (chromaticity / tune / orbit errors, ...).
  - **Beam instability** (high beam / bunch current).
- Failure parameters:
  - **Damage** potential.
  - **Probability** for the failure.
  - **Time constant** for beam loss.
- Machine state (when failure occurs):
  - Linac, beam transfer, injection and extraction (single pass).
  - Stored beam.

Design Strategy

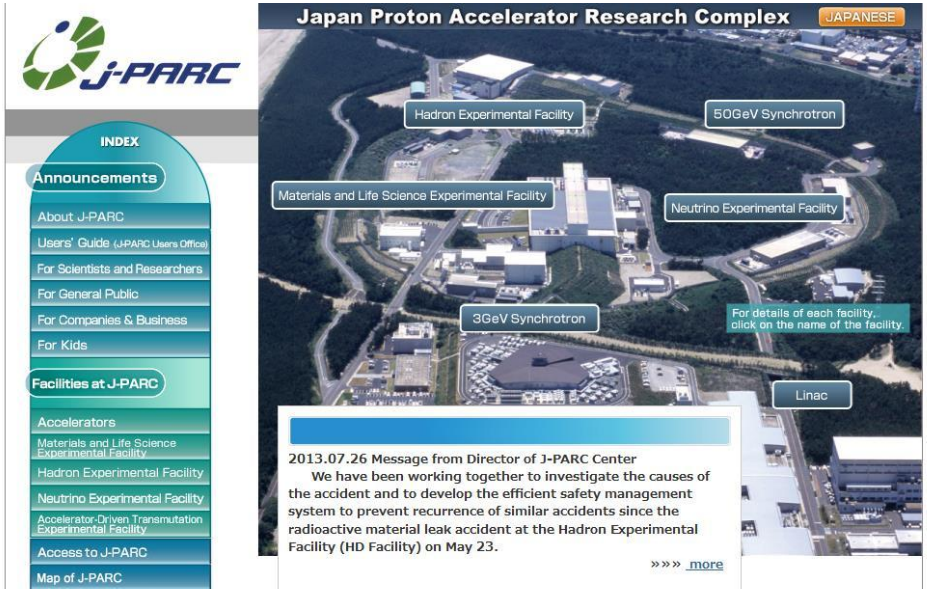
- Avoid a failure by design – if you can.
- **Detect a failure at the hardware** (equipment) level and stop operation. – 1st protection layer
- **Detect the consequences of the failure** on beam parameters (orbit, tune, losses etc) and stop operation. – 2nd protection layer
- Stop beam operation
  - Inhibit injection,
  - Send beam to a dump,
  - Stop the beam by collimators / absorbers.
- Elements of protection:
  - Equipment and beam monitoring,
  - Collimators and absorbers,
  - Beam dumps,
  - Interlock system linking different systems.

Timescales @ LHC



Failure Analysis

- **Figure out what can go wrong…**
- Requires good understanding of accelerator physics: how does a given element affect the beam?
- Requires good understanding of the hardware: time scales, failure modes?
- Requires a complete overview of all machine equipment that affect the beam.
- The analysis must be done systematically for every system, from bottom up – including the software/controls.



- Due to a power converter failure, a slow extraction was transformed into a fast extraction.

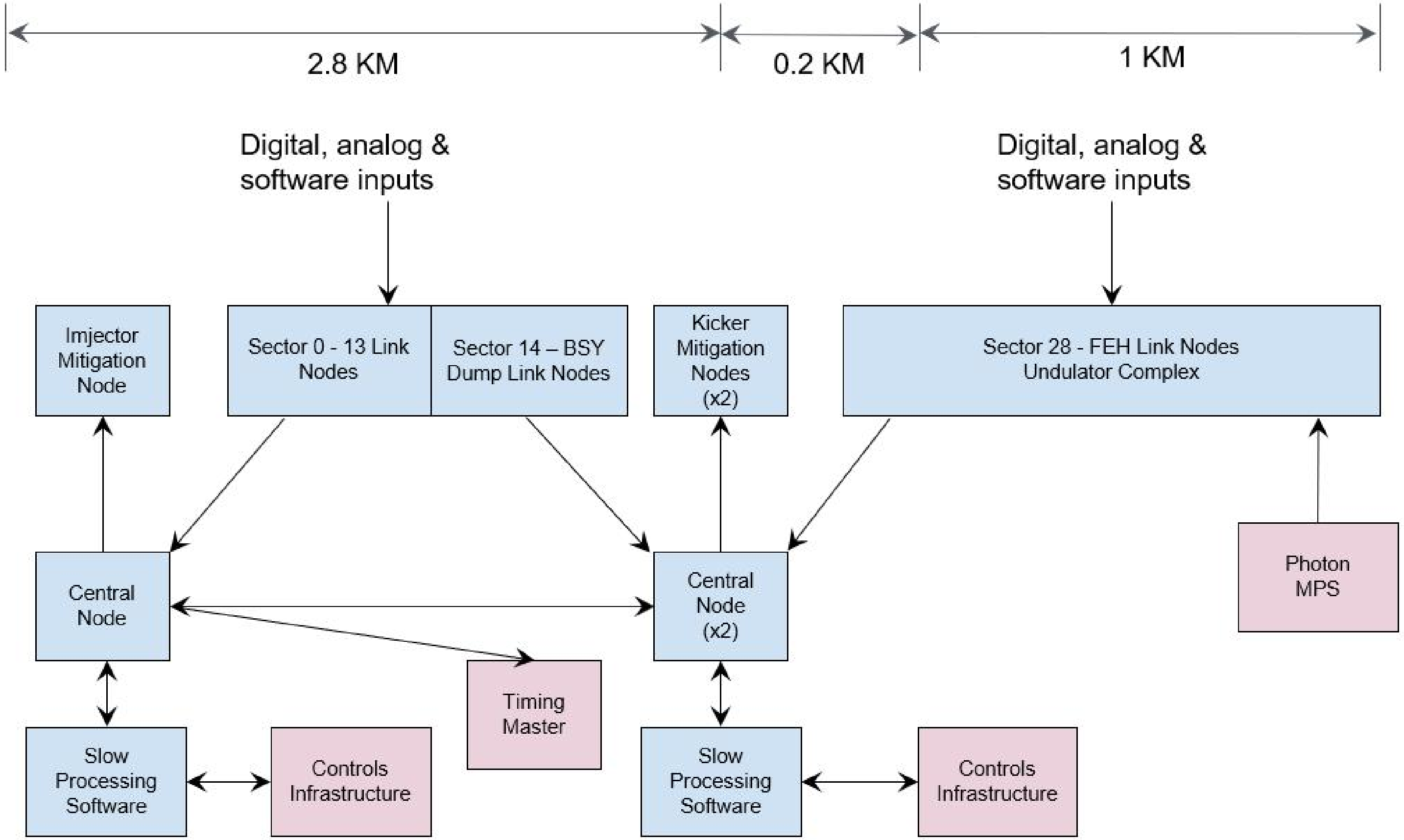
  Extraction in milliseconds instead of seconds.
- As a consequence of the high peak power a target was damaged and radio-isotopes were released into experimental halls.

  Machine protection coupled to personnel protection !

One insufficiently covered failure case had major consequences !

Architecture

- MPS is comprised of a collection of distributed nodes that collect and process data and send them off the central node.
- The central node collects the data and compares them against a pre-programmed logic table to determine the overall state of the accelerator.
- The output is then distributed to the destination nodes for certain action.



J. A. Mock, Commissioning of the LCLS-II Machine Protection System for MHz CW Beams

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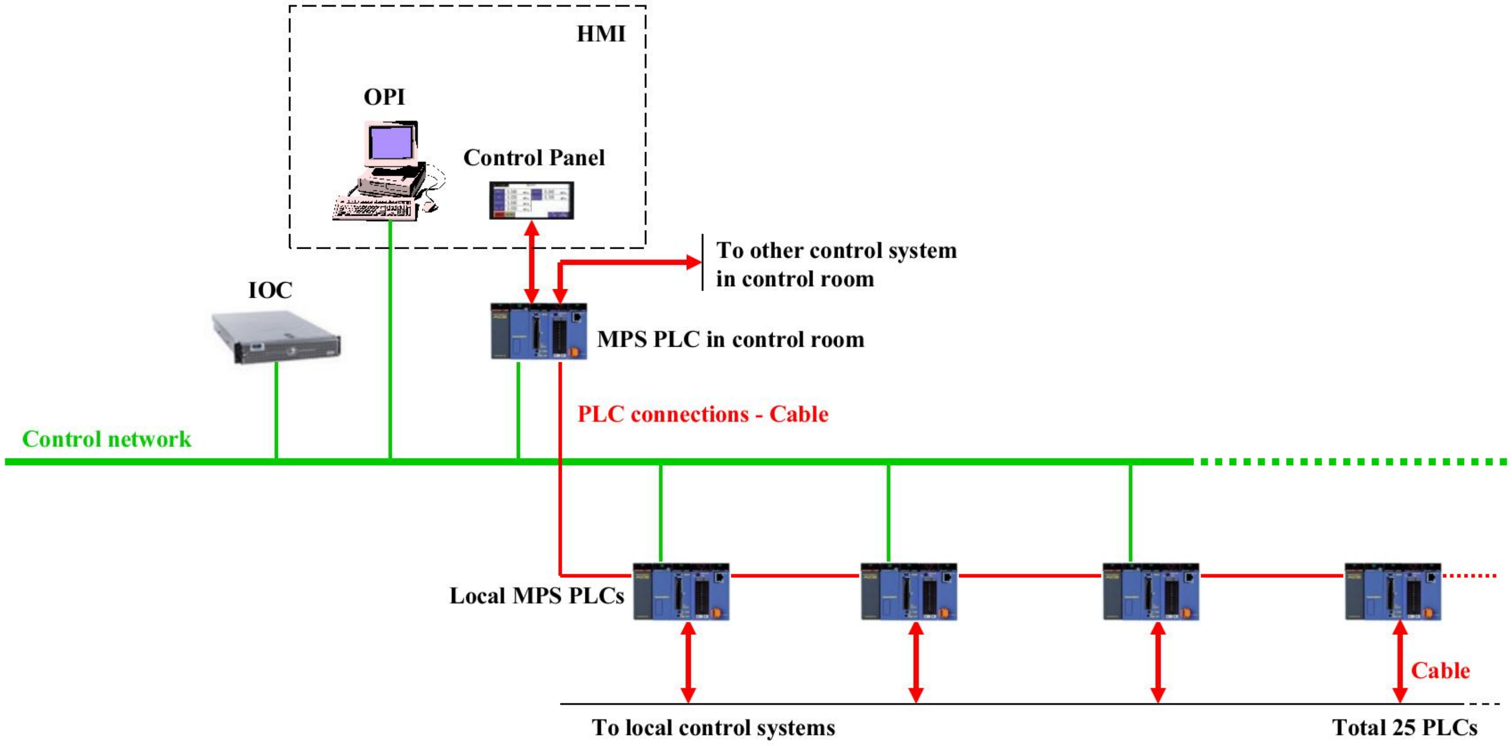
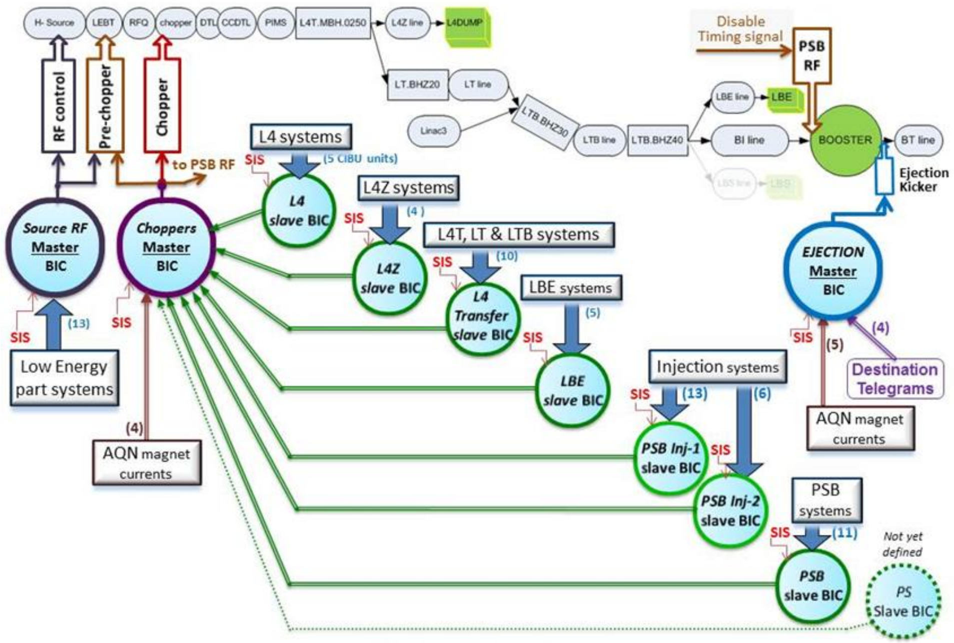


Truth Table

- Truth Table defines the **relationship** between **inputs** (sensor signals, faults, or triggers) and **outputs** (protective actions, interlocks, or alarms).

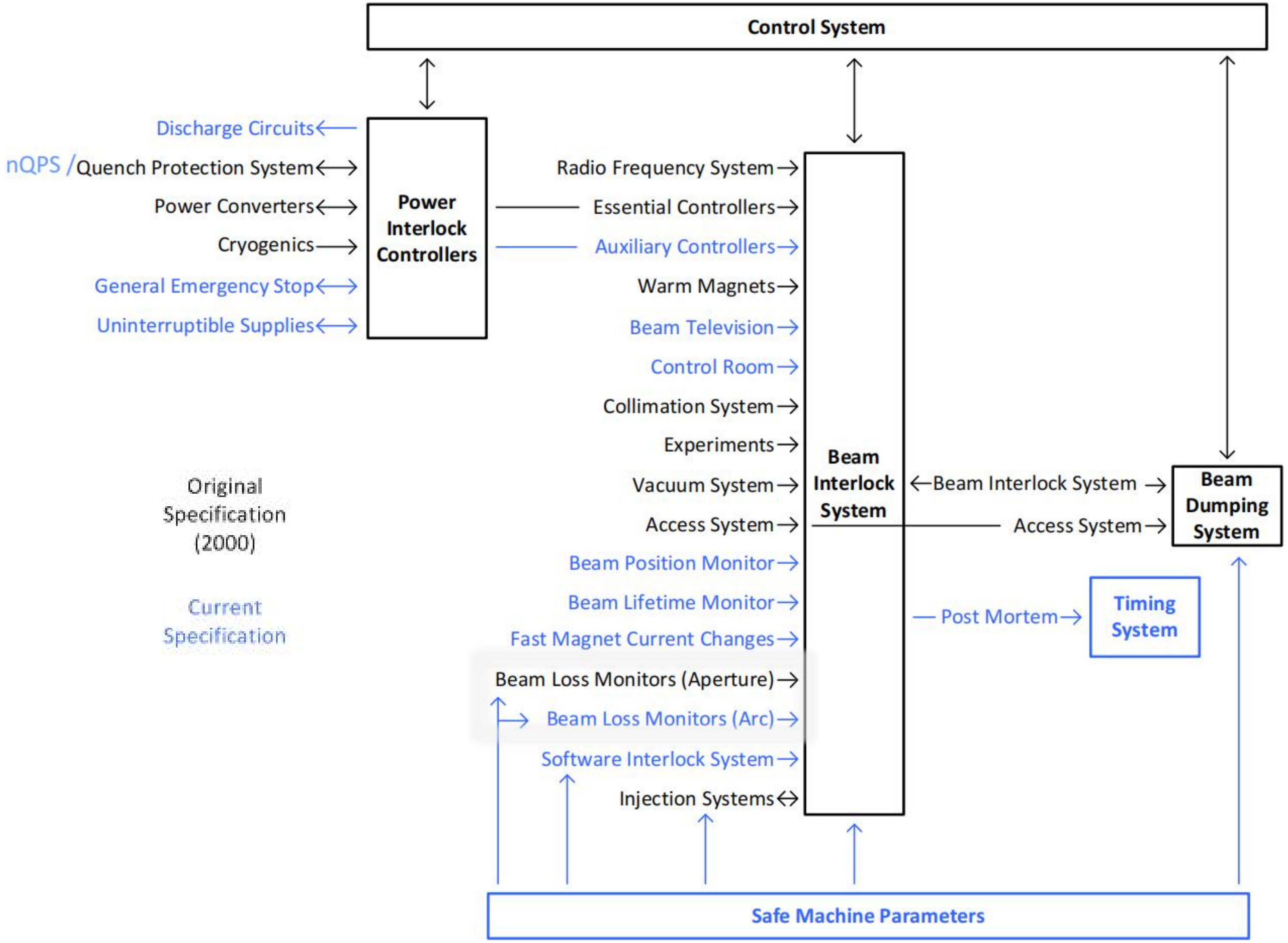


BIS Linac4 & PSB layout

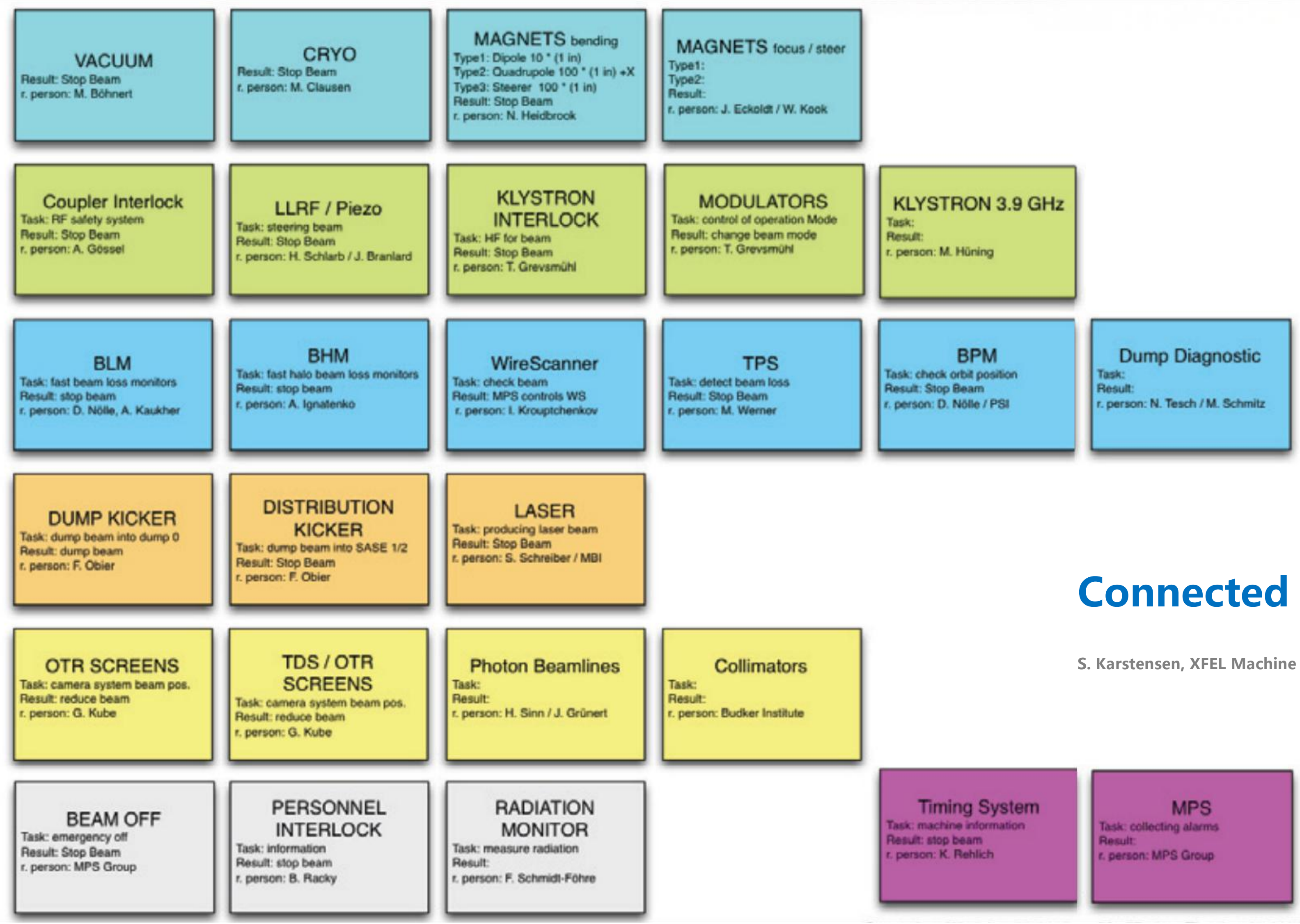
Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT	
Interlock Element	**SIS**	**Linac4 OK**	**AQN L4T.MBH_DUMP**	**L4Z OK**	**AQN L4T.MBH_L4T**	**Linac4 Transfer OK**	**AQN LTB.BHZ40_LBE**	**LBE OK**	**AQN LTB.BHZ40_PSB**	**PSB Injection-1 OK**	**PSB Injection-2 OK**	**PSB OK**	Destination PS	**PS OK**	*Not used*	**Choppers Beam_Permit**	
	1	1	1	1	0	x	x	x	x	x	x	x	x	x	x	1	Beam to Dump
	1	1	0	x	1	1	1	1	0	x	x	x	x	x	x	1	Beam to LBE
	1	1	0	x	1	1	0	x	1	1	1	1	x	x	x	1	Beam to PSB
	1	1	0	x	1	1	0	x	1	1	1	1	1	1	x	1	Beam to PS

Continue to learn

- MPS architecture is constantly **evolving**, more interlock conditions request an abort of the beam.
- In addition every year some major **changes** to operational systems that require tracking and follow-up (threshold changes, maintenance/ replacement of components, operational tools, procedures,…)



Interface

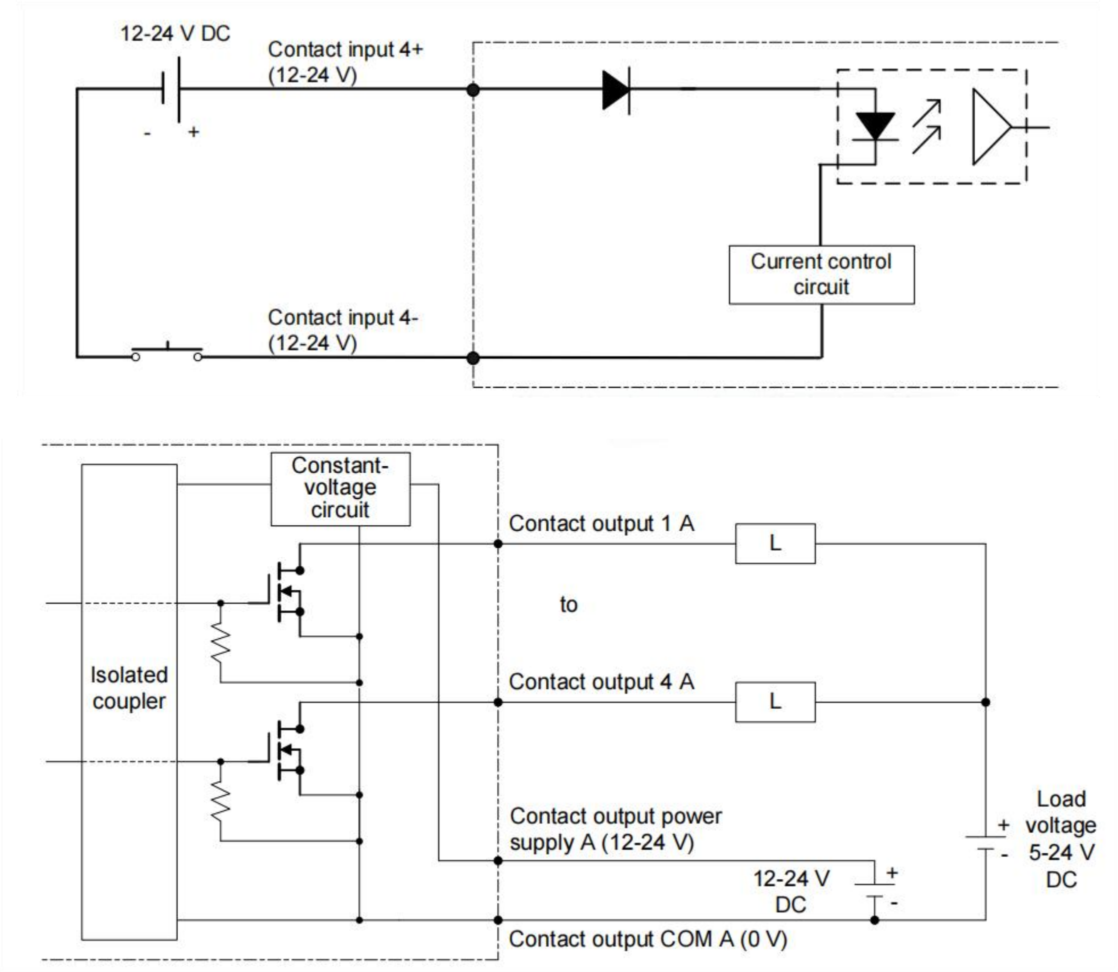


Connected systems to MPS

S. Karstensen, XFEL Machine Protection System based on uTCA, ICALEPCS 2013

Hardware

	PLC	FPGA
Speed	Moderate (10-50ms)	Ultra-fast (100ns - 10μs)
Determinism	Soft real-time (jitter)	Hard real-time (precise timing)
Complexity	Simple to medium logic	High-speed parallel logic
Flexibility	Easily reprogrammed	Fixed logic (hard to modify)
Standards	Certified (SIL 3/PL e)	Custom safety validation needed
Development	Faster (ladder logic)	Slower (VHDL/Verilog coding)

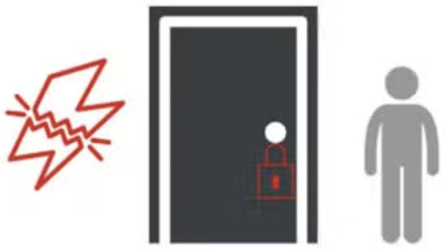


Yokoyama PLC input and output diagram

Principle

- **Isolation**: Full input/output isolation preferred; output isolation mandatory.
- **Cabling**: Shielded twisted pair (<200m), dual-end grounding (or input-side grounding if restricted).
- **Fail-Safe**: defaults to a safe state in the event of a failure (e.g., power loss, broken wire, or malfunction).

Fail Safe - When looking at fail safe locks this means that it's defaut state is actually unlocked.
To keep it locked during normal business operations, power is applied.
Should the power be interupted or fail, the door automaticaly unlocks or releases to let people out of the space.
That's why it's called "safe"-it's safe forpeople-not the space!

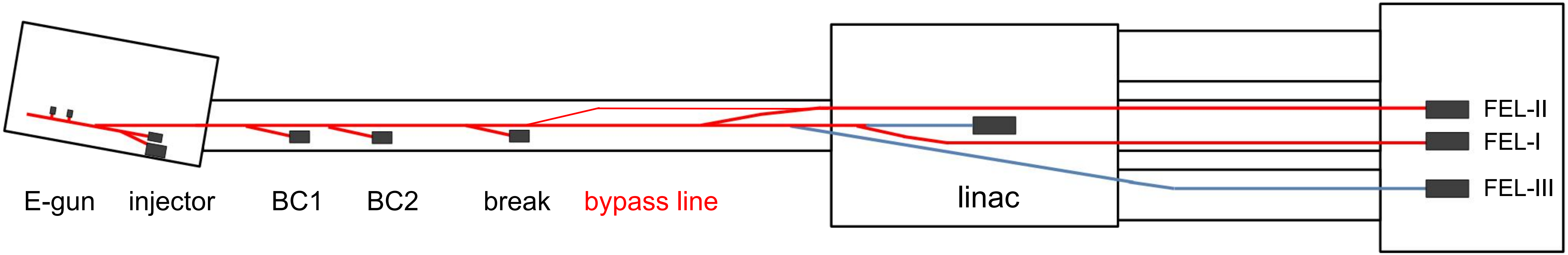


Fail Secure - fail secure means that if the power is interrupted, the door stays locked.
That's why it's called "secure"
It's default state is locked or secured. So a falsecure lock locks the door when power is removed.
Often fail secure locks are used for IT rooms or other sensitive areas.

https://www.acslocks.com/fail-safe-vs-fail-secure/

Operation Mode

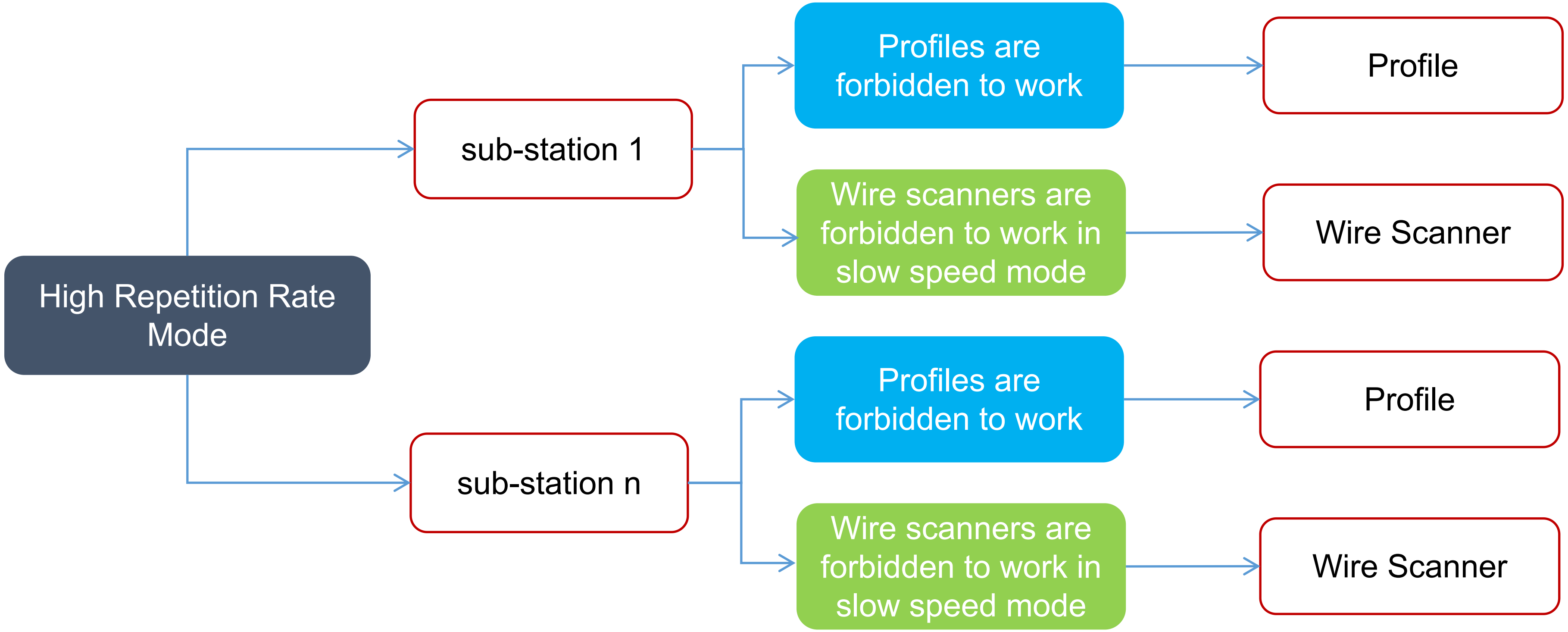
- The Operation Mode is segmented according to the position of the beam dump.
- Different logic can be automatically matched in different modes.



- Injector: E-gun operation mode, injector operation mode.
- Linac: Bunch Compressor 1, Bunch Compressor 2, Break, Bypass line.
- Undulator and beamlines: The selection is independent and can be freely combined.
- Low Repetition Rate ≤ 50Hz, Mid Repetition Rate 50 ~ 1kHz, High Repetition Rate ≥1kHz

Operation Mode

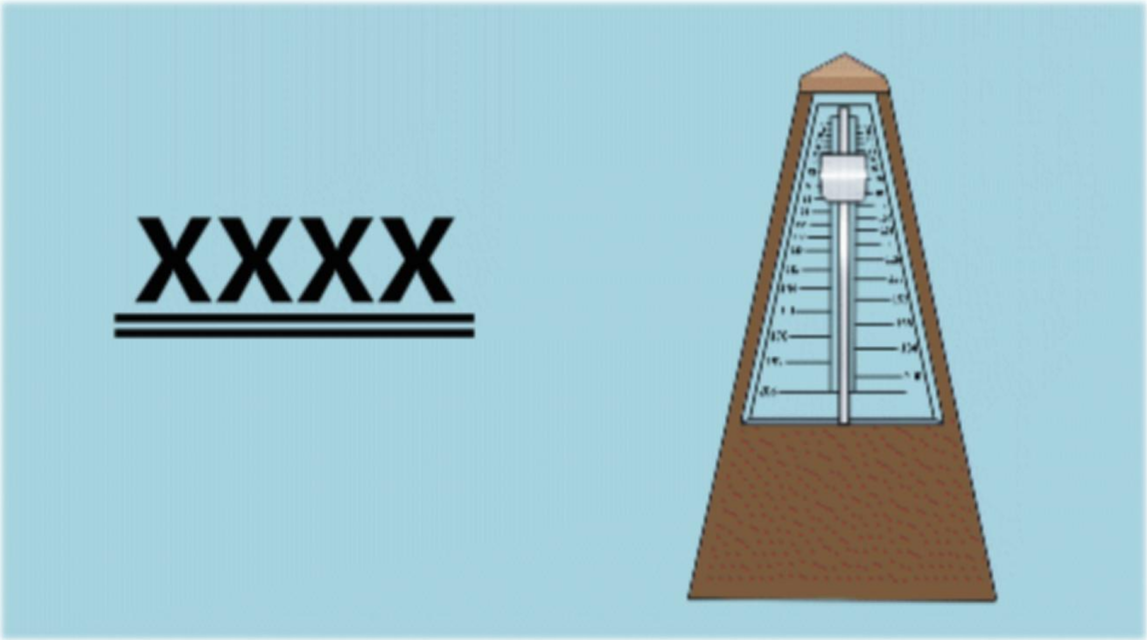
- **High Repetition Rate Mode** (e.g. SHINE)
- The profiles are **forbidden** to work on-line, and the wire scanners are forbidden to work in **slow** speed.



Timing System

Timing

- Providing precise **triger** or **reference signals** for lasers, modulators, LLRF, beam & optical diagnostics, ...

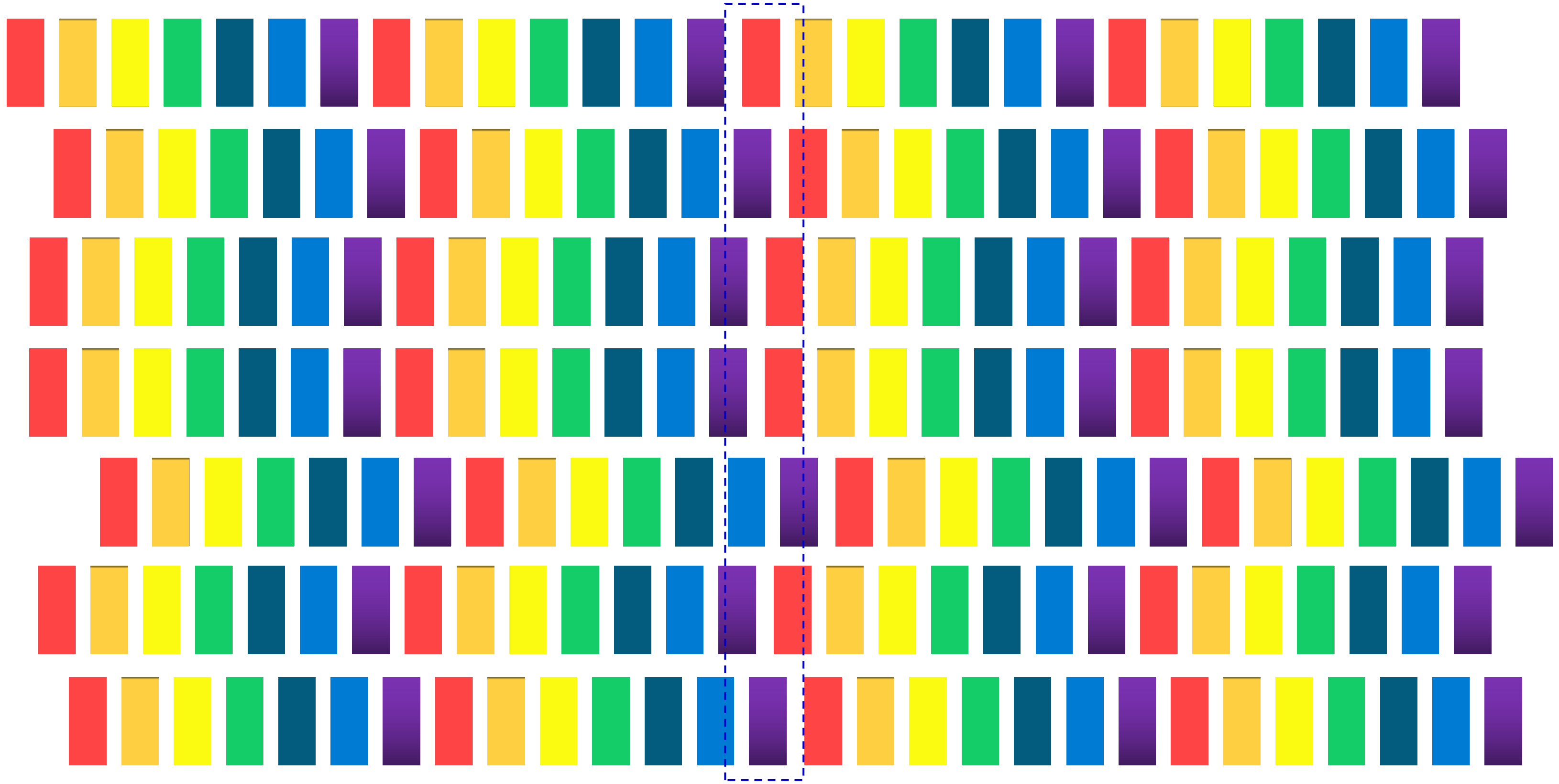


Metronome

Conductor’s baton

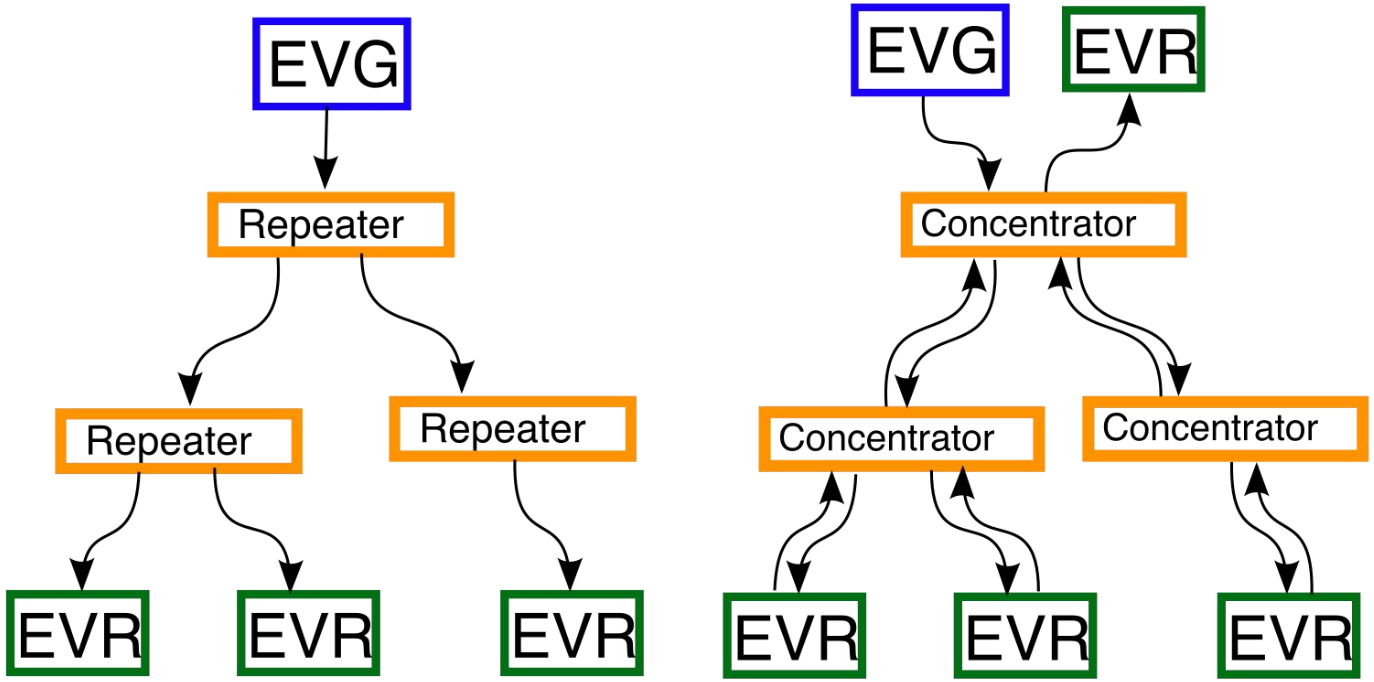
Timing

- Providing precise **triger** or **reference signals** for lasers, modulators, LLRF, beam & optical diagnostics, ...
- Providing hardware **BunchID / PulseID** for beam parameter analysis and failure diagnosis.



MRF (1990s ~)

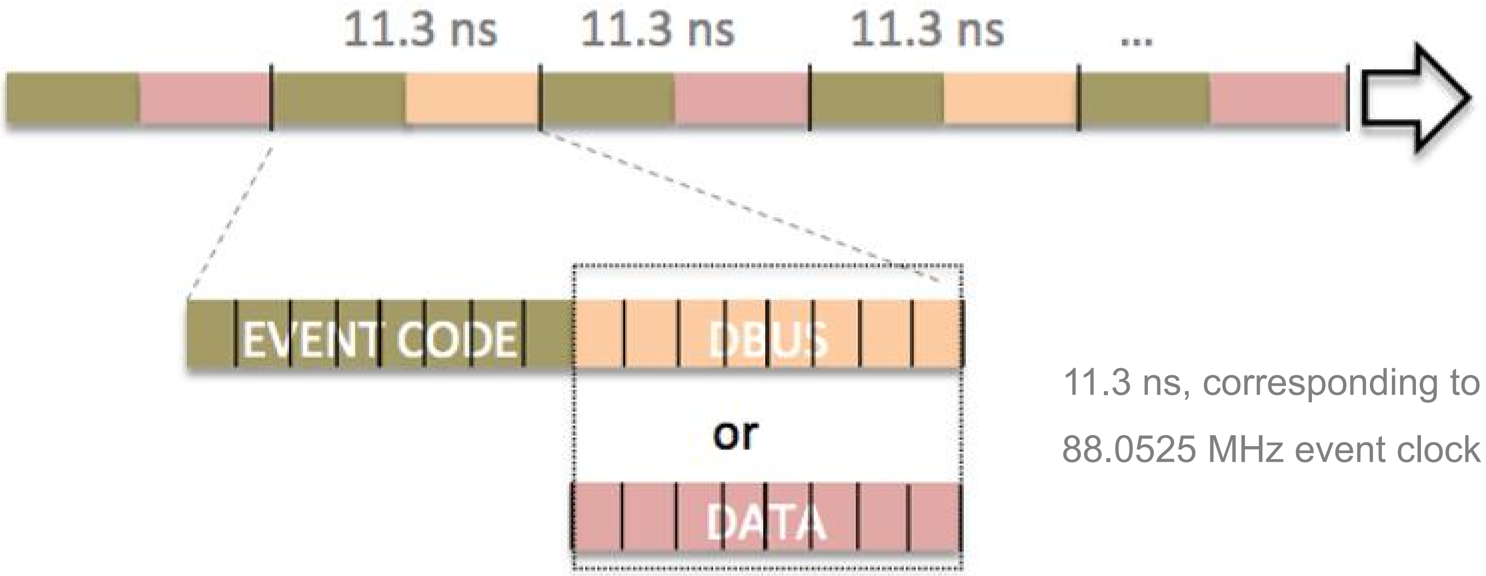
- MRF (**Micro-Research Finland**) Timing System is a high-precision **event synchronization system** widely used in particle accelerators.
- It is capable of generating subharmonic frequency signals, triggers and sequences of events, etc.
- A basic setup of the timing system consists of an Event Generator (**EVG**), the distribution layer (Fan-Out, or Repeater/Concentrator) and Event Receivers (**EVR**).



https://mrftiming.readthedocs.io/en/latest/

Event Stream

- The event stream protocol is based on 8b10b encoded characters.
- Each frame of the stream consists of two bytes.
  - The first byte is dedicated for transmitting timing events, and always contains an event code.
  - The second byte can be configured as distributed bus bits or synchronous data transmission.

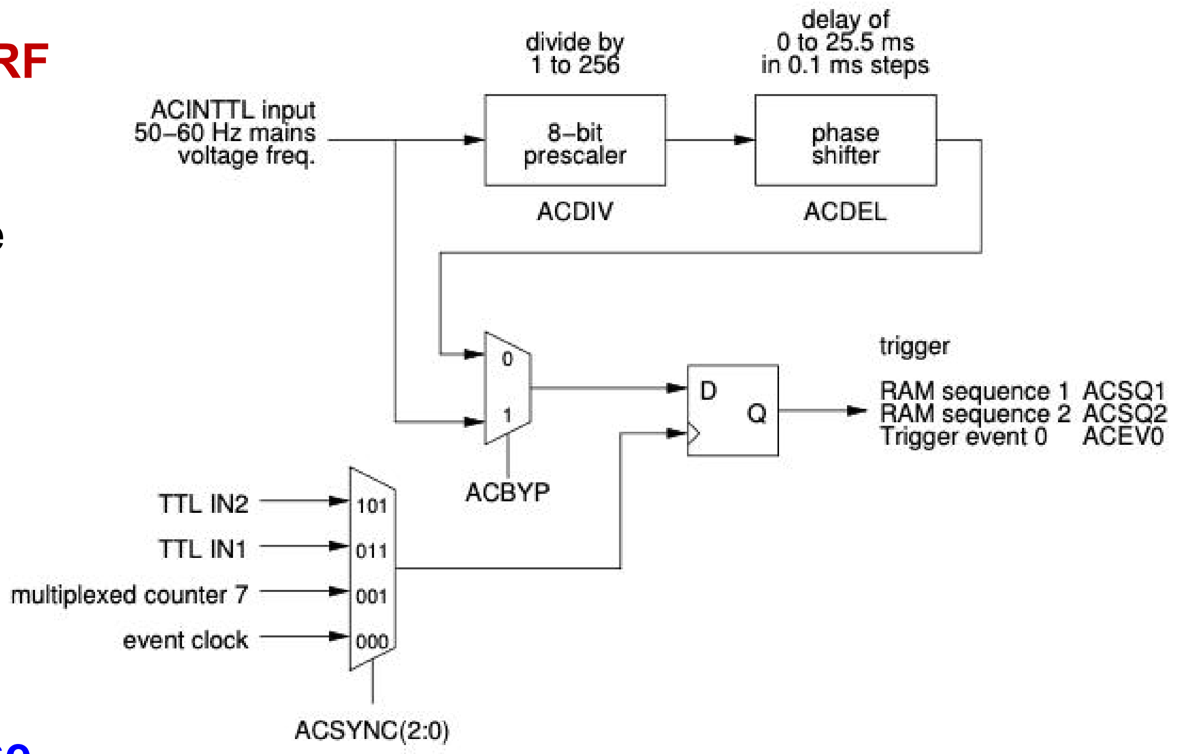


11.3 ns, corresponding to 88.0525 MHz event clock

https://mrftiming.readthedocs.io/en/latest/

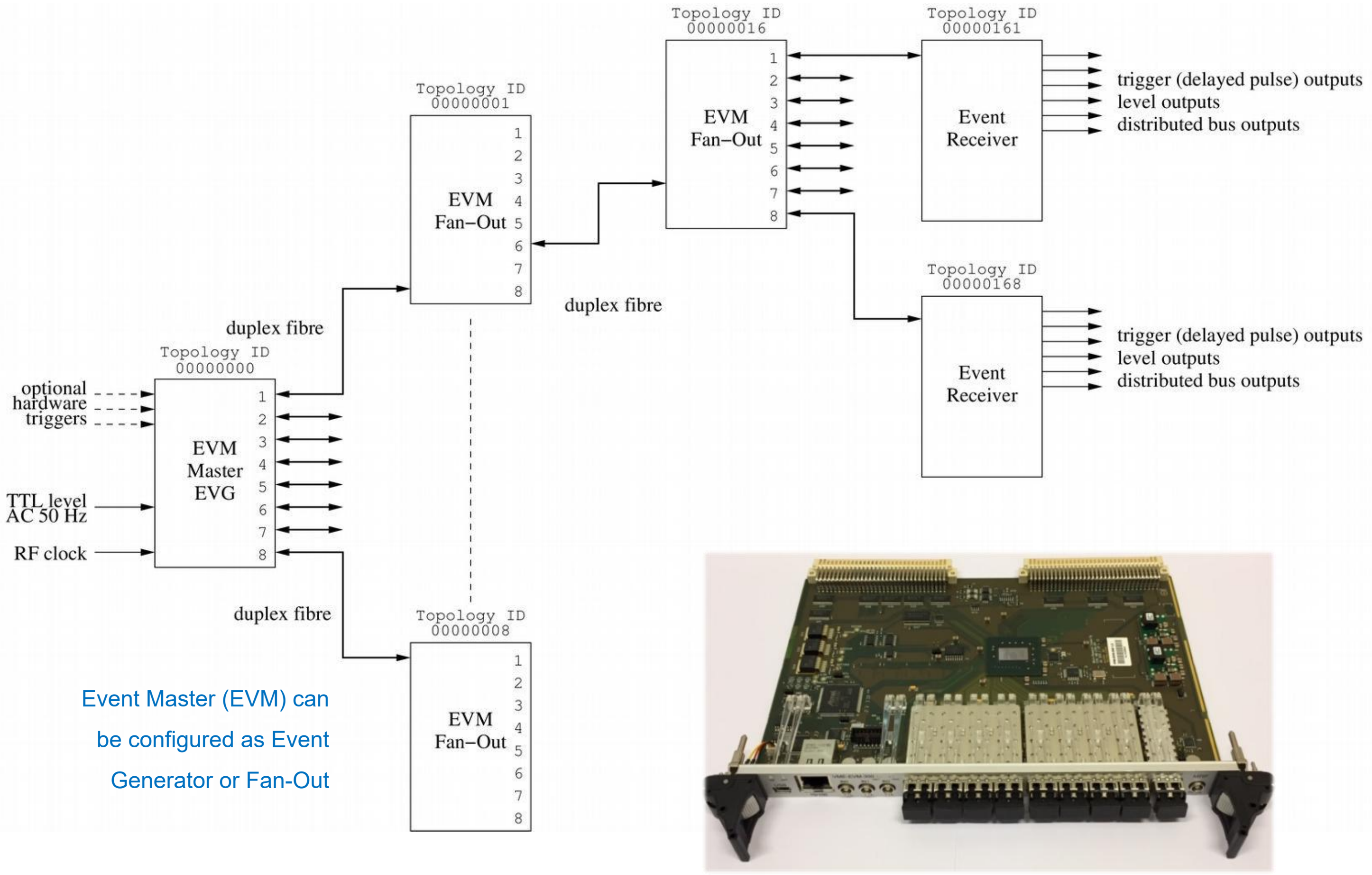
Event Generator (EVG)

- **Event Generator** generates the event stream and sends it out to an array of **Event Receivers**.
- Events are sent out by the event generator as **event frames (words)** which consist of an eight bit event code and an eight bit distributed bus data byte.
- The event transfer rate is **derived** from an **external RF clock** or optionally an on-board clock generator.
- The Event Generator provides synchronization to the **mains voltage frequency** or another external clock.
- The mains voltage frequency can be divided by an eight bit programmable divider. The output of the divider may be delayed by 0 to 25.5 ms by a phase shifter in 0.1 ms steps to be able to **adjust the triggering position relative to mains voltage phase.**



Event Generator (EVG)

- With **different cable lengths**, long distances and **thermal gradients**, the propagation delays could **drift** and disturb operation in cases where long-term timing **stability** is critical.
- The **delay compensation** can be used to stabilize the system against e.g, thermal drifts of optical cables.
- In the **300-series** event system, an active delay compensation feature was added.



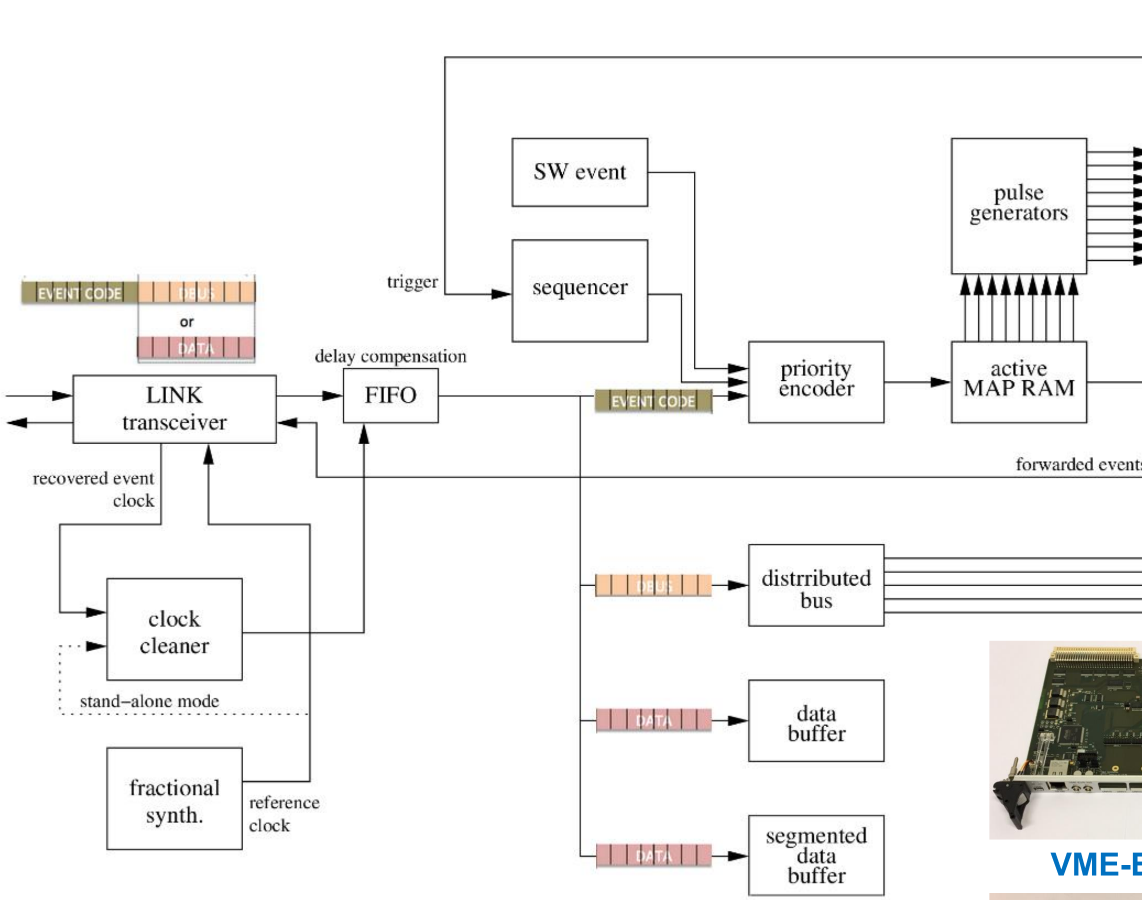
Event Master (EVM) can be configured as Event Generator or Fan-Out

VME-EVM-300

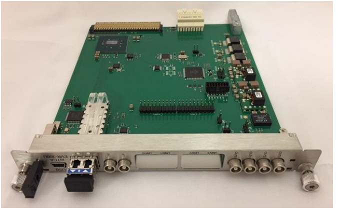
https://mrftiming.readthedocs.io/en/latest/

Event Receiver (EVR)

- EVR **decode** timing events and signals from an optical **event stream** transmitted by EVG.
- EVR lock to the phase event clock of the Event Generator and are thus phase **locked to the RF reference**.
- EVR convert event codes to hardware outputs.
- It also generate software interrupts and store the event codes with globally distributed timestamps into FIFO memory to be read by a CPU.



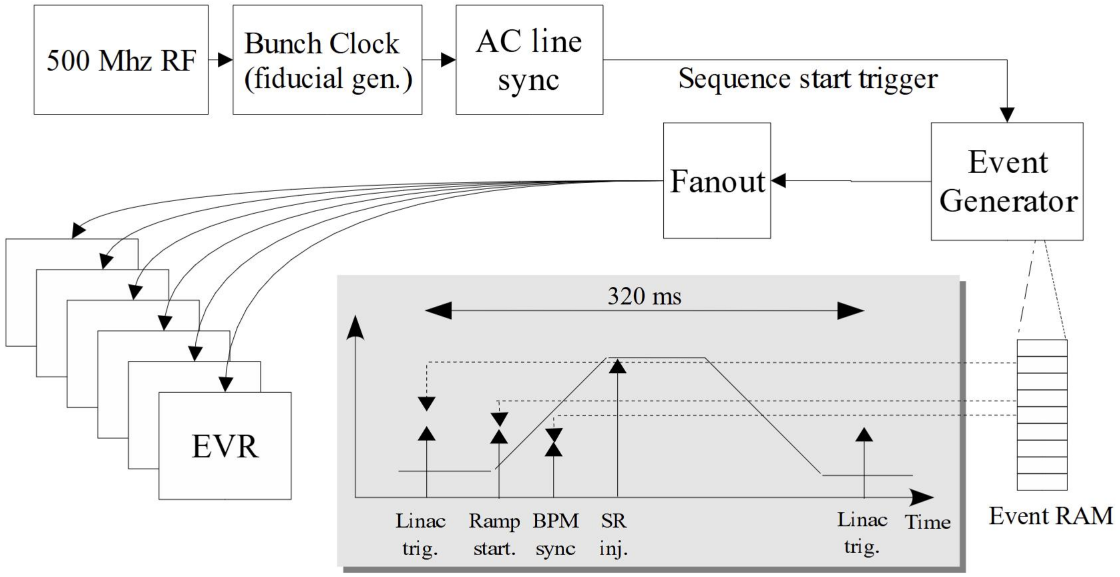
VME-EVR-300

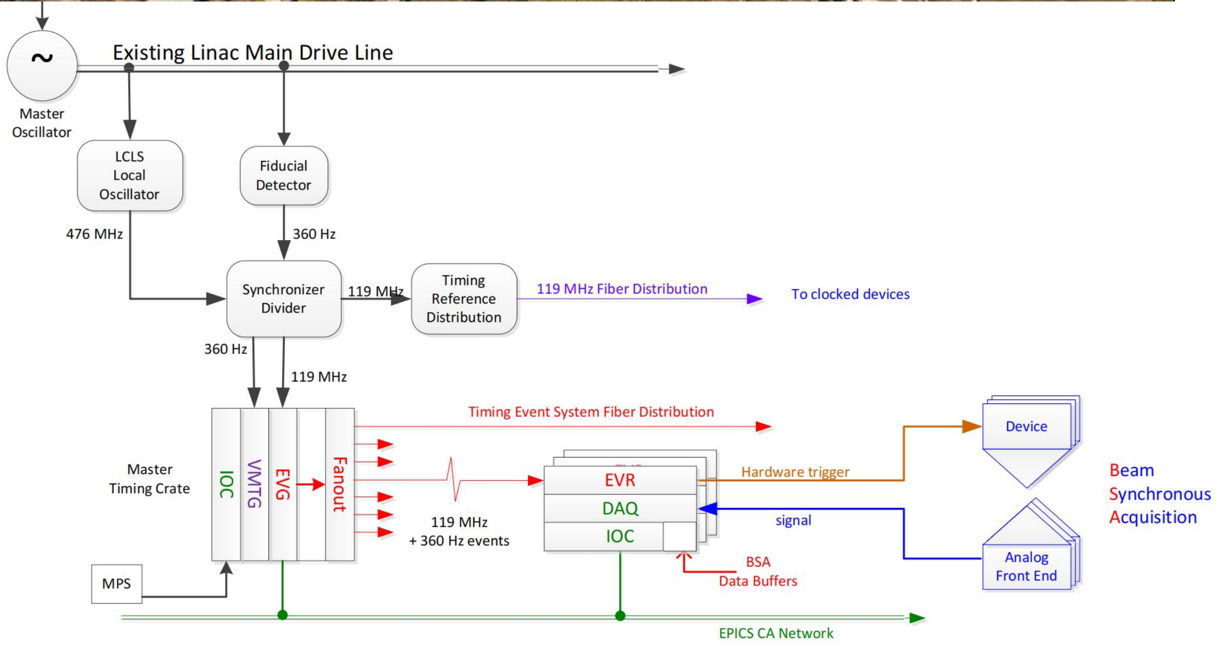


mTCA-EVR-300U

https://mrftiming.readthedocs.io/en/latest/

SLS and LCLS-II Timing System





White Rabbit

- The **White Rabbit Project** is a multilaboratory, multicompany and multinational **collaboration** to develop new technology that provides a versatile solution for control and data acquisition systems.
- The project was started within an effort to renovate the current CERN control and timing system.
- The main features of the White Rabbit Network are:
  - **sub-ns** accuracy and **ps** precision of synchronization
  - connecting thousands of nodes
  - typical distances of **10 km** between network elements
  - Gigabit rate of data transfer
  - **fully open** hardware, firmware and software
  - commercial availability from many vendors

02/2008 : Project start

12/2010 : Basic Ethernet switching demonstrated

04/2011 : PTP working on a WR node

05/2012 : The first system was successfully in CERN

...

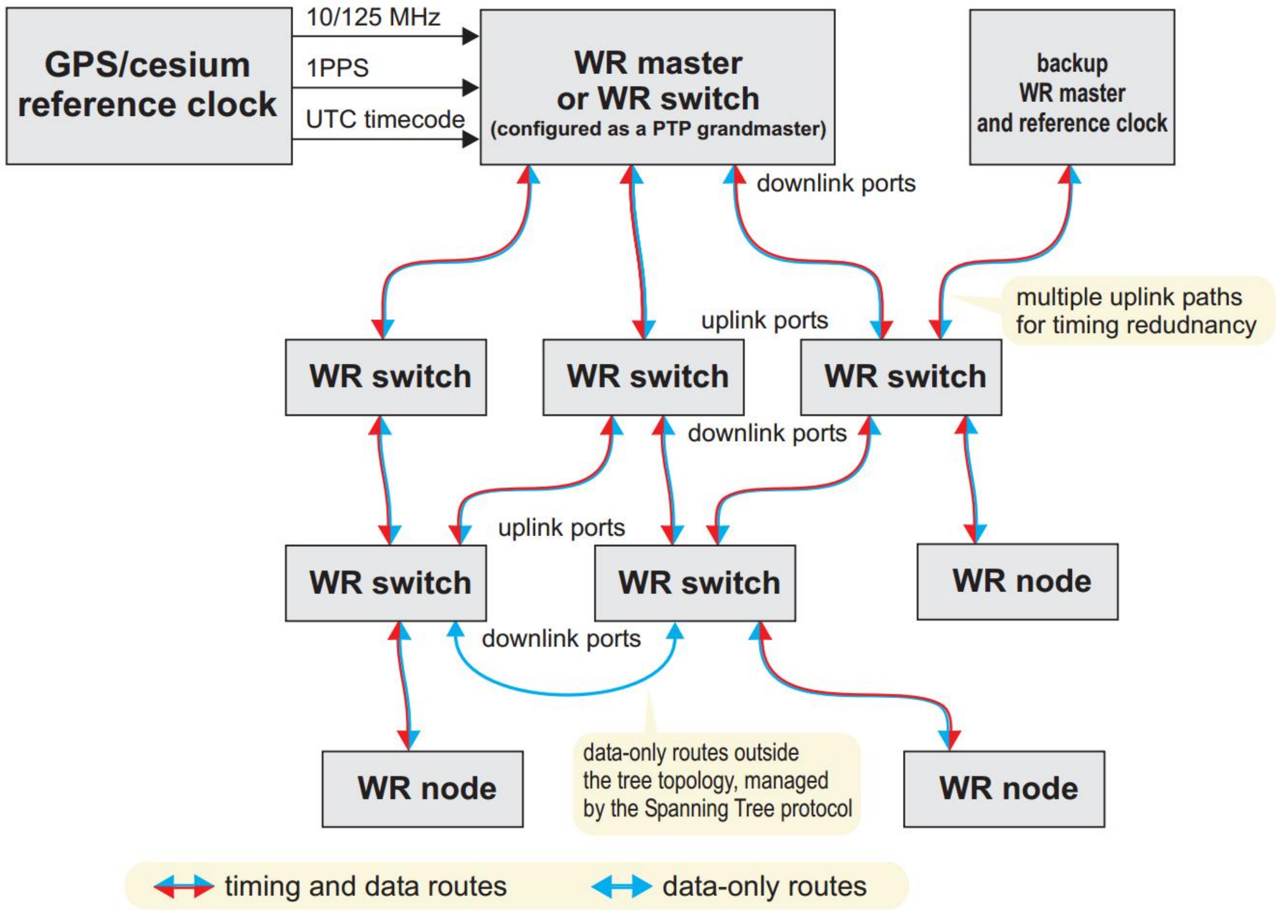
06/2020 : IEEE-1588-2019 v2.1 officially published

...

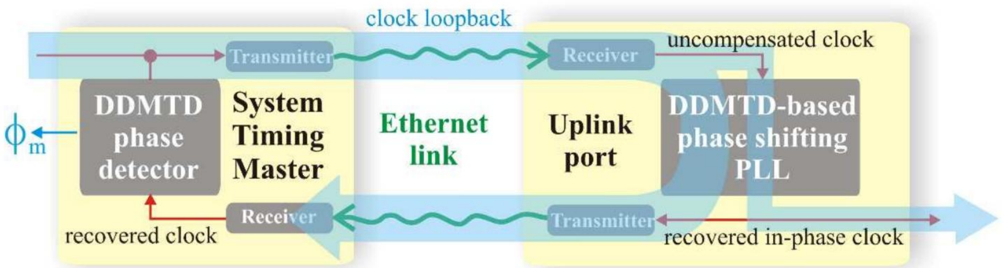
- CERN, GSI, ESRF, ELI-ALPS, ELI-BEAMS, Fermilab, ...
- LHAASO, SHINE, SXFEL, HIAF, CiADS, ...

https://white-rabbit.web.cern.ch/

White Rabbit



- ❑ Synchronous Ethernet (**SyncE**)
  - frequency synchronization over Ethernet
- ❑ Precision Time Protocol (**IEEE 1588**)
- ❑ Double Dual Mixer Time Difference (**DDMTD**)

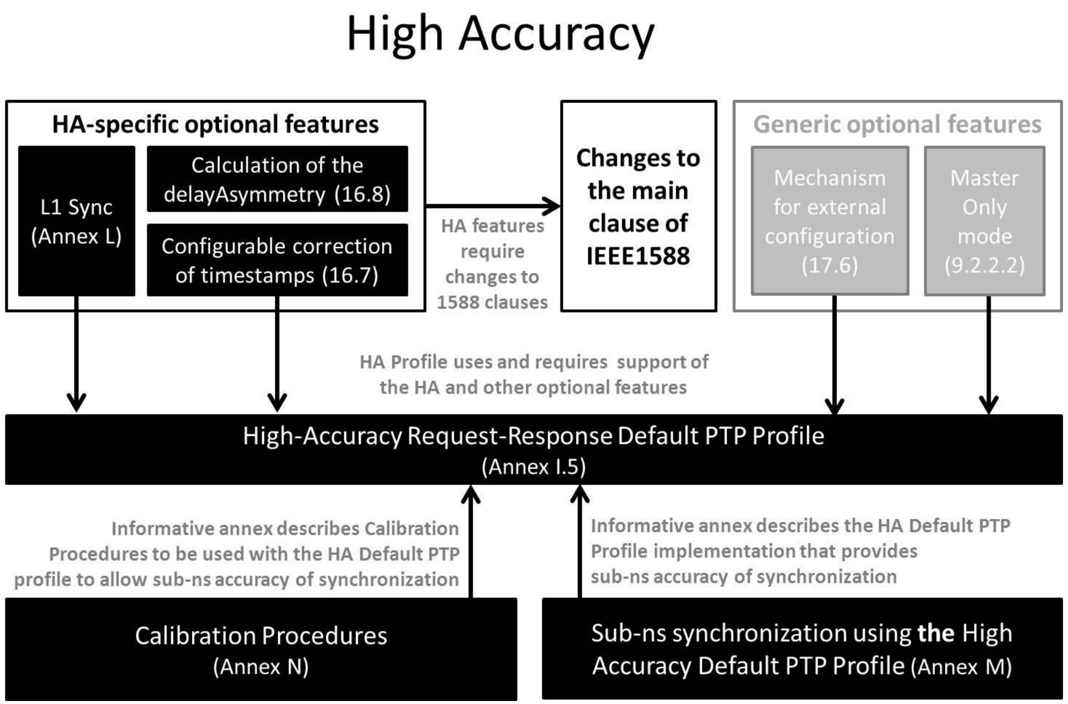


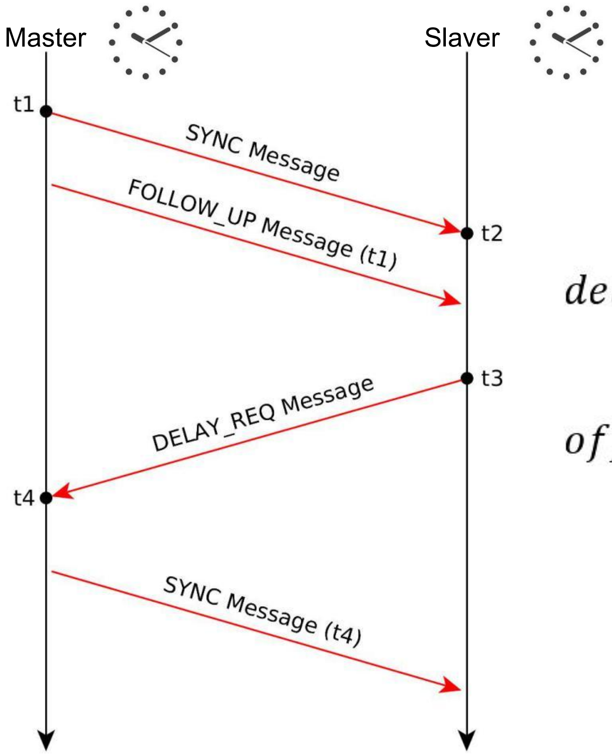
measure ultra-small time intervals or phase differences between two signals with picosecond-level resolution

https://white-rabbit.web.cern.ch/

PTP

- The **Precision Time Protocol** (**PTP**) is specified in the IEEE 1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.
- The currently active **2019 edition** was preceeded by 2008 and 2002 editions.





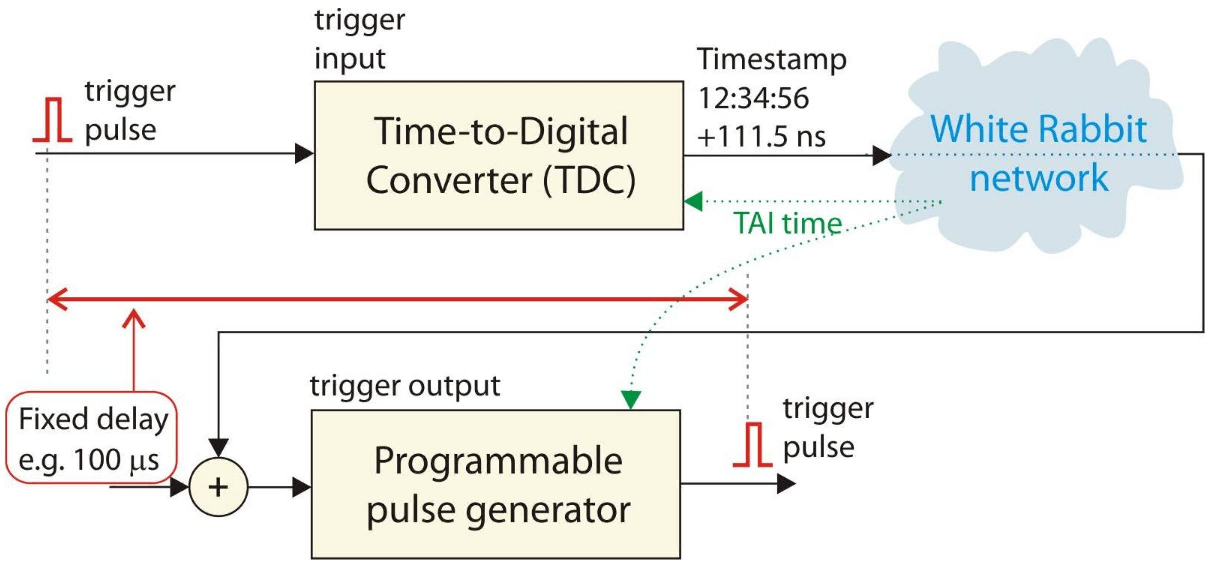
$$delay = \frac{(t_2 - t_1) + (t_4 - t_3)}{2}$$

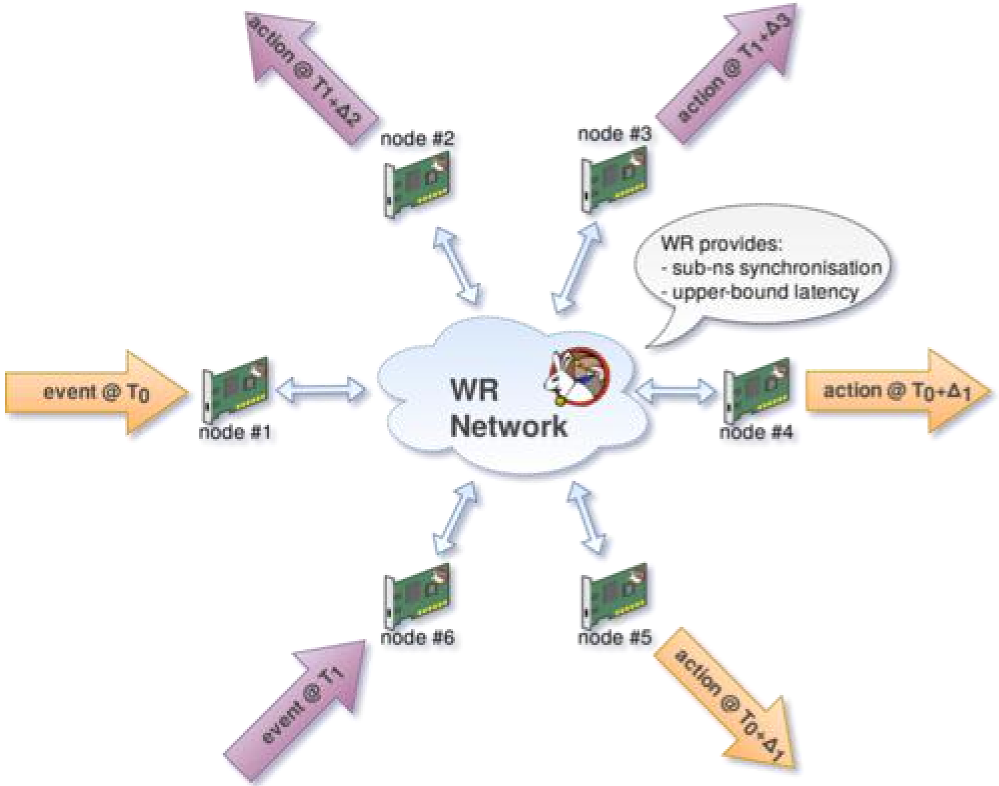
$$offset = (t_2 - t_1) - delay$$

https://www.white-rabbit.tech/

WRTD

- **White Rabbit Trigger Distribution** (**WRTD**) is a generic framework for distributing **triggers** (events) between Nodes over a White Rabbit network.

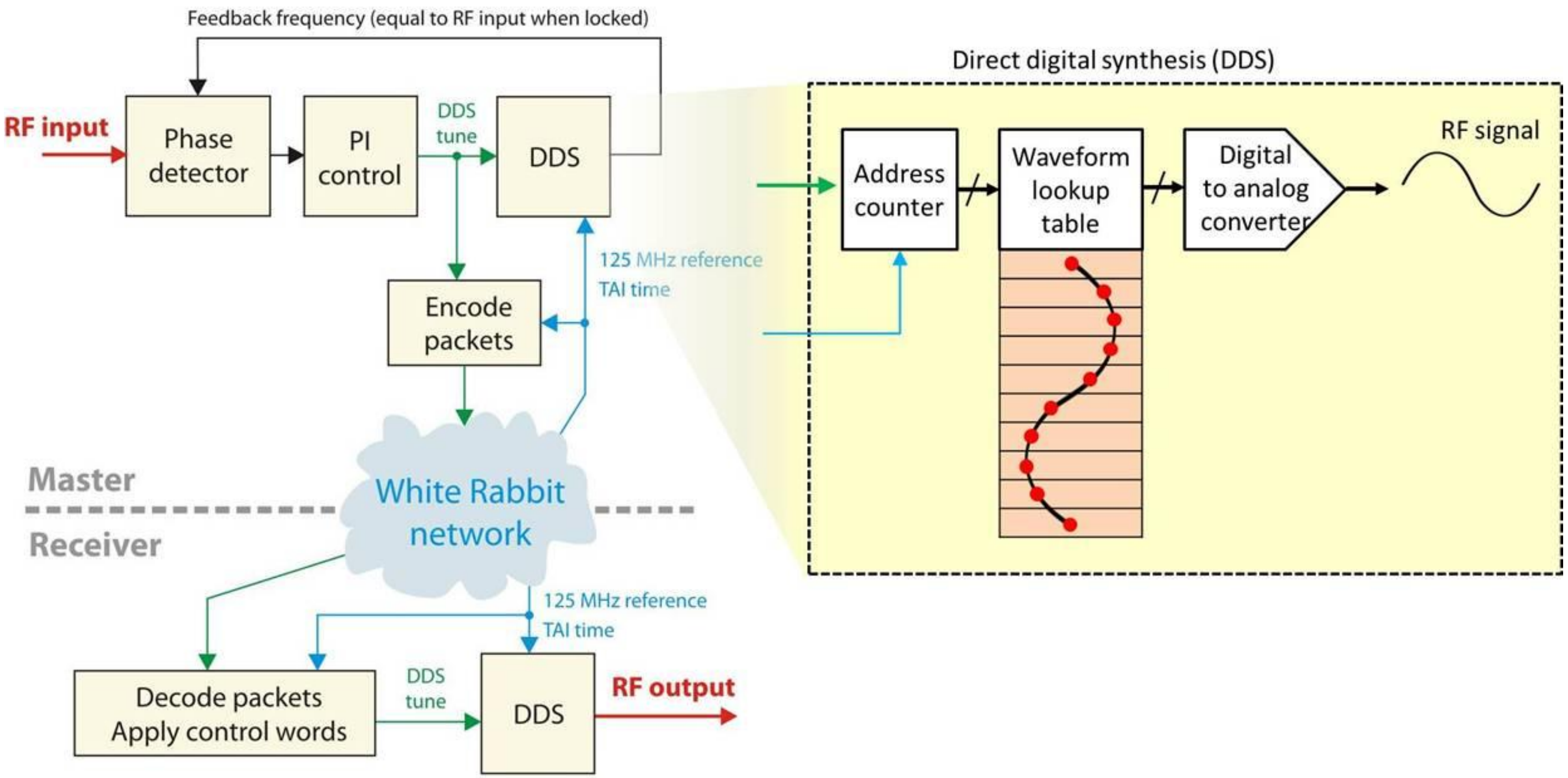




https://www.white-rabbit.tech/

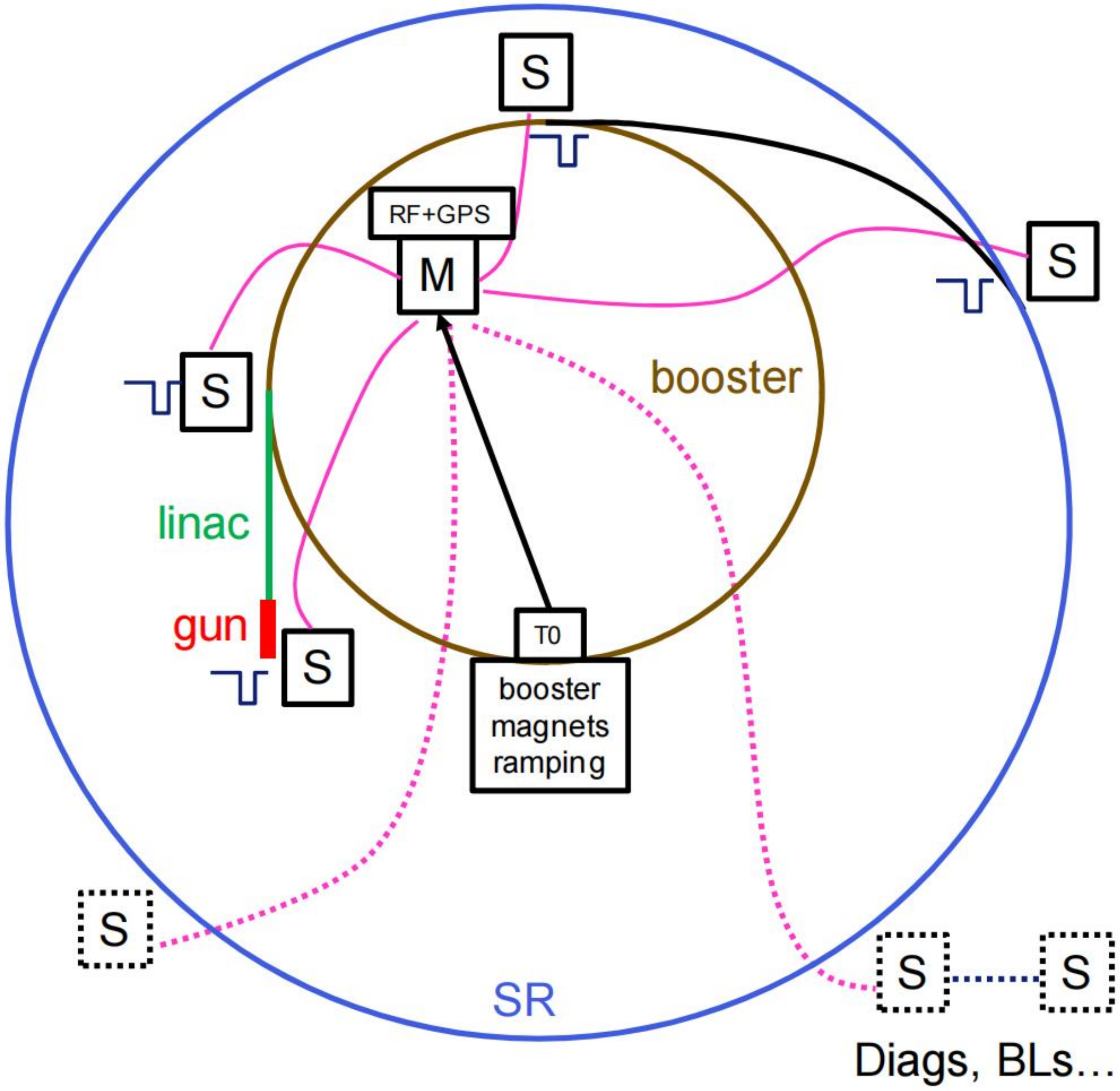
RF over WR

- RF over WR allows real-time transmission of **frequency tuning words** over a White Rabbit network.
- WR is used to distribute the base phase-aligned WR clock signal and the frequency tuning words representing the RF signals.



https://www.white-rabbit.tech/

ESRF Timing system



optical fibre network
1 master (CTRM)
+ satellite slaves
(WR switches not shown)

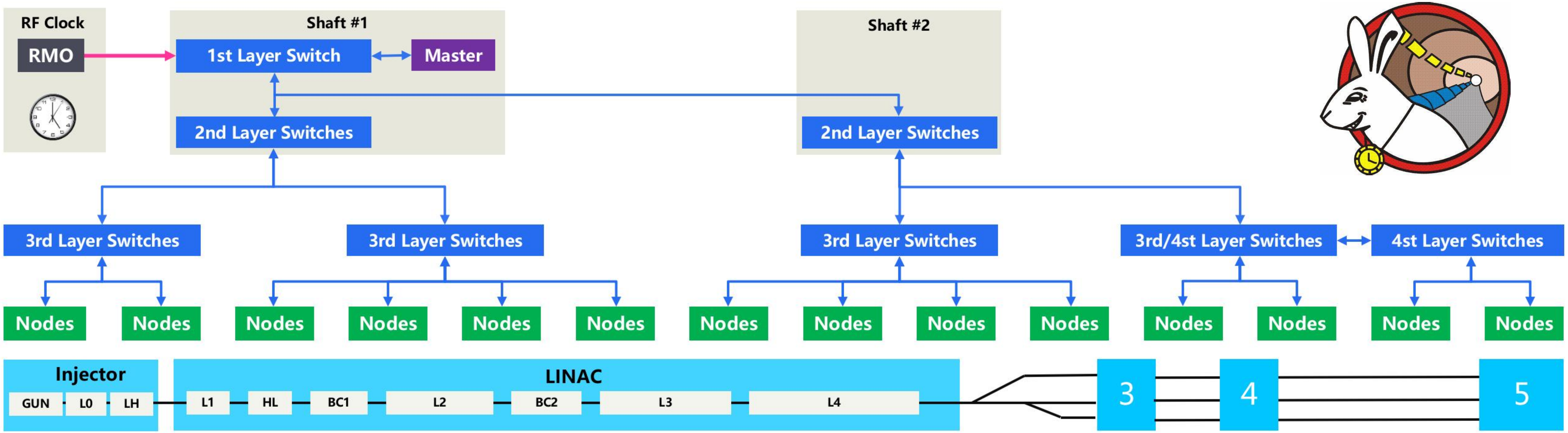
MASTER manages
RFoE
booster_ramp_start (T0)

SLAVES manage
time (RF+UTC)
time stamping of inputs
main sequencer
local pulse production

G.Goujon, tucpl01_talk, ICALEPCS 2017

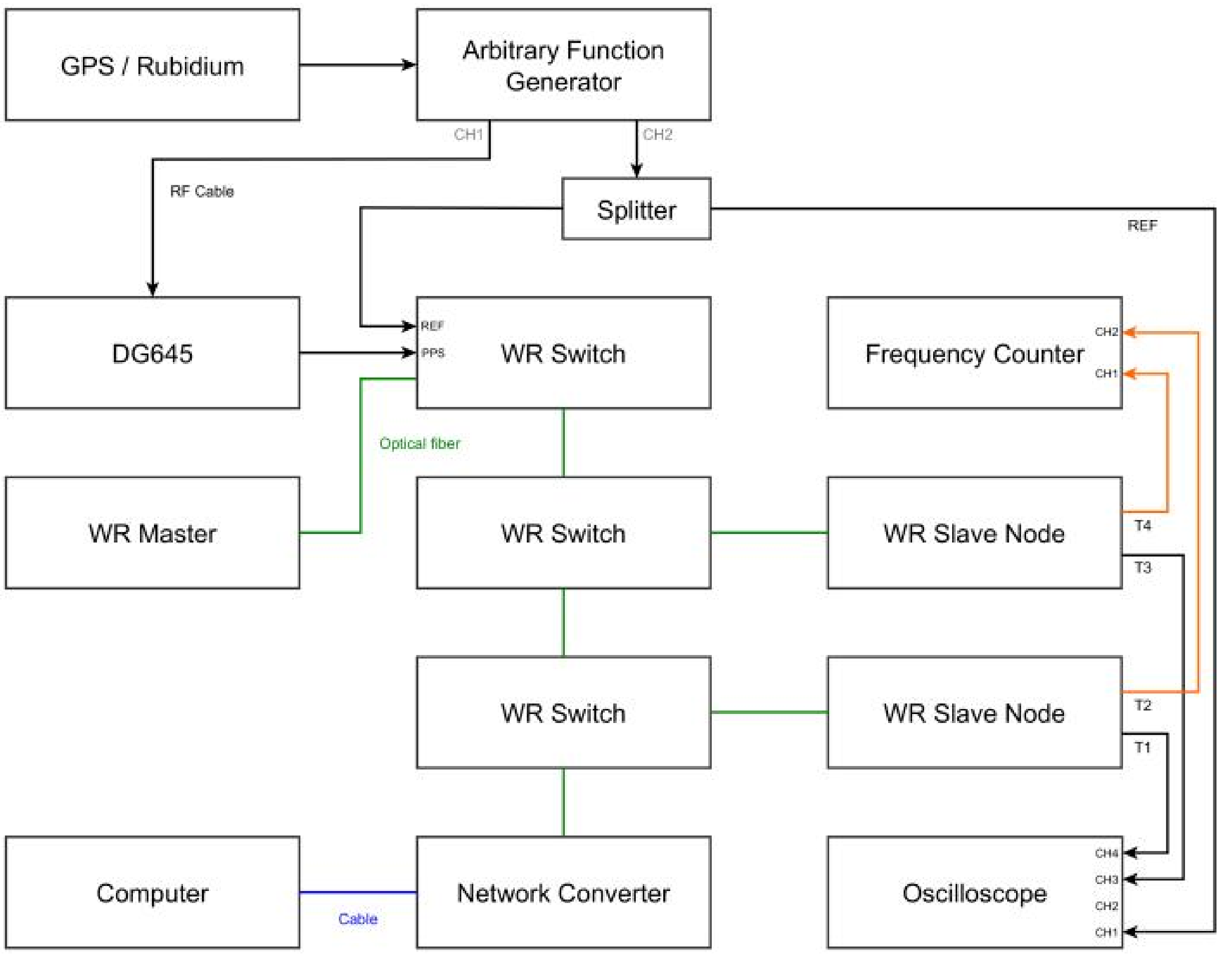
SHINE Timing System

- Beam-synchronous **trigger** signal distribution (1.003086MHz timing signals over ~ 3.1 km).
- Random-event **trigger** signal distribution (event signals, such as beam loss, machine snapshot, etc.).
- **Bunch ID,** which provides a data alignment basis for beam parameter analysis and failure diagnosis.



non-standard clock White Rabbit timing system

SHINE Timing System



Beam-synchronous trigger signal

- Jitter between the slave node output and reference signal < **10ps**
- Jitter between slave nodes outputs < **5ps**

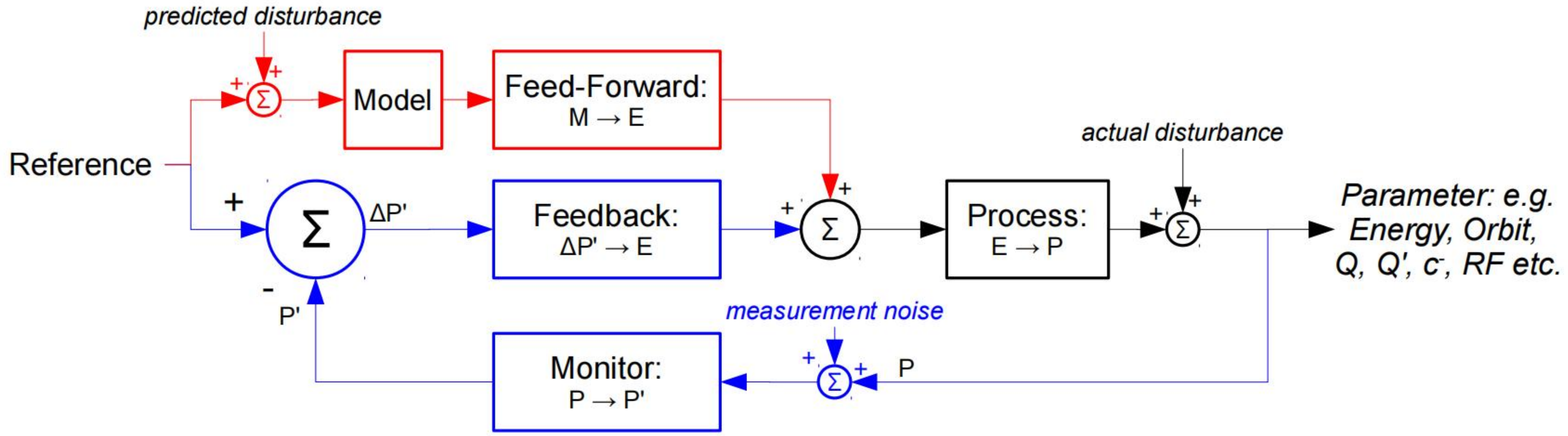
Clock Phase Noise

- 10Hz - 10MHz jitter < **2ps**
- Agilent E5052B Signal Source Analyzer

Feedforward & Feedback

Feedforward & Feedback

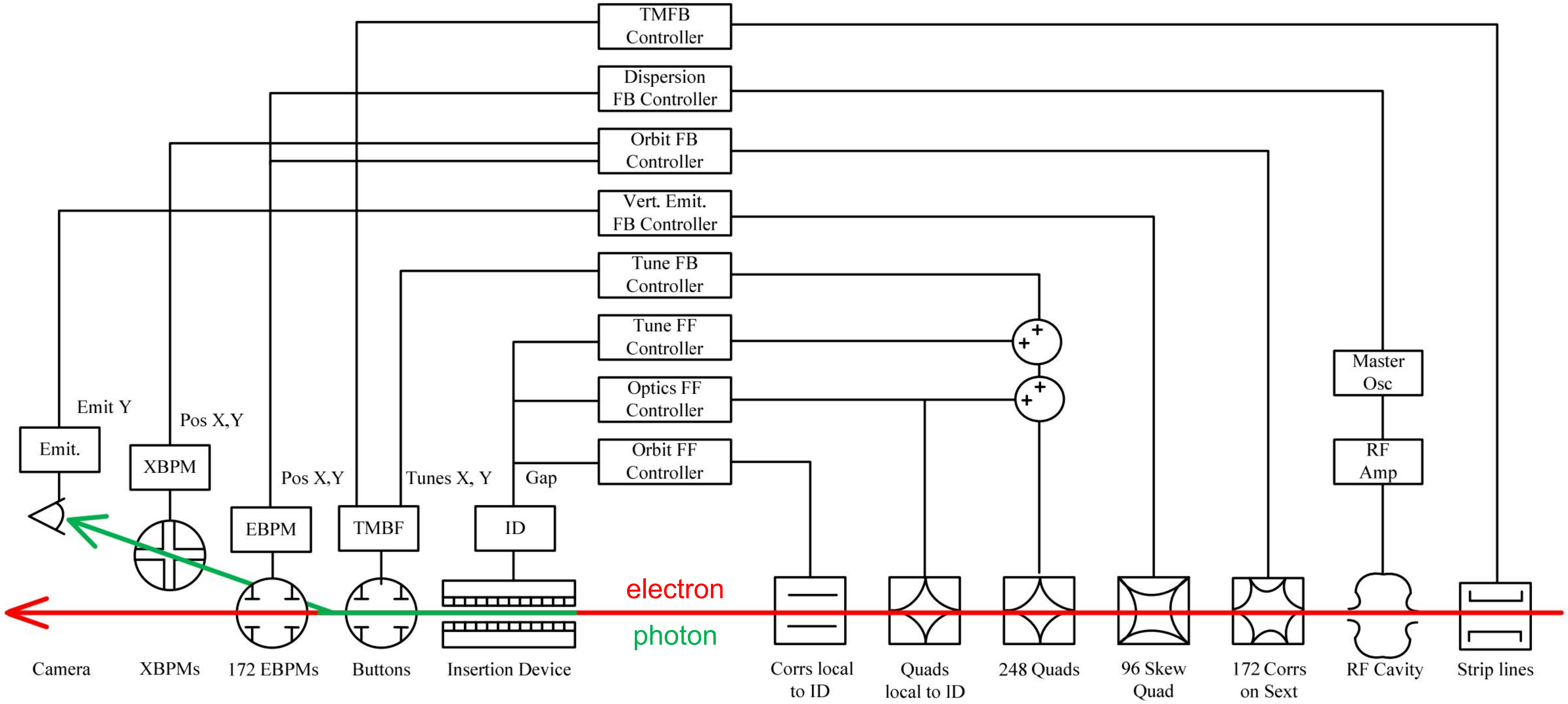
- **Feed-Forward (FF)**
  - Steer parameter using precise process model and disturbance prediction.
- **Feedback (FB)**
  - Steering using rough process model and measurement of parameter.



Ralph J. Steinhagen, Feedback Control for Particle Accelerators, PCaPAC 2016

Feedforward & Feedback

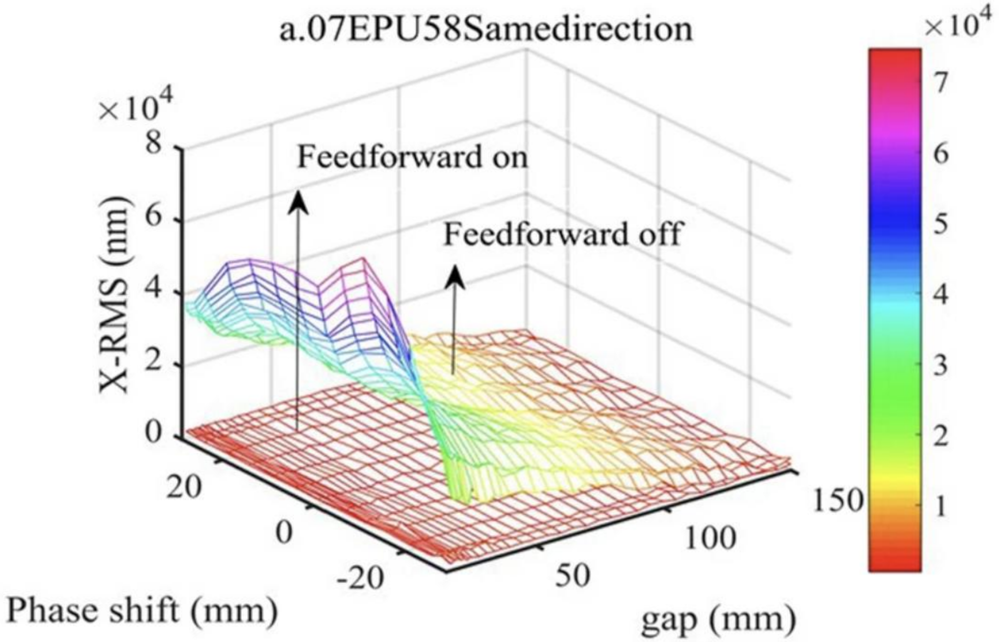
Conceptual view of the feedback (FB) and feed-forward (FF) correction schemes on the Diamond storage ring

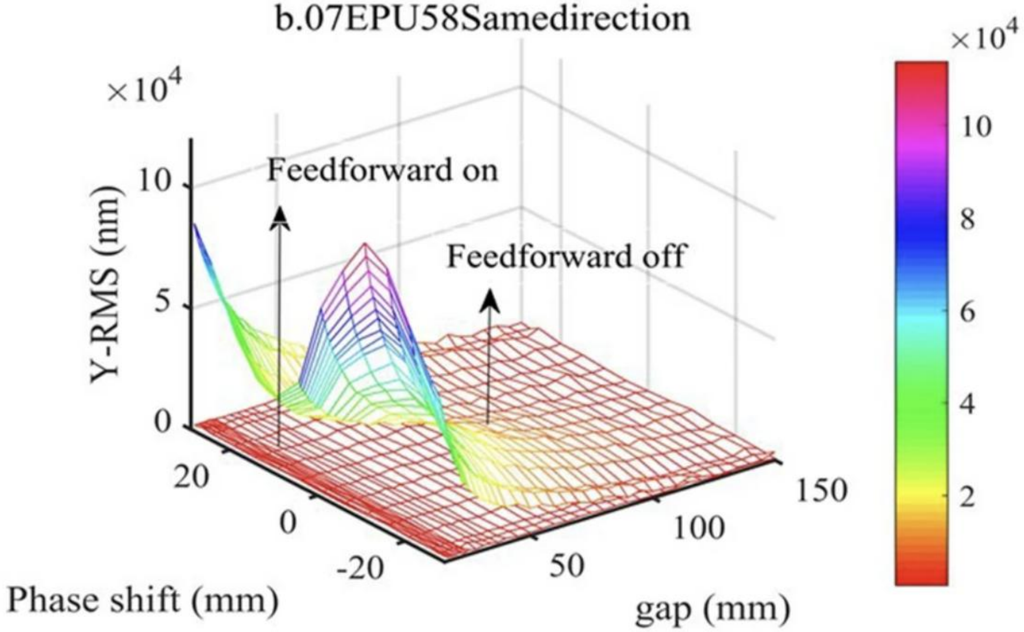


M.T. Heron, TUPRI081, IPAC2014

Feedforward of IDs effects at SSRF

- Insertion Devices (IDs) cause closed-orbit distortions, tune drift, and coupling distortions in the storage ring.
- **ID orbit feedforward compensation system** based on a response matrix using corrector coils.
- ID_IOC (gap and phase shift) ➡ FF_IOC (Python based) ➡ PS_IOC (current of the corrector coils)





Changes in the same-direction orbit distortion with gap size and phase shift before and after feedforward compensation of the 07EPU58

Xin-Zhong Liu, Shun-Qiang Tian, etc. Nuclear Science and Techniques, Volume 33, article number 70, (2022)

FB Design Paradigms – Stability

Perturbation Sources or “Know your enemy”

- **Environmental sources:**
  (mostly propagated through quadrupoles/girders)
  - temperature and pressure changes
  - ground motion, tides
  - 'cultural noise'
- **Machine inherent sources:**
  - decay and snap-back of magnetic multipoles,
  - cooling liquid flow, pumps/ventilation vibrations
  - eddy currents
  - changes of machine optics (feed-down effects)
  - machine impedance, trapped RF modes/wake-fields
  - Intensity-related and collective effects
- **Machine element failures:**
  - magnet quenches, power converter/RF trips, ...
  - corrector circuits

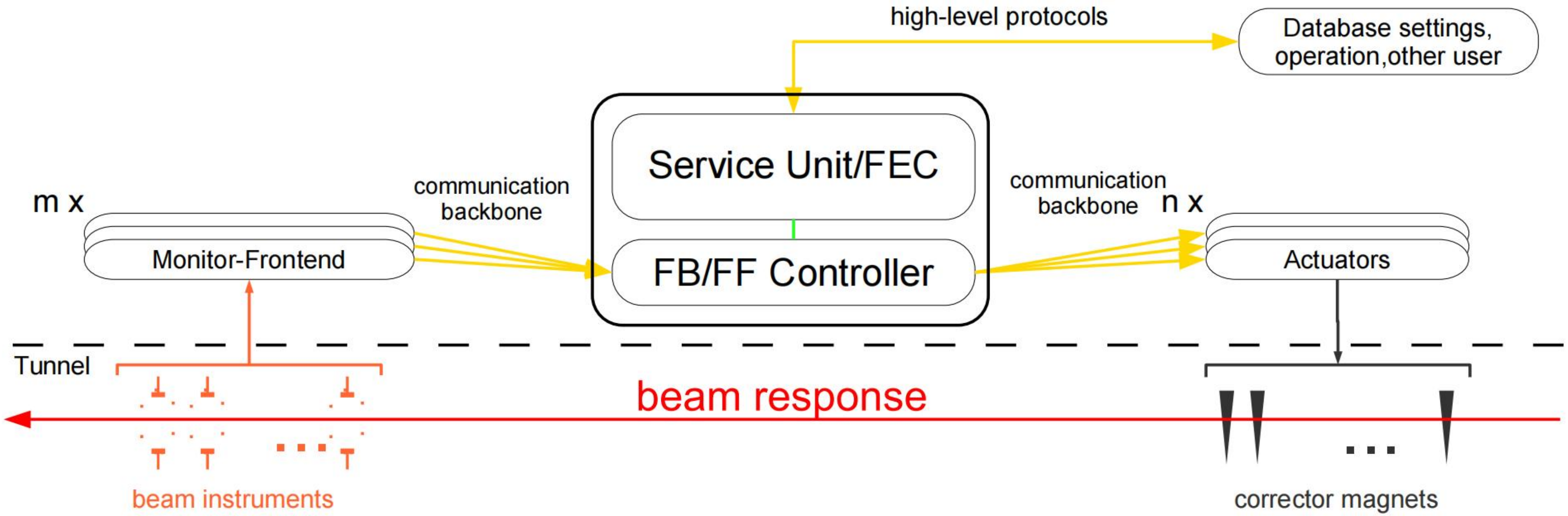
months
↓
weeks
↓
days
↓
hours
↓
sec
↓
ms
↓
minutes
↓
us
↓
ns

Stability defined by accelerator design

Stability defined by feedback design

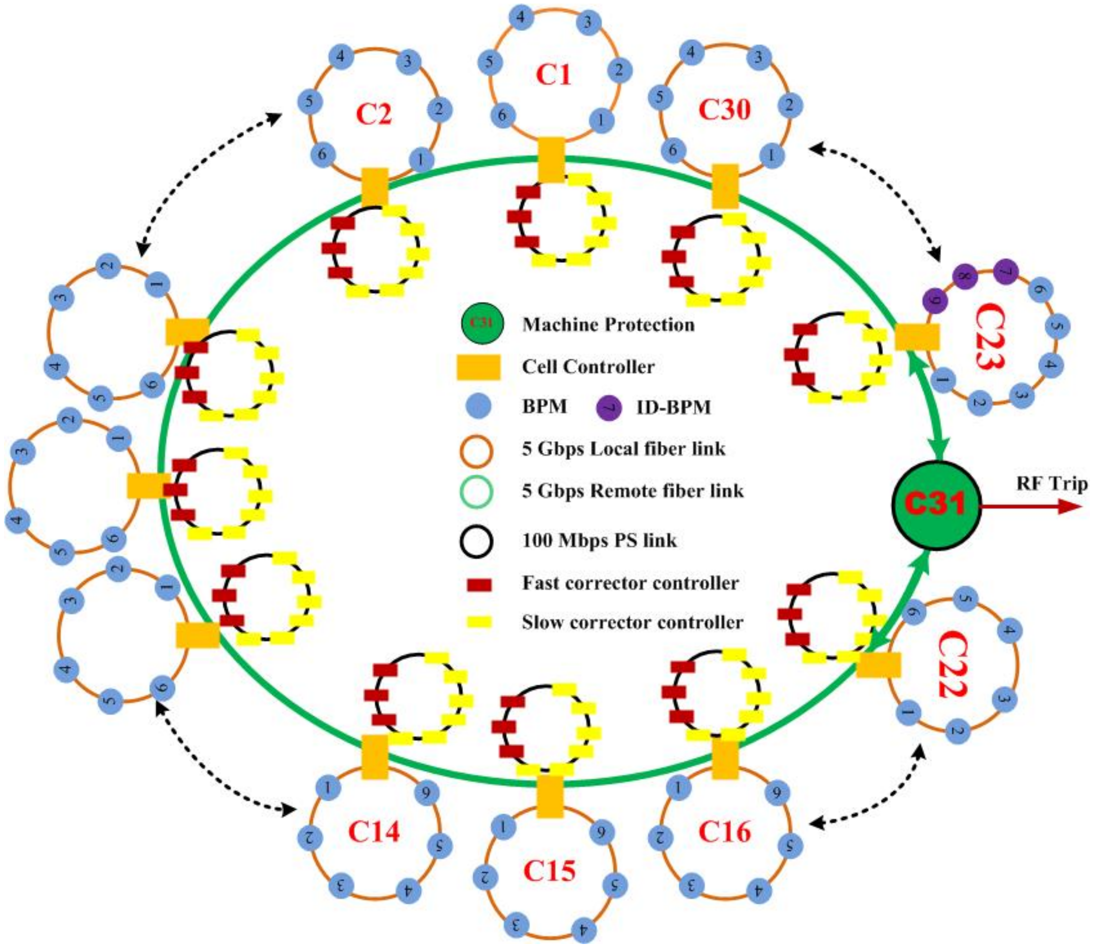
Feedbacks - Control Layout & Implementation

- fairly generic, typically MIMO & often split into two sub-systems.
  - **Feedback Controller**: actual feed-forward/feedback controller logic.
    - specific implementation depends on the bandwidth requirement.
  - **Service Unit**: Interface to control system.
- Overall strength depends on the knowledge / reliability of the weakest link in the chain.

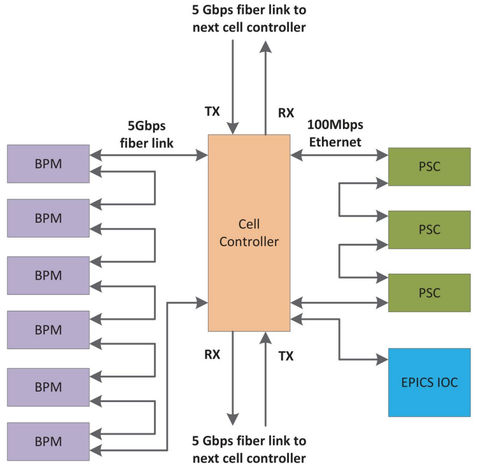


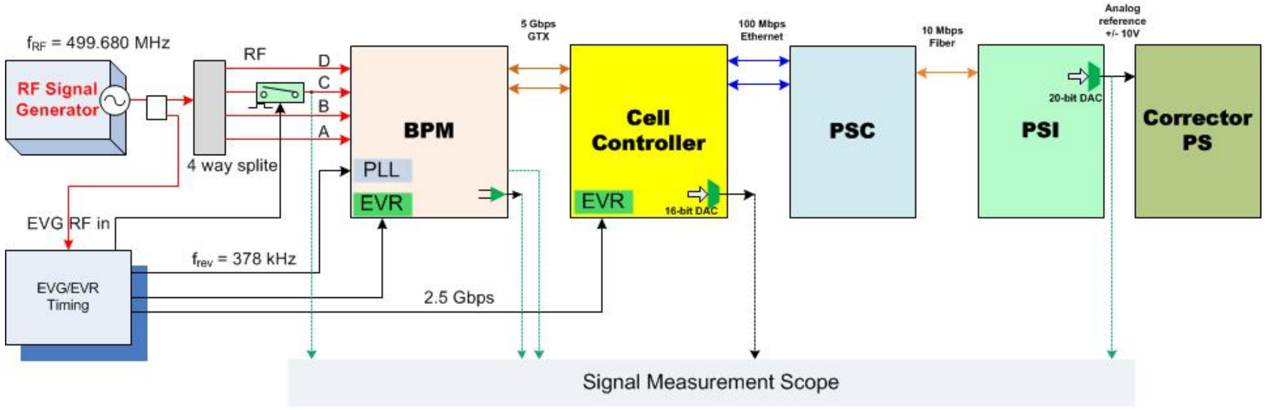
Ralph J. Steinhagen, Feedback Control for Particle Accelerators, PCaPAC 2016

Fast Orbit Feedback System of NSLS-II



- Feedback rate : 10 kHz
- Bandwidth : ~ 200 Hz
- Control algorithm : SVD + PID
- Number of BPMs : 180 ea + ID bpms (27)
- Number of a fast correctors : 90 ea
- Communication update rate is 10 kHz
- All CC/BPM/AI/PS synchronized with timing

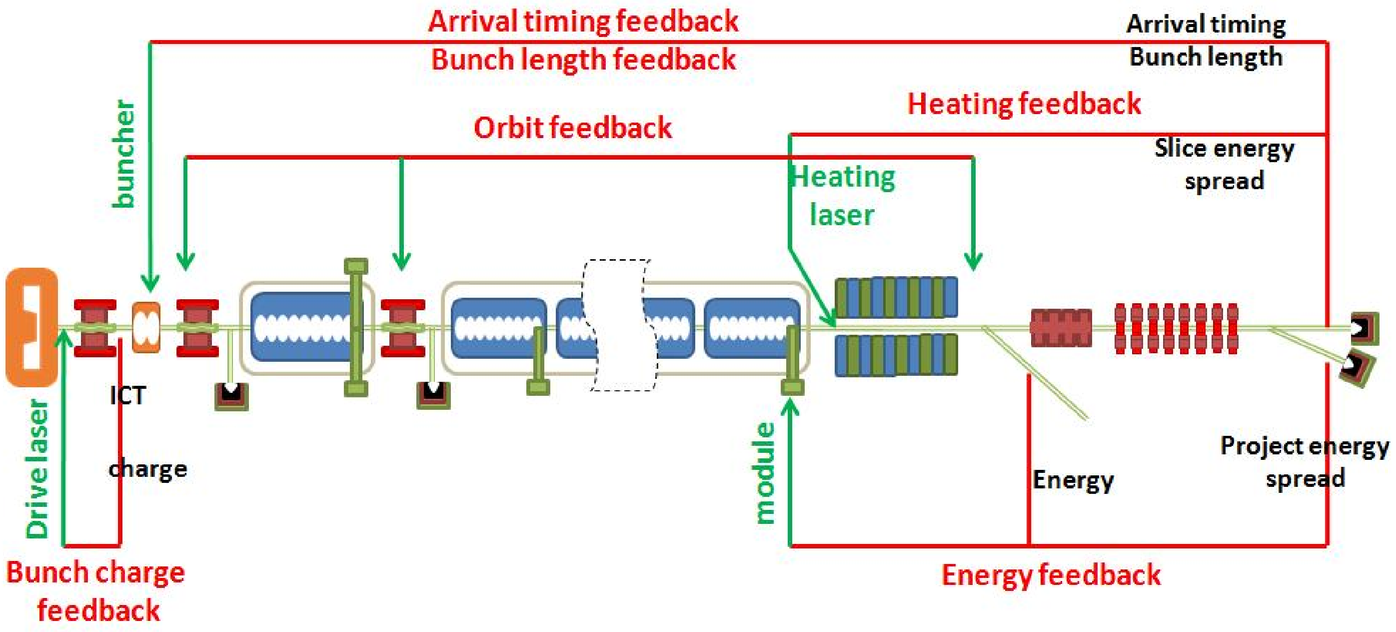




K. Ha, Y. Tian, MOC3O05, ICALEPCS 2015

Feedbacks System of SHINE

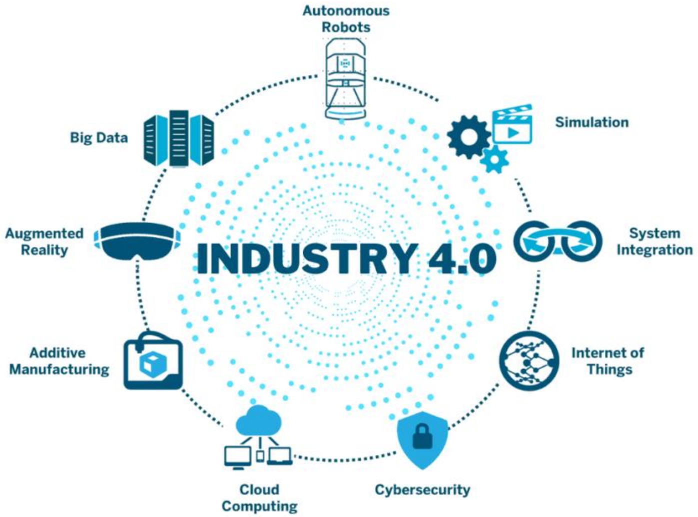
- Transverse Loops: beam orbit, laser pointing (drive, heater and seed laser)
- Longitudinal Loops: bunch length, energy, charge, laser-electron relative time
- **Slow Feedback loops:**
  - Run at 1-10 Hz
  - Controlled by soft IOCs
  - Slow change parameters such as bunch length or laser position
- **Fast Feedback loops:**
  - Run at > 100Hz or kHz
  - Controlled by dedicated FPGA systems and low latency network
  - Fast actuators (air-cored coil) and RF amp/phase tuning
  - Fast orbit feedback ~ 1kHz

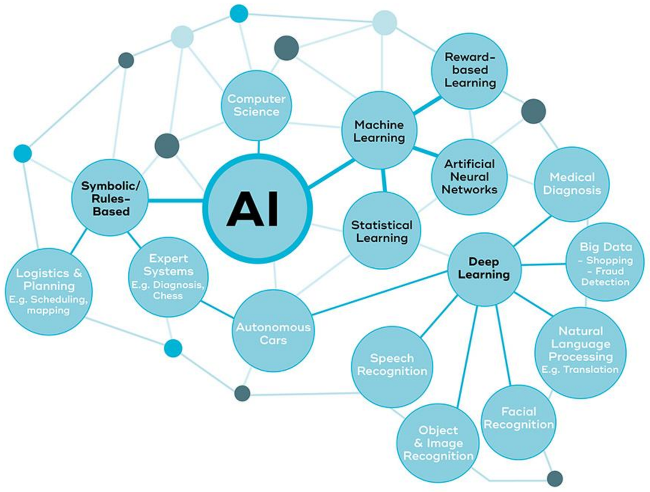


SHINE Injector

Summary

The large-scale control system integration requires extensive knowledge and comprehensive consideration.





more devices & more data | **more intelligent** | **high availability**

https://www.calsoft.com/what-is-industry-4-0/

https://qbi.uq.edu.au/brain/intelligent-machines/

https://www.apixel.com.sg/

If you want to know more ...

- International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS)
- This series of conferences facilitates fruitful collaborations among the world's control system specialists from particle accelerators, light sources, laser facilities, telescopes, tokamaks, etc.
- It started in 1987 and subsequently rotated between America (including North, Central and South America), Asia (including Oceania) and Europe (including Russia, the Near East and Africa).

...

ICALEPCS 2021, hosted by SARI, Shanghai, China

ICALEPCS 2023, hosted by SARAO, Cape Town, South Africa

ICALEPCS 2025, hosted by APS/ANL, Chicago, USA

ICALEPCS 2027, hosted by KEK, Mito, Japan

...

Saturday September 20th Workshops

- EPICS Collaboration
- Tango
- PBCS: PLC Based Control Systems
- Towards Efficiency and Long-term Sustainability
- Controls GUI Strategies

Sunday September 21st Workshops

- Control System Cybersecurity
- Bluesky
- Motion Control and Robotics
- Advancing AI/ML and Generative Models for the Control of Large Complex Systems
- Advanced Control (half-day)
- Safety Lessons Learned (half-day)

ICALEPCS 2025

Sep 20 - 26, 2025

https://www.icalepcs.org/

Thanks for Your Attention !