Evaluation of PLC-Based EtherNet/IP Communication for Upgrade of Electromagnet Power Supply Control at RIBF

RIKEN Nishina Center
Beam Dynamics & Diagnostics Team

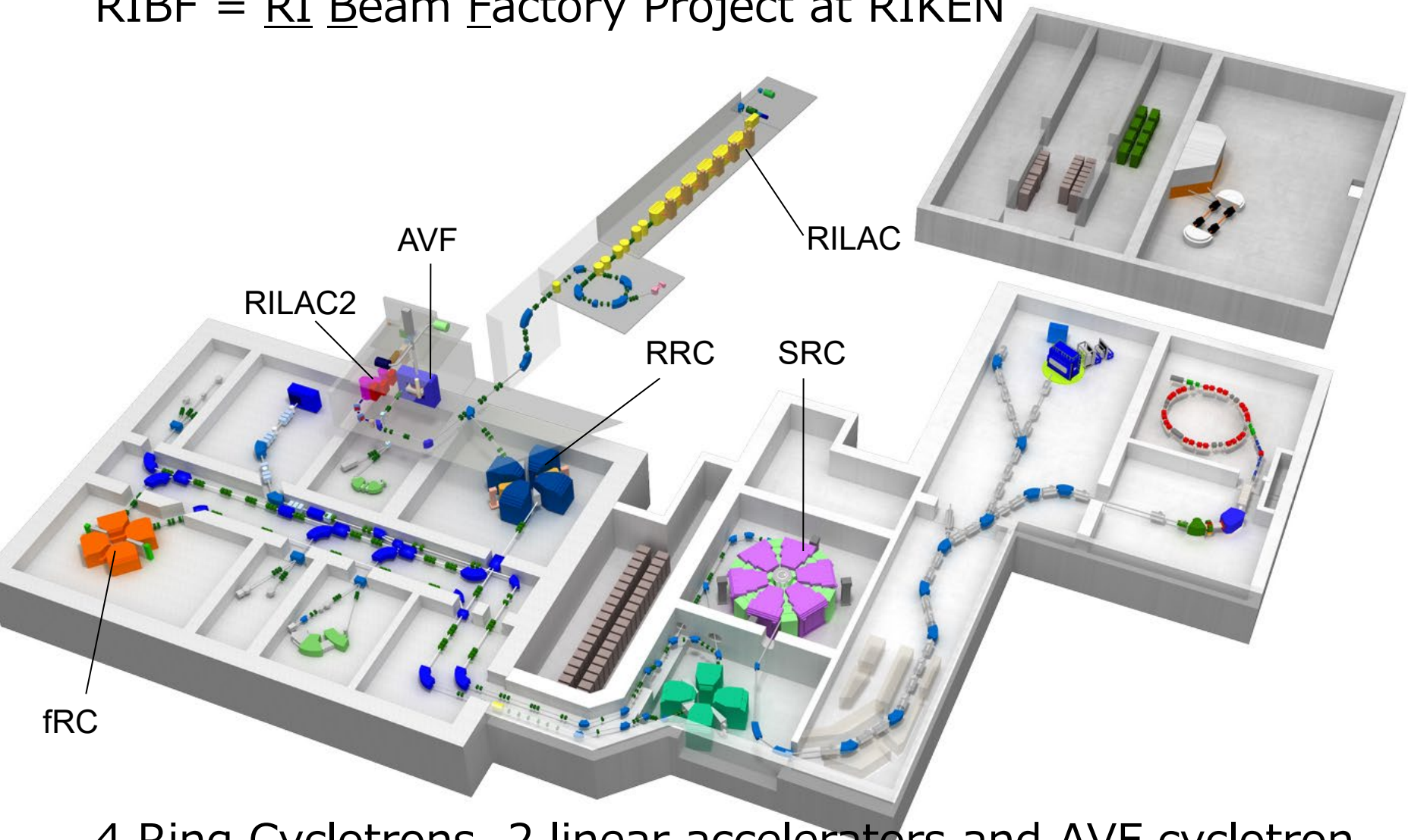
Akito UCHIYAMA, Keiko Kumagai, Misaki Komiyama, Nobuhisa Fukunishi

Outline

- Overview of RIBF
- Control system for RIBF
- Electromagnet power supply control
- Field network as the device interface layer
- Evaluation of PLC-based EtherNet/IP
- Conclusion

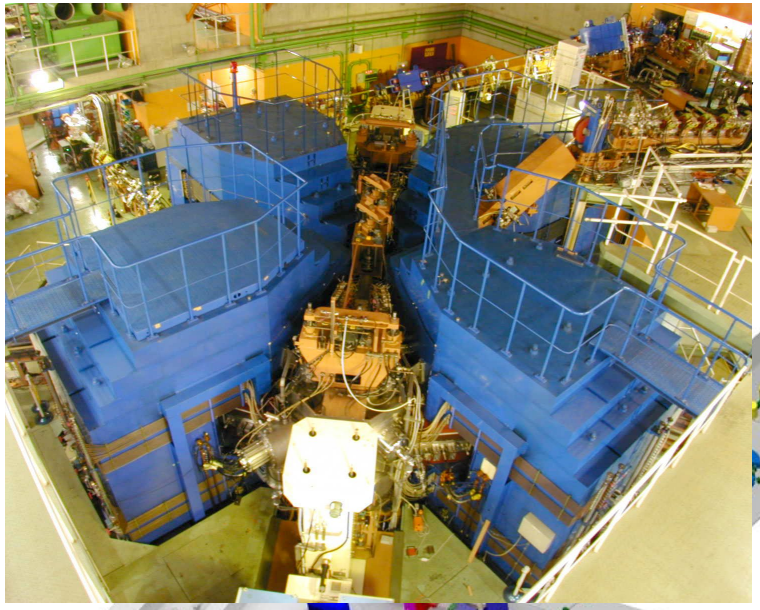
Overview of RIBF

RIBF = RI Beam Factory Project at RIKEN

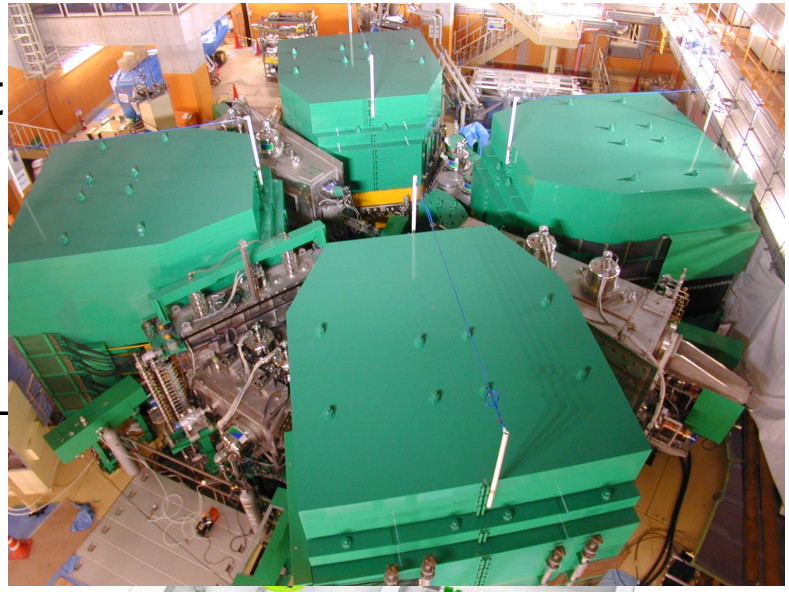


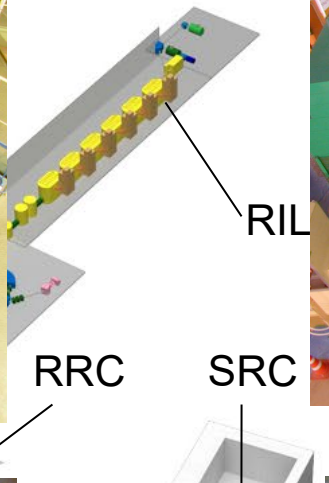
4 Ring Cyclotrons, 2 linear accelerators and AVF cyclotron.

Overview of RIBF

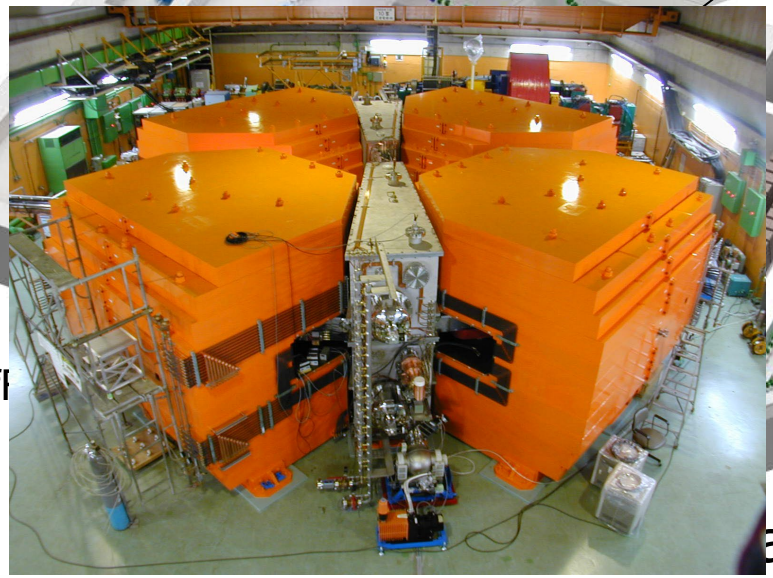


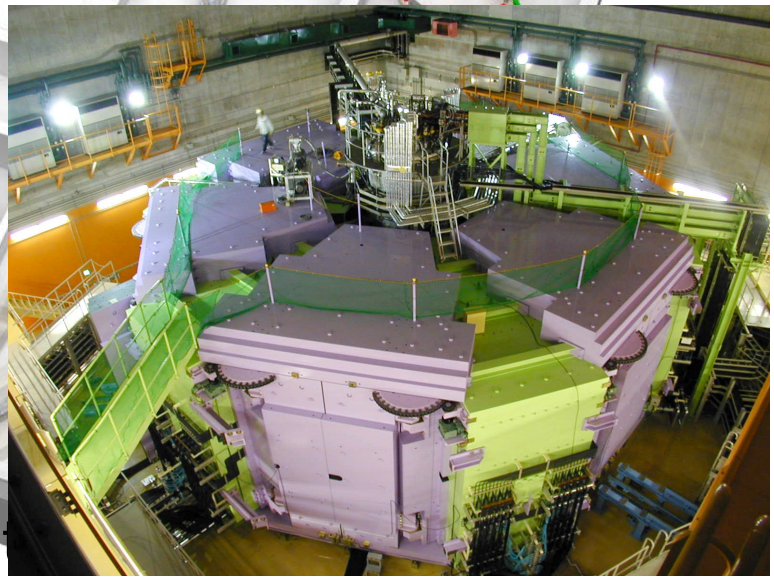
Project at

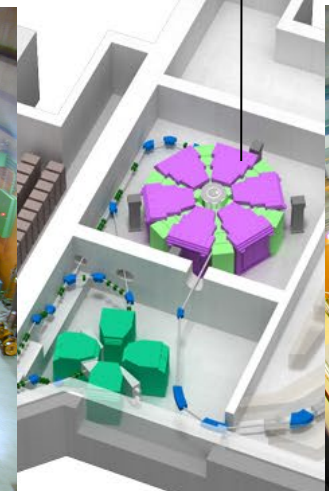




RRC SRC







fl ar accelera

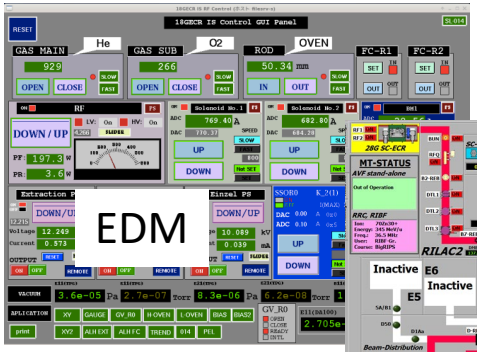
Control System for RIBF

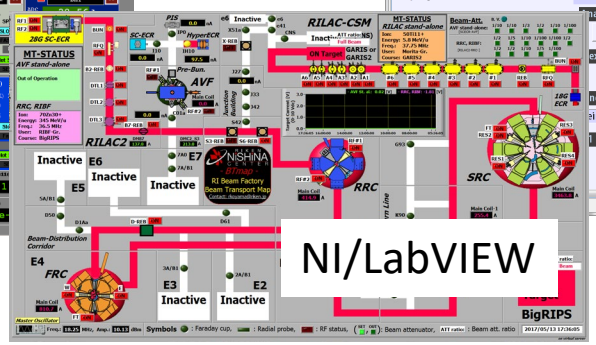
RIBF control system is based on EPICS.

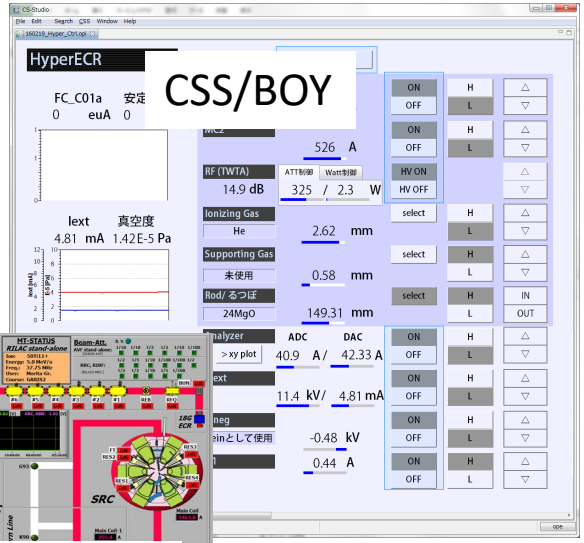
EPICS covers
- Magnet Control
- Beam Diagnostics
- ECR Ion Source Control
- Vacuum Control
- Machine protection system
- RF operation

Other EPICS services
- Operational Log system
- Data Archive system (Archiver Appliance)
- EPICS Management system (like IRMIS)
- Alarm system

Operator Interface

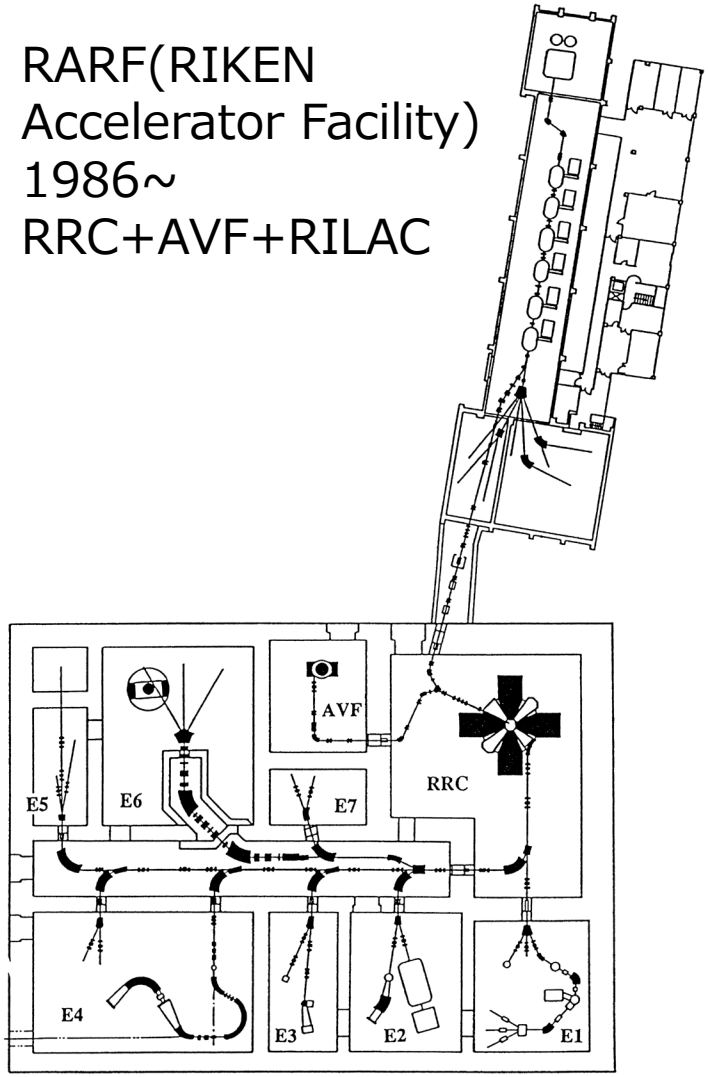






Upgrade project

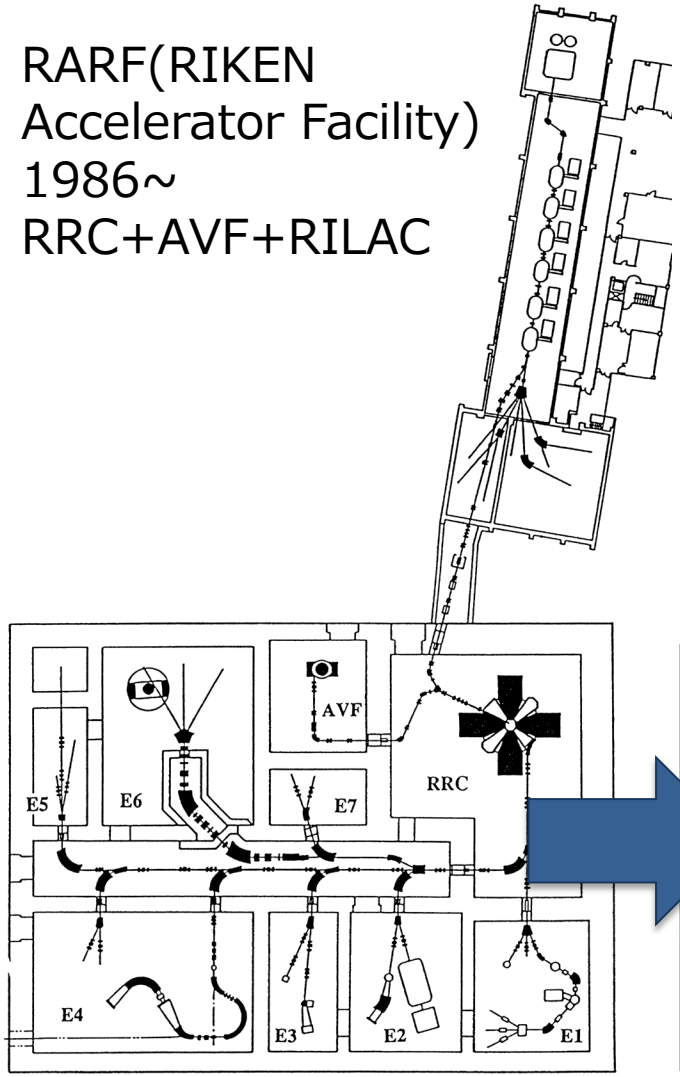
RARF(RIKEN Accelerator Facility)
1986~
RRC+AVF+RILAC

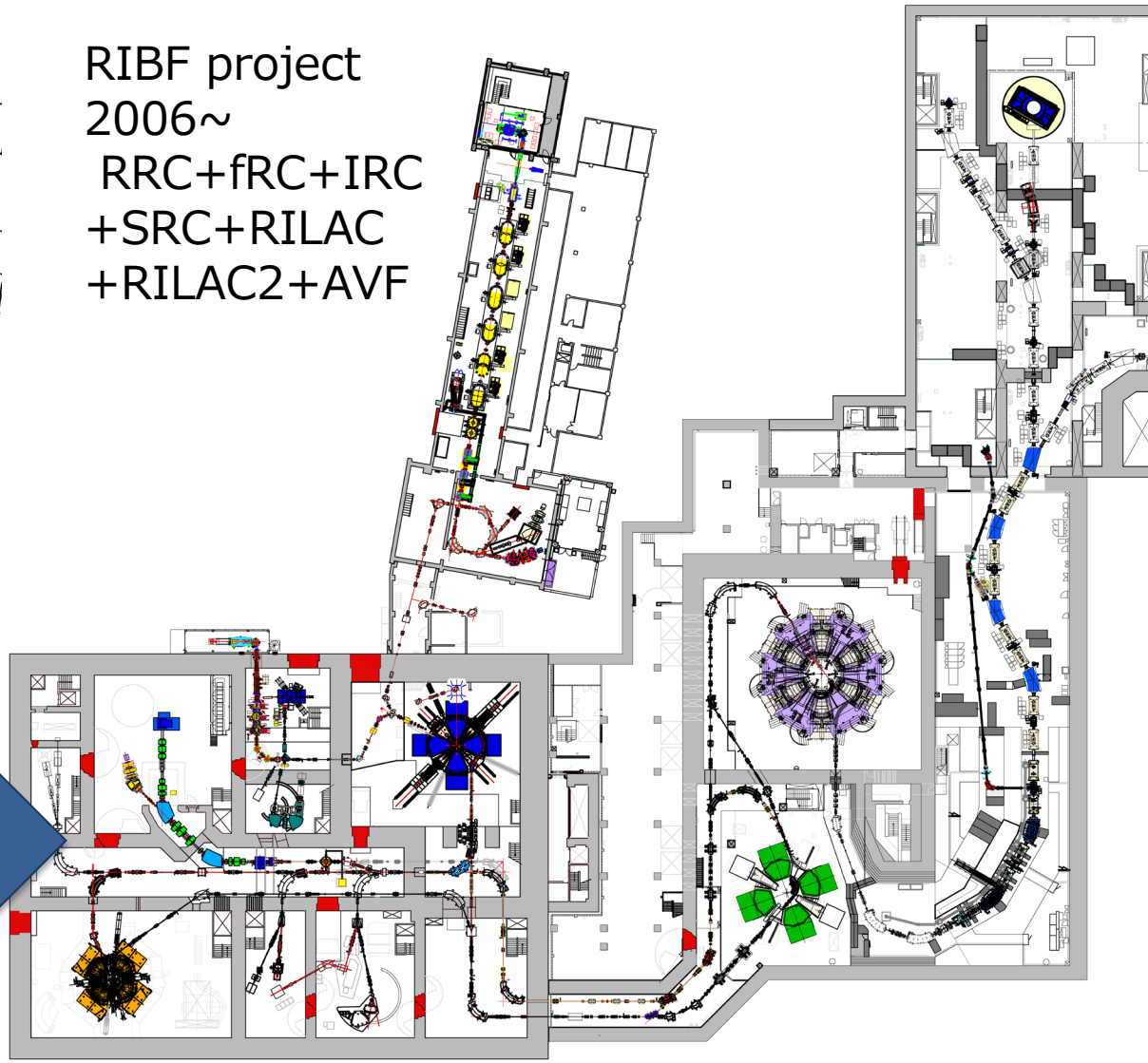


Upgrade project

RARF(RIKEN Accelerator Facility)
1986~
RRC+AVF+RILAC

RIBF project
2006~
RRC+fRC+IRC
+SRC+RILAC
+RILAC2+AVF



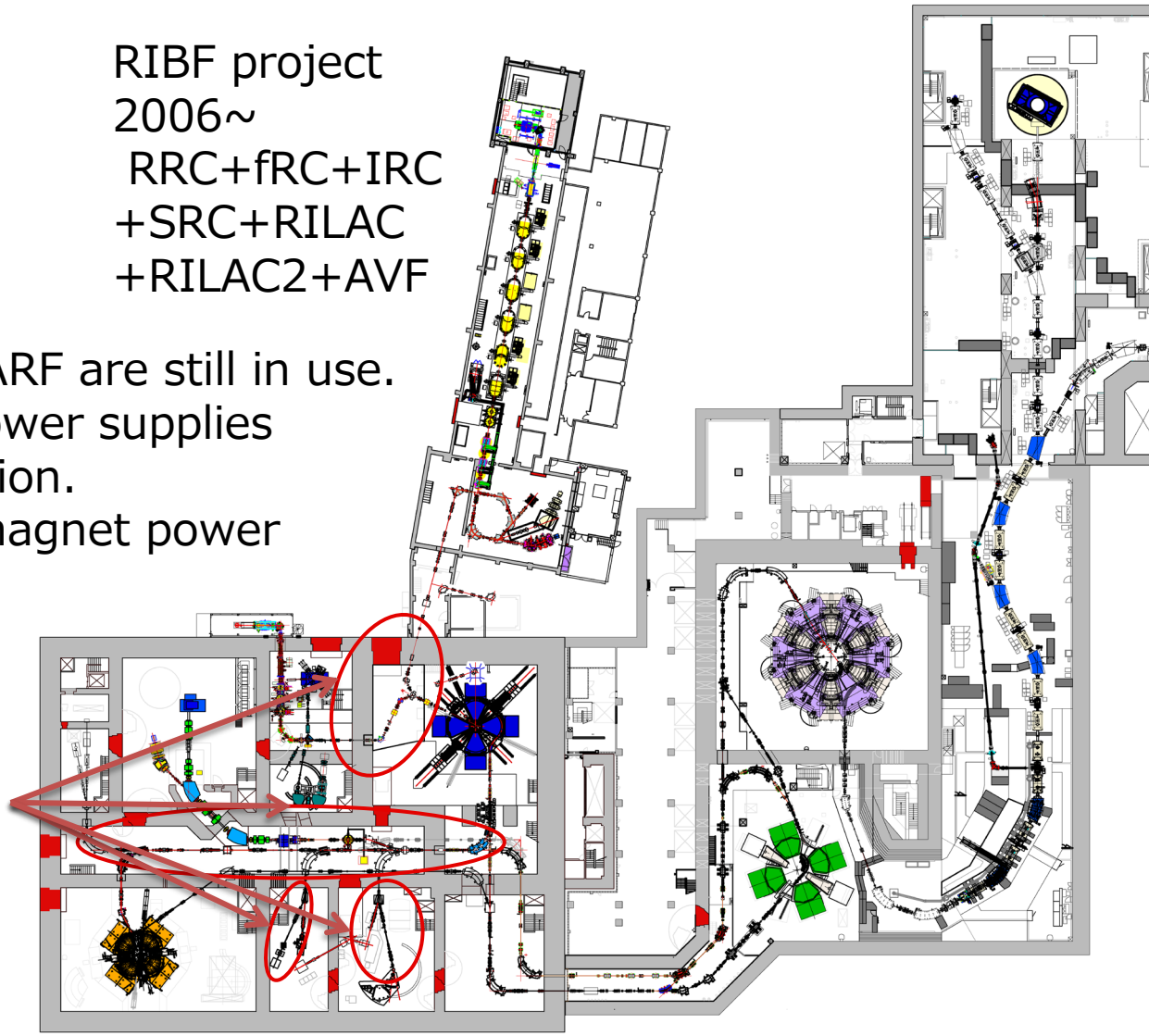


Upgrade project

RIBF project
2006~
RRC+fRC+IRC
+SRC+RILAC
+RILAC2+AVF

- The electromagnets of RARF are still in use.
- The old electromagnet power supplies (~300) are also in operation.
- The controller of electromagnet power supply is aging.

Beamline locations, which continue to be used since the RARF.



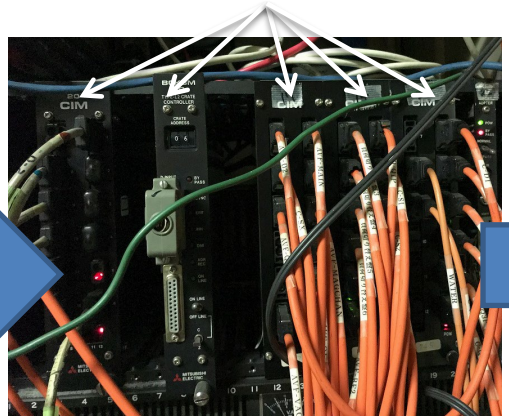
Electromagnet power supply control

1986~

- The CIM installed in the CAMAC crate was connected to the DIM.
- DIM was installed into the power supply.
- The connection was through optical fiber.

Device Interface Module(DIM)

CIM



Minicomputer as controller

CAMAC crate with Communication Interface Module (CIM).

Magnet power supply

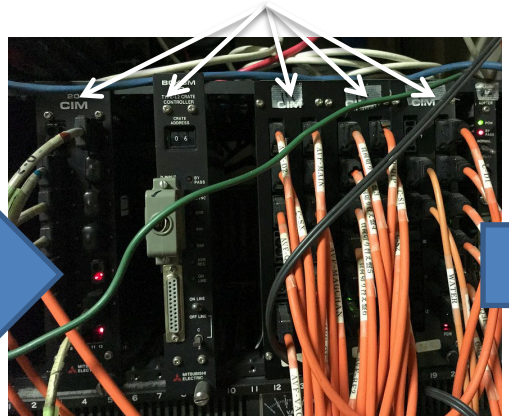
Electromagnet power supply control

2001~

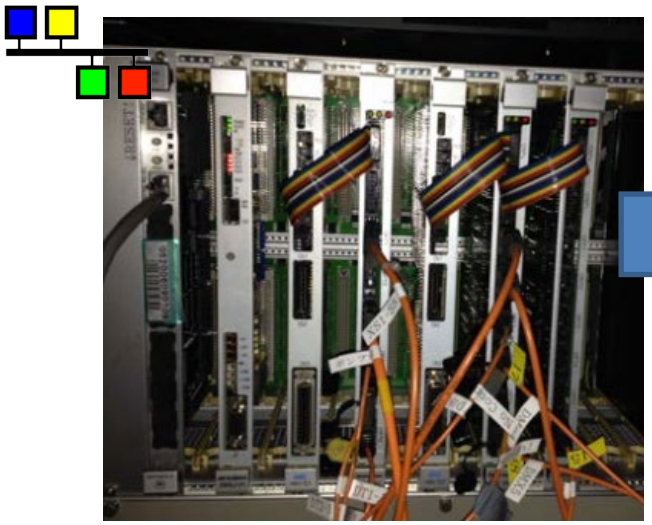
- The VME CPU board was adopted to support EPICS.
- But the CIM and DIM were still used.

Device Interface Module(DIM)

CIM



EPICS



VME CPU board with EPICS

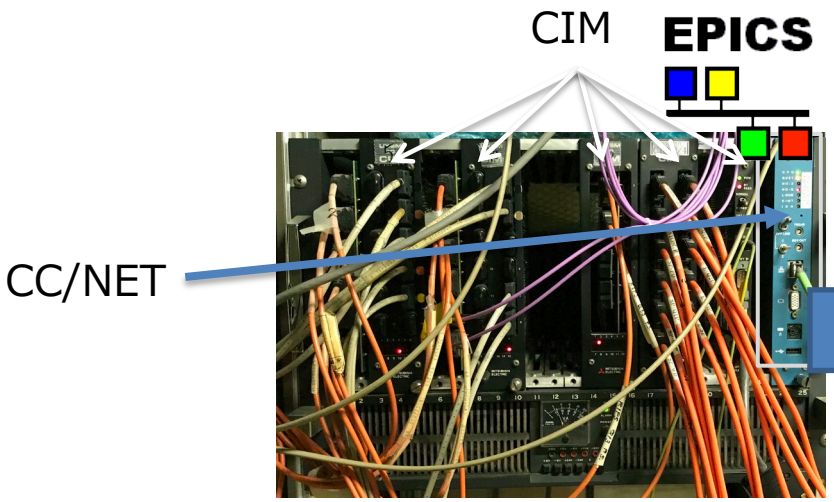
CAMAC crate with Communication Interface Module (CIM).

Magnet power supply

Electromagnet power supply control

2004~

- The VME CPU board was replaced by CC/NET.
- CC/NET is a CAMAC crate controller running EPICS.
- But the CIM and DIM were still used.



CAMAC crate controller as CC/NET installed EPICS and CIM.

Device Interface Module(DIM)

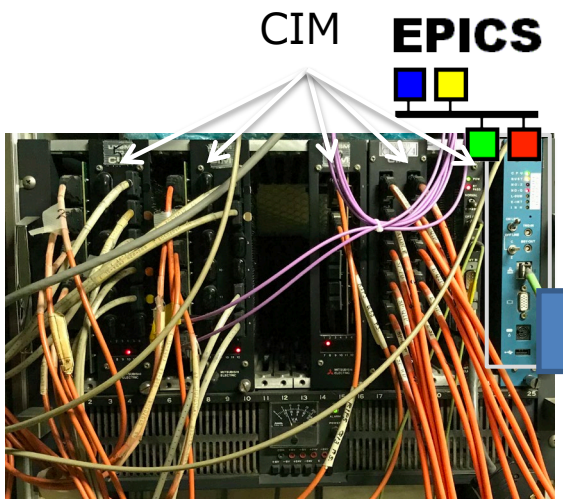
Magnet power supply

Electromagnet power supply control

2004~

- The VME CPU board was replaced by CC/NET.
- CC/NET is a CAMAC crate controller running EPICS.
- But the CIM and DIM were still used.

The CIM/DIM has already been in use for 35 years!!

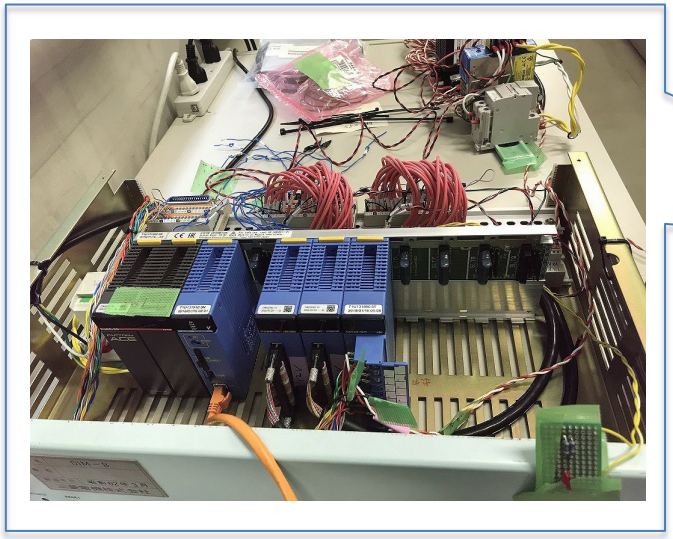


CAMAC crate controller as CC/NET installed EPICS and CIM.

Device Interface Module(DIM)

Magnet power supply

Electromagnet power supply control



Device Interface Module(DIM)

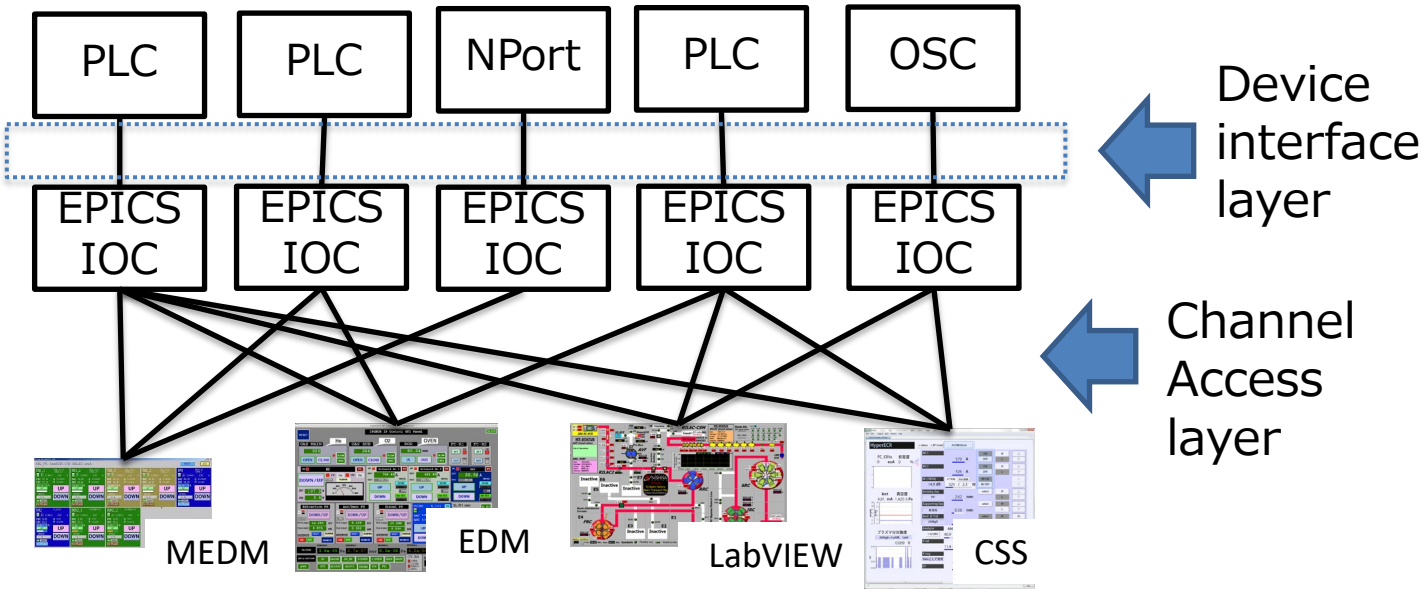
The DIM functional part currently under development.
Yokogawa FA-M3 PLC is a candidate to update the DIM.

The communication between the controllers, and the EPICS implementation method are studied.

Magnet power supply

Field network as the device interface layer

- FA-M3 CPU module is equipped with standard Ethernet.
- EPICS device support software is ready.(NetDev, AsynDriver, StreamDevice)
- TCP/IP is very useful and used for general purpose !!
- The system development is low cost in case of TCP/IP as the device interface layer.

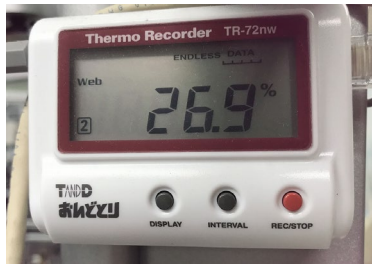


Field network as the device interface layer

In-house network device

Mitsubishi PLC (MLSEC-Q, MELSEC iQ-R)

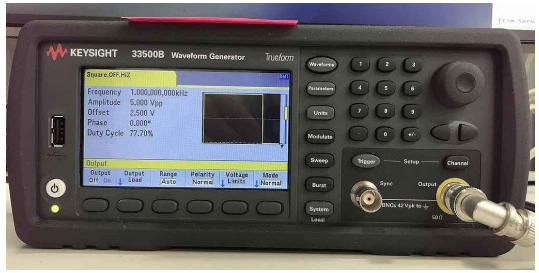
Yokogawa PLC (FA-M3)



Ondotori

We are using about 600 TCP/IP-based device for RIBF control system.

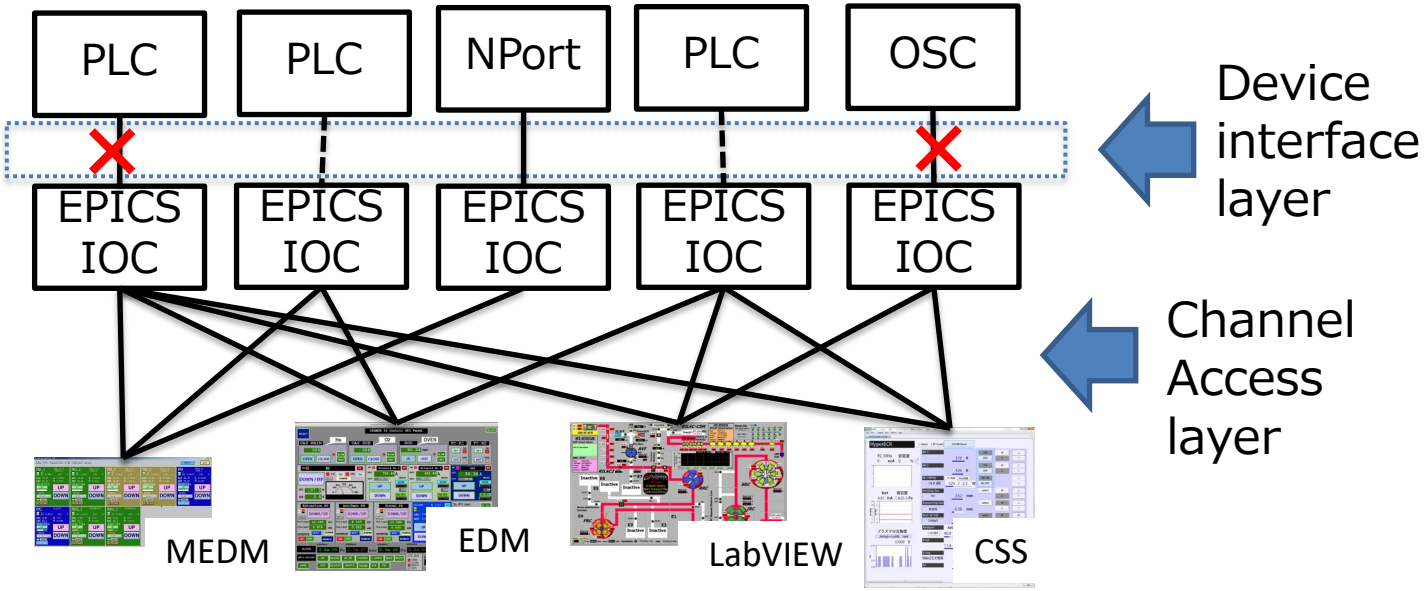
Omron PLC



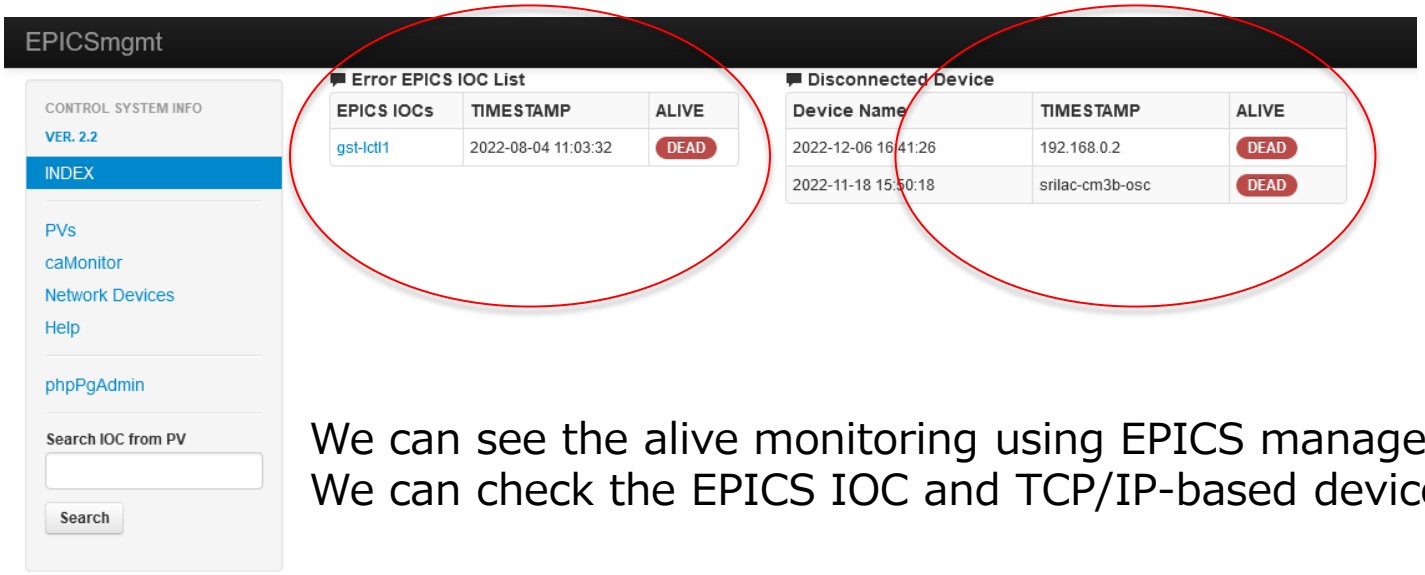
Keysight

Field network as the device interface layer

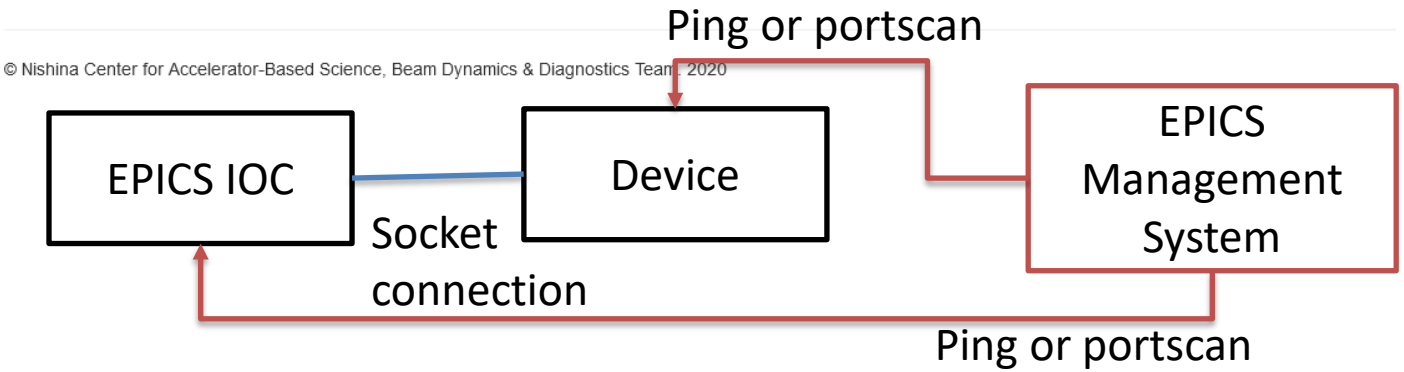
- In some case, the reconnection is failed after TCP/IP is disconnected by trouble (need to restart EPICS IOC).
  - When the socket is closed properly, the reconnection is usually succeeded.
- TCP/IP is low real-time performance (low reliability).
- Slow I/O communication (not suitable for interlock).



Field network as the device interface layer



We can see the alive monitoring using EPICS management system.
We can check the EPICS IOC and TCP/IP-based devices down.



However, the EPICS management system checks the status using ping and portscan by an external program, so it does not check the socket status between EPICS IOC and the devices.

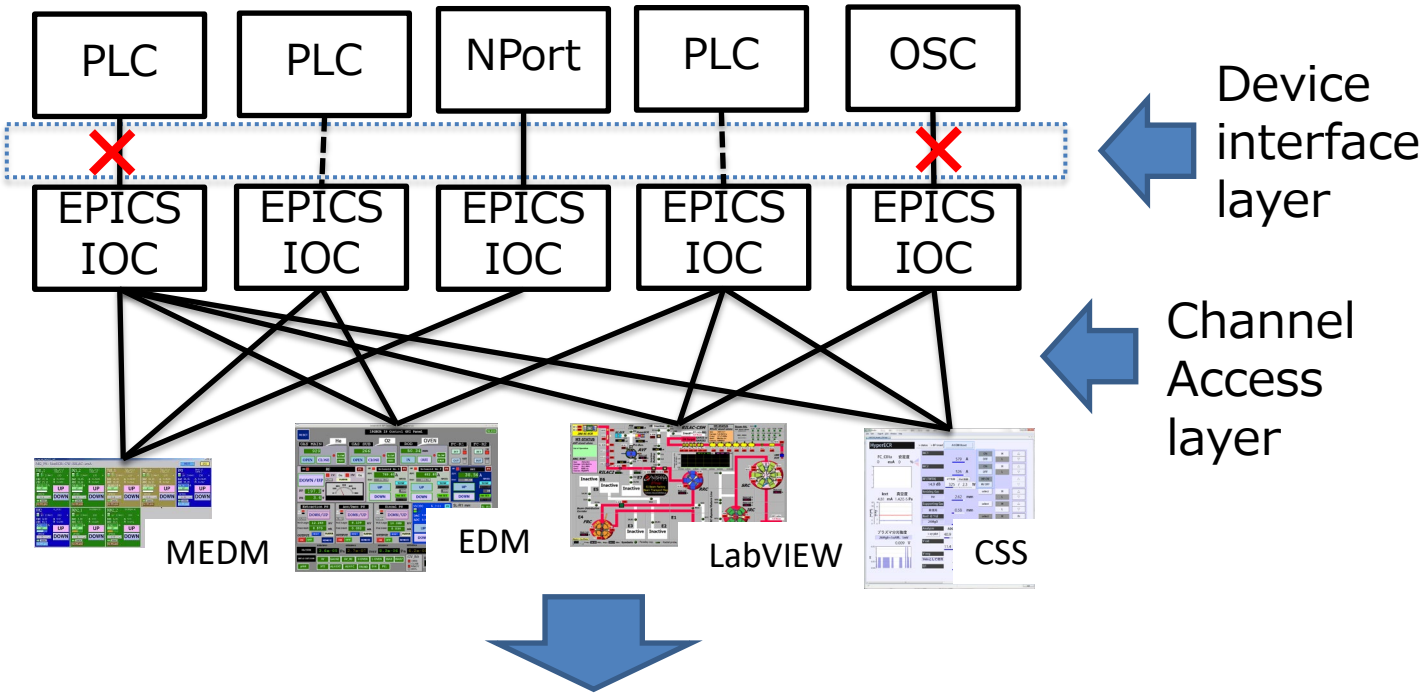
Field network as the device interface layer

```
EPICS SNC:ndim_scan_restart comp.
drvNetMpf: sanity check OK (22144 times)
cancel : 8 times
receive: 1099887 times
timeout: 105 times
send   : 1100000 times
delta  : 0 times
drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.179"...
drvNetMpf: connected to "172.23.2.179"
drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.178"...
drvNetMpf: connected to "172.23.2.178"
EPICS SNC:ndim_scan_restart ndim_reset.
PV: ndim_vac:vac_B12:vac_Pa dbGetLinkValue

PV: ndim_vac:vac_B12:vac_Pa dbGetLinkValue

drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.45"...
drvNetMpf: connected to "172.23.2.45"
EPICS SNC:ndim_scan_restart start.
EPICS SNC:ndim_scan_restart comp.
EPICS SNC:ndim_scan_restart ndim_reset.
drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.177"...
drvNetMpf: connected to "172.23.2.177"
drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.176"...
drvNetMpf: connected to "172.23.2.176"
EPICS SNC:ndim_scan_restart start.
EPICS SNC:ndim_scan_restart comp.
drvNetMpf: EOF found while receiving
drvNetMpf: tcp client trying to connect to "172.23.2.180"...
drvNetMpf: connected to "172.23.2.180"
PV: ndim_vac:vac_B12:vac_Pa dbGetLinkValue
```

- We can check the status of the TCP/IP connection on the EPICS startup screen.
- It is very easy to implement this function.
- But this is for developer, not for operators.

Field network as the device interface layer

- In some case, the reconnection is failed after TCP/IP is disconnected by trouble (need to restart EPICS IOC).
  - When the socket is closed properly, the reconnection is usually succeeded.
- TCP/IP is low real-time performance (low reliability).
- Slow I/O communication (not suitable for interlock).



Ethernet-based field network as the device interface layer

Field network as the device interface layer

Development of dedicated protocol is usually high cost.

Ethernet-based standard protocol.
General technology to reduce the cost of debugging.

- EtherCAT — Hard realtime, fast response, but require dedicated network.
- FL-net — Realtime, middle response, but require dedicated network.
- EtherNet/IP — Realtime, middle response, allowing general-purpose network switches with other TCP/IP protocols, low-cost wiring work.

Field network as the device interface layer

Development of dedicated protocol is usually high cost.

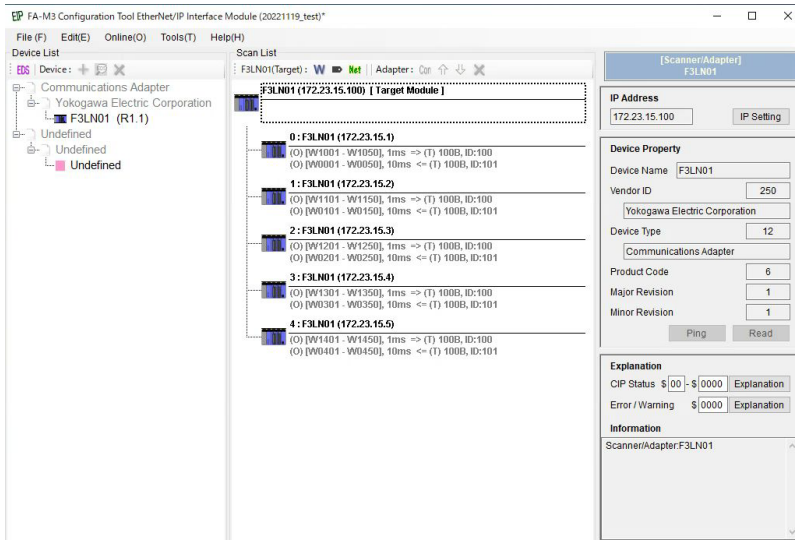
Ethernet-based standard protocol.
General technology to reduce the cost of debugging.

- EtherCAT — Hard realtime, fast response, but require dedicated network.
- FL-net — Realtime, middle response, but require dedicated network.
- EtherNet/IP — Realtime, middle response, allowing general-purpose network switches with other TCP/IP protocols, low-cost wiring work.

Field network as the device interface layer

EtherNet/IP

- EtherNet/IP is one of the field networks widely used in the industrial field using Ethernet.
- EtherNet/IP is compatible with conventional Ethernet, sharing the same physical layer such as frame structure, connectors, and cables.
- EtherNet/IP is also compatible with TCP/IP. EtherNet/IP utilizes the Common Industrial Protocol (CIP) control communication protocol in the application layer.
- The main features of EtherNet/IP are allowing general-purpose network switches with other TCP/IP protocols, low-cost wiring work, soft real-time performance.



We utilize Yokogawa FA-M3 PLC to implement the EtherNet/IP function.

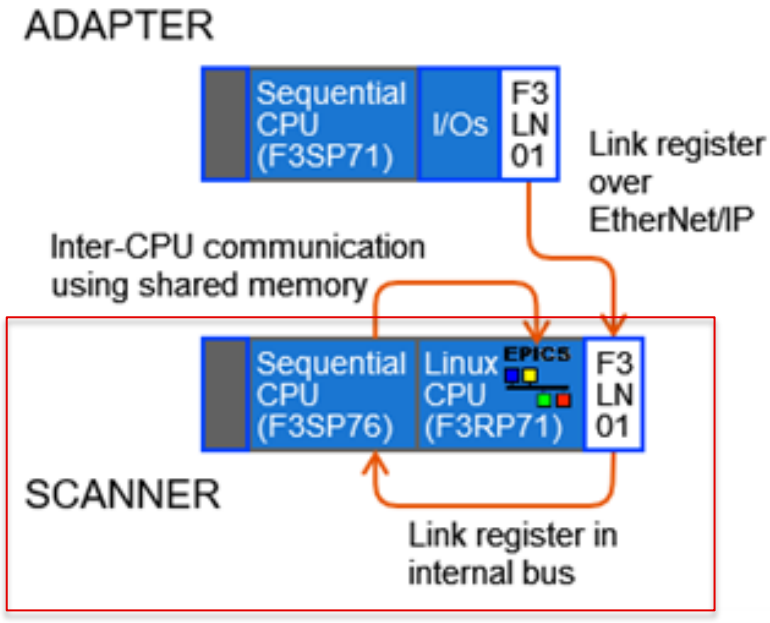
This figure shows about the screenshot to set up for configuration of EtherNet/IP.

Evaluation of PLC-based EtherNet/IP

EPICS Interface

- EtherNet/IP-based system consists of a scanner and adapters.
- Scanner has the EPICS IOC, F3RP71 is installed as Linux CPU in second slot.
- The scanner and adapters exchange the data via the link register. (Low development cost)

SCANNER



Evaluation of PLC-based EtherNet/IP

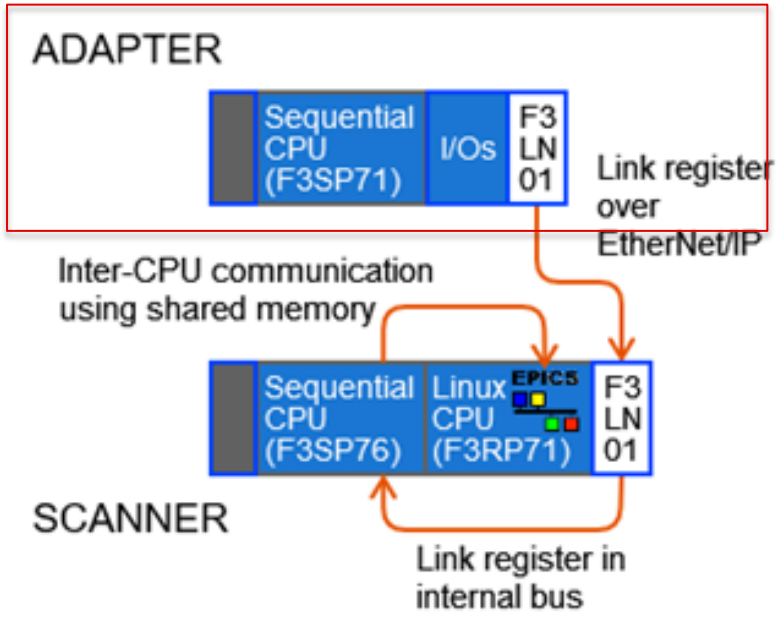
EPICS Interface

- EtherNet/IP-based system consists of a scanner and adapters.
- Scanner has the EPICS IOC, F3RP71 is installed as Linux CPU in second slot.
- The scanner and adapters exchange data using the link register. (Low development cost)

ADAPTER

F3SP71
Sequential
CPU

F3LN01
EtherNet/IP
module



Evaluation of PLC-based EtherNet/IP

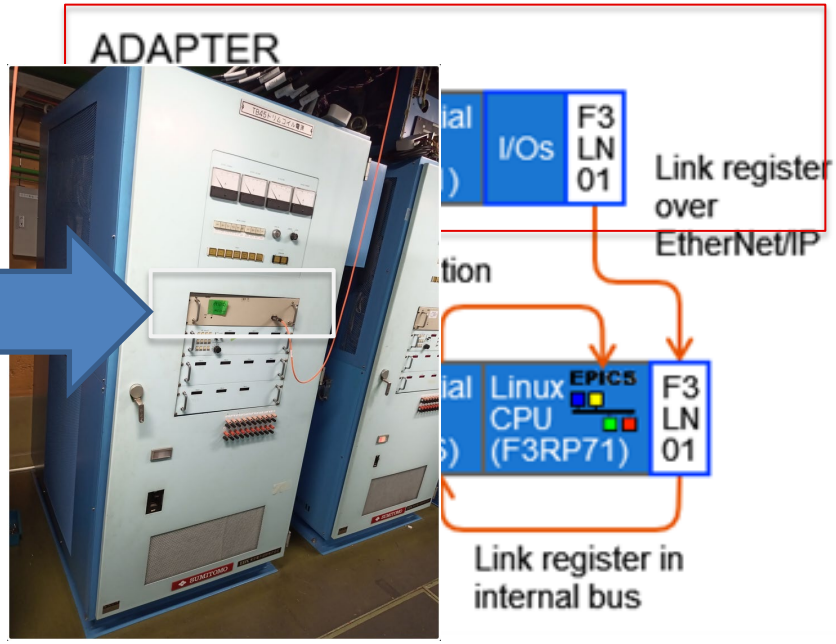
EPICS Interface

- EtherNet/IP-based system consists of a scanner and adapters.
- Scanner has the EPICS IOC, F3RP71 is installed as Linux CPU in second slot.
- The scanner and adapters exchange data using the link register. (Low development cost)

ADAPTER

F3SP71
Sequential
CPU

F3LN01
EtherNet/IP
module

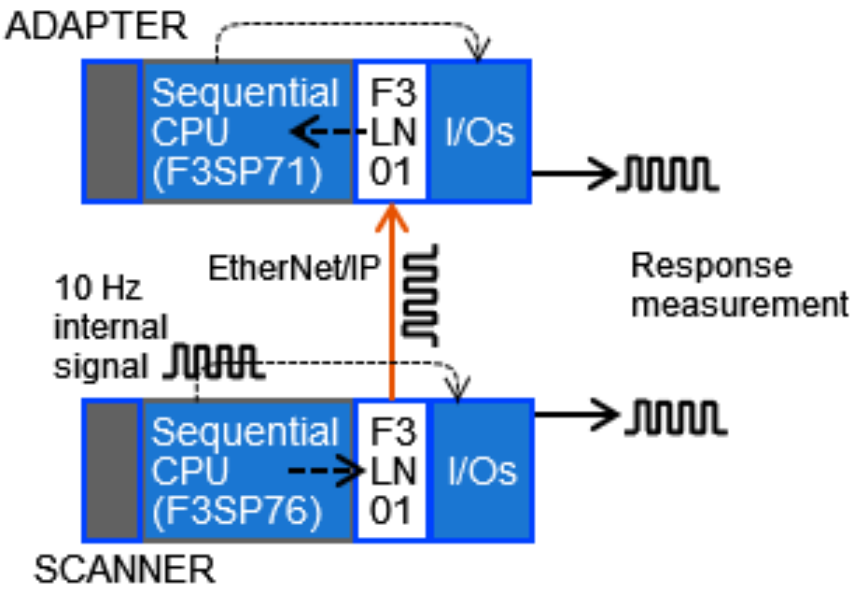


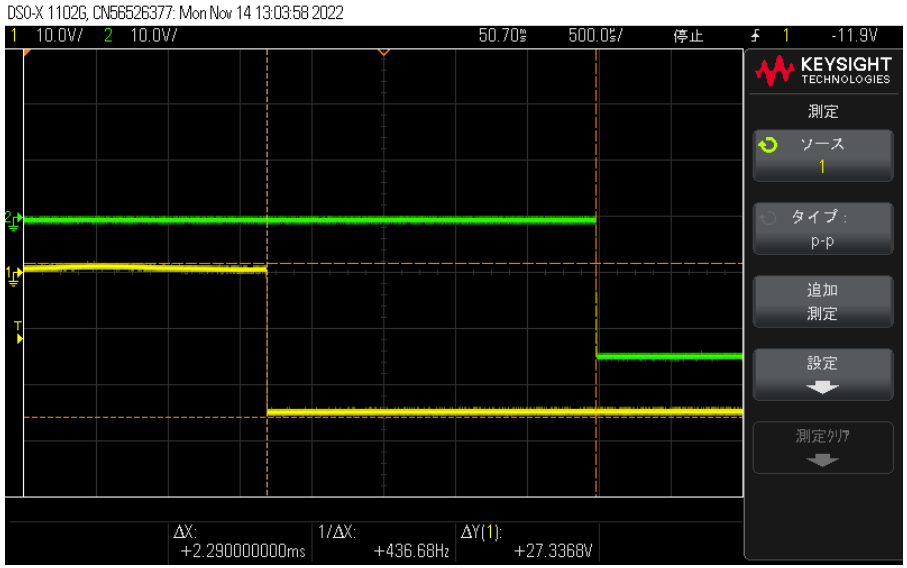
Adapters will become DIM and built inside the power supply chassis.

Evaluation of PLC-based EtherNet/IP

Response of EtherNet/IP

- Create a 10 Hz signal in the scanner's sequence CPU, trigger it to output to the scanner and adapter simultaneously.
- Measure the time difference depending on EtherNet/IP communication.
- One Ethernet/IP scanner and one adapter connected in one 1Gbps switching hub.
- Note, the connection with requested packet interval 1 msec.



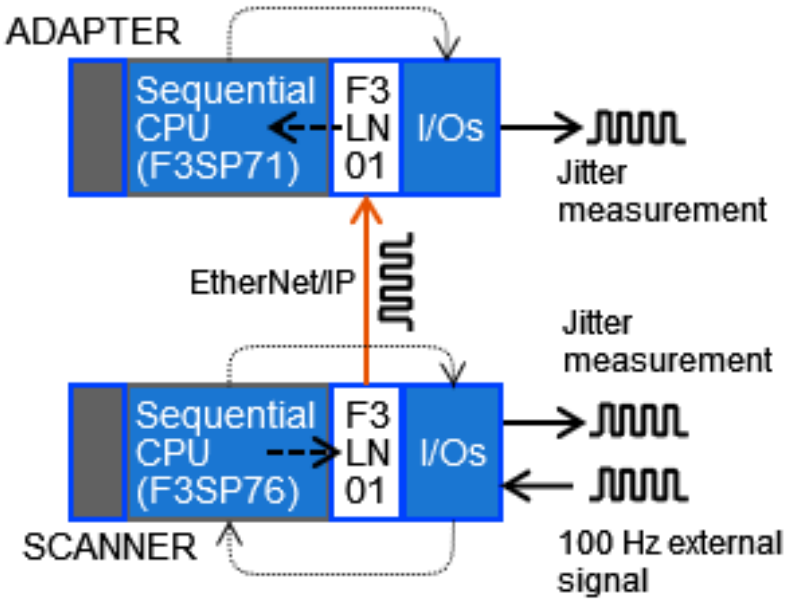


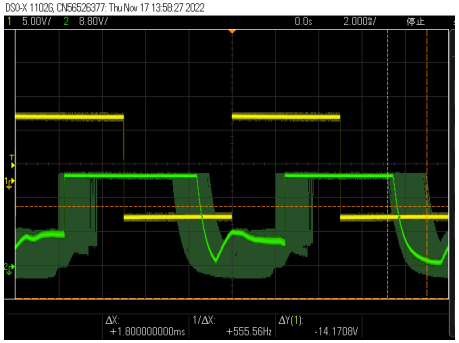
The difference in average response time is about 2.3 msec

Evaluation of PLC-based EtherNet/IP

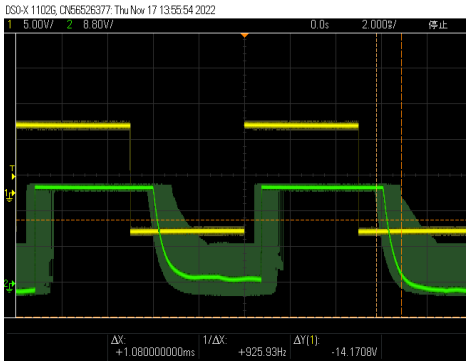
Jitter of EtherNet/IP

- Create a 100 Hz external signal and input to the scanner.
- The scanner triggered the input signal and output to both the scanner and adapter.
- One Ethernet/IP scanner and one adapter connected in one 1Gbps switching hub.
- Note, the connection with requested packet interval 1 msec.





1.8 msec



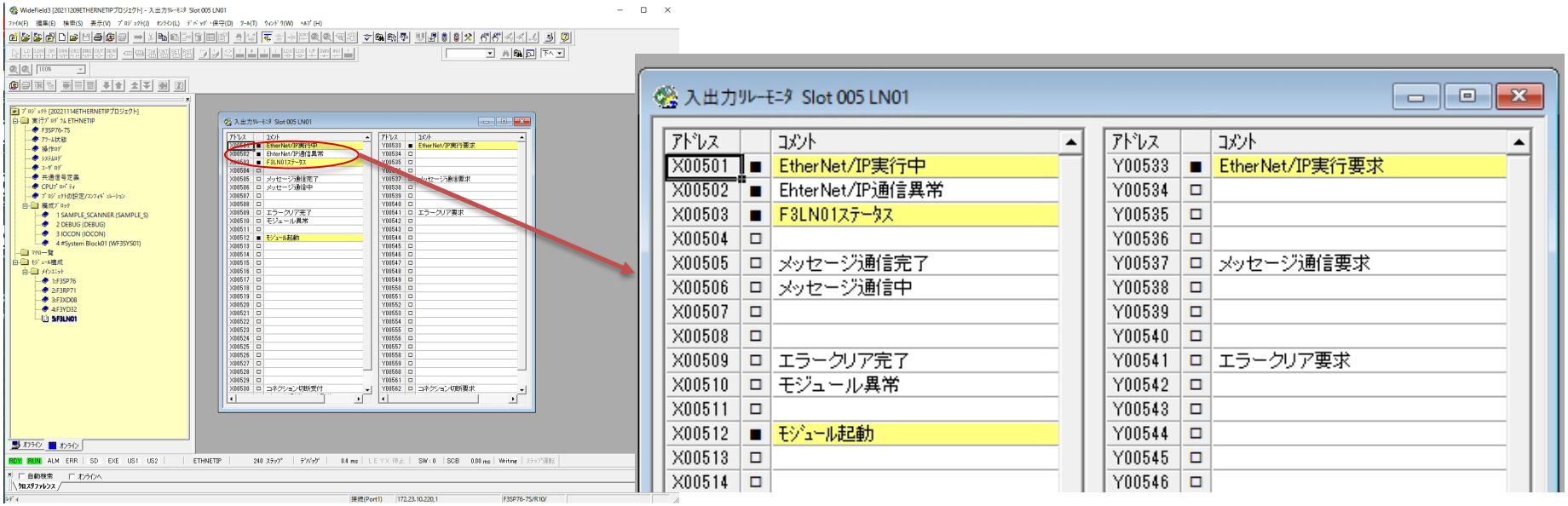
1.08 msec

The jitter is about 0.7 ms larger via EtherNet/IP.

Evaluation of PLC-based EtherNet/IP

Failure tests of EtherNet/IP

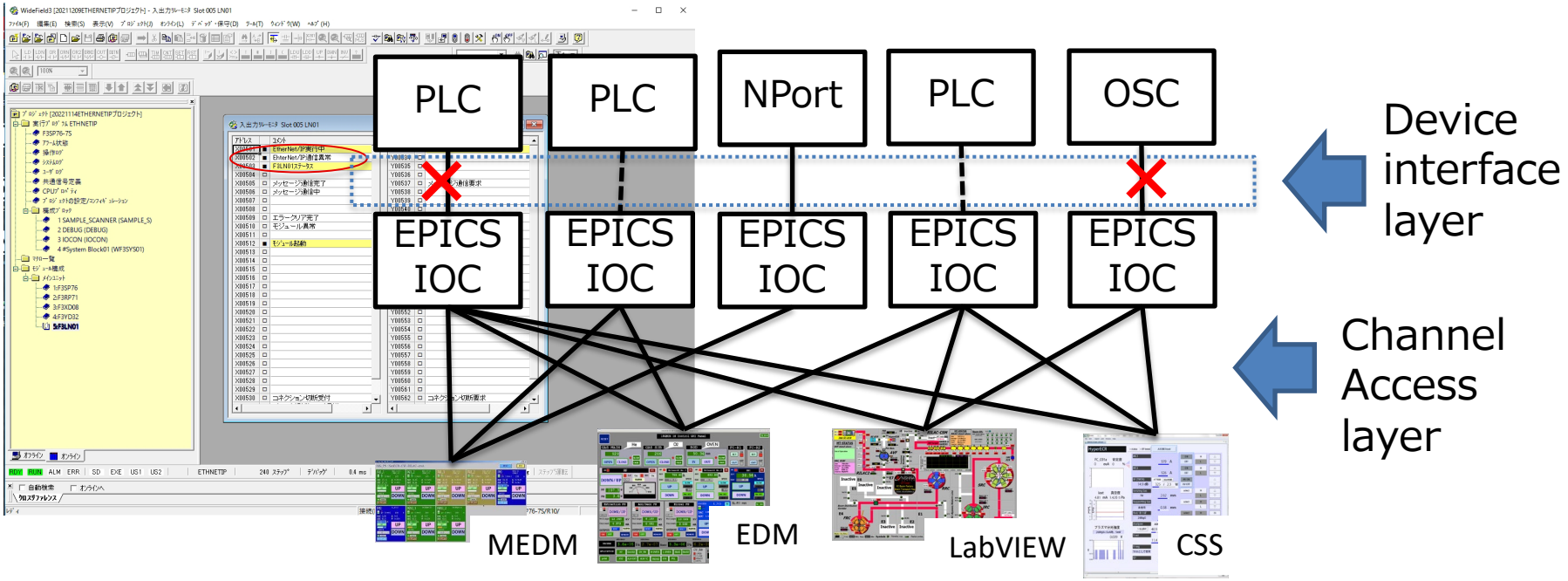
- Disconnect and check the status.
- The PLC CPU is fully capable of detecting failures in the device interface layer.
- The error status by standard registers so that the operator can be informed via EPICS.



Evaluation of PLC-based EtherNet/IP

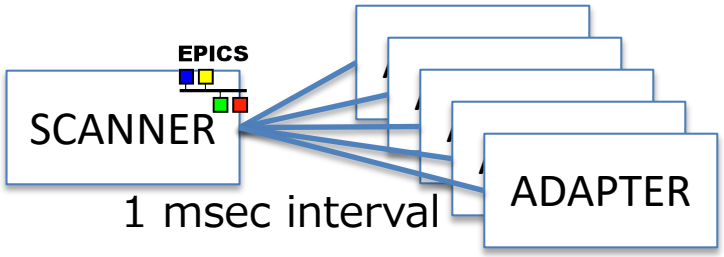
Failure tests of EtherNet/IP

- Disconnect and check the status.
- The PLC CPU is fully capable of detecting failures in the device interface layer.
- The error status by standard registers so that the operator can be informed via EPICS.

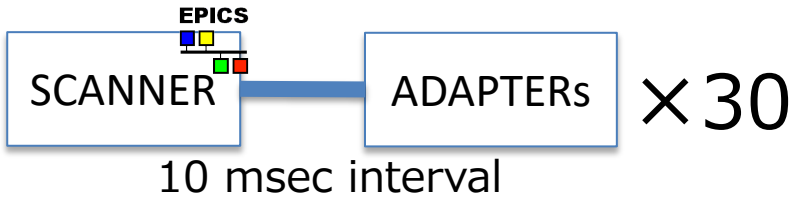


Evaluation of PLC-based EtherNet/IP

- In requested packet interval is 1 msec, EtherNet/IP connection takes 2.3 msec to deliver the signal.
- We had an FL-net-based application with the minimum number of nodes before.
- About response time of EtherNet/IP, the performance was comparable to FL-net.
- While the transmission time of FL-net becomes proportionally slower as the number of connected nodes increases.
- The jitter is only about 0.7 ms larger via EtherNet/IP, though soft realtime system.
- Sufficient performance as an interlock signal to be output when stopping the beam due to power supply problems.
- It is possible to transmit interlock signals to distant locations via a general-purpose network switches.



In requested packet interval is 1 msec, SCANNER handles 5 ADAPTERs.



In requested packet interval is 10 msec, SCANNER handles 30 ADAPTERs without interlock signal.

Conclusion

- To upgrade the old electromagnet power supply control, we studied the EPICS IOC and the device interface layer.
- General TCP/IP-based device is very useful but there are some concerns for electromagnet power supply operation.
- EtherNet/IP does not require the dedicated network and it can be mixed with the other protocols, so low-cost wiring work.
- As a result of evaluation EtherNet/IP communication, the performance is sufficient.
- When updating 50 old DIMs for RIBF, this method will be the first choice.

Thank you