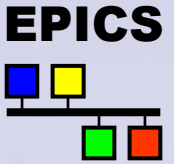

Diamond Control System

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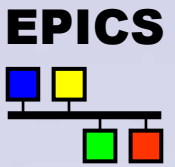
Introduction



- Review Key Decisions
- Recap on EPICS
- Generic Work
- Hardware
- Software
- Controls for Technical Systems

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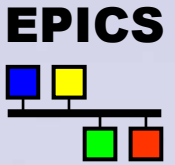
Diamond Control System

Key Decisions: Scope

- Scope of the Diamond Control System
  - *The DIAMOND control system will be a site wide monitoring and control system for the accelerators, beamlines and conventional facilities …… ……. The control system will not include any control or data acquisition for the experimental stations.*
  - *……..*

Key Decisions: Design Goals

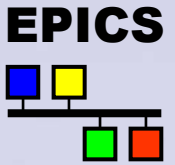


- High CS Reliability
  - High MTBF and Low MTTR
- Facility operate for 5000-6000hrs per year
  - CS available when the facility is shutdown
- Minimise in-house design of electronics
  - Use of COTS instruments and hardware
- Aggressive installation
  - Minimise installation and commissioning time
- High “day 1” functionality
  - Debugged applications before accelerator systems available
- Partition the CS into managable sizes block
  - Split by technical system and geographical location

Key Decisions: Procurement

- Set out to buy turnkey systems complete with EPICS controls from industry
- Achieved this with
  - Linac, RF Amplifiers, eBPMS, LLRF, SCMPW, PM IDs, Girder alignment, 3 MX Beamlines and 4 Monos
- To facilitate this
  - Running EPICS training courses 2-3 times a year
    - Make 2-3 places available to industry at no charge
    - Prior to getting contracts.
  - Loaned industry complete, fully set up development environment
    - We've then gone to or have staff in for further tuition
  - Work with companies and individuals who can provide consultancy services to industry which does not have necessary skills

Key Decisions: Structure

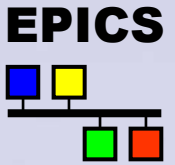


- Based on EPICS using Two Layer Model
  - Primary interface to CS through VME IOCs
  - Use VME64x, IP carriers, IP Modules and transition board for rear connection
  - Hot Swap capability
- Will use PLCs to manage interlocks for protection
  - Avoids Watch Dogs on IOCs and allow warm reboot of IOCs
  - Two families of PLC required
    - High-end applications, process control
    - Low-end applications, interlocking and control of Vac Valves
- Serial Interface to Instrumentation
  - Potentially several thousand
  - Serial support through Stream Device and ORNL Serial

Key Decisions: Platforms

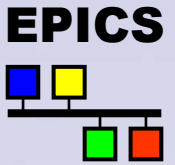
- Development
  - Linux for development
  - Running EPICS 3.13.9 will move to 3.14.x
- Consoles
  - PCs running Linux
  - Will support Win2000 (looks Less likely)
- IOCs
  - VME64x
  - PPC Processor boards MVME5500
  - Will use IP carrier and modules
  - Primarily 7 slot crates

EPICS: What Is EPICS?



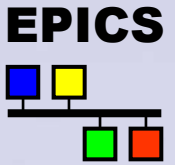
- EPICS is Experimental Physics and Industrial Control System
- It is software “Lego” (Building Block) to build control systems
  - Control system tool kit
  - Suite of software tool to facilitate building a distributed control system without having to develop software.
  - The control system is developed using the tools, display editors, alarm handlers, data base generators
- Architecture for building a distributed control system
- EPICS is more than the packaged software
  - Collaboration of hundreds of laboratories around the world to build and share software

EPICS: EPICS on other Light Sources



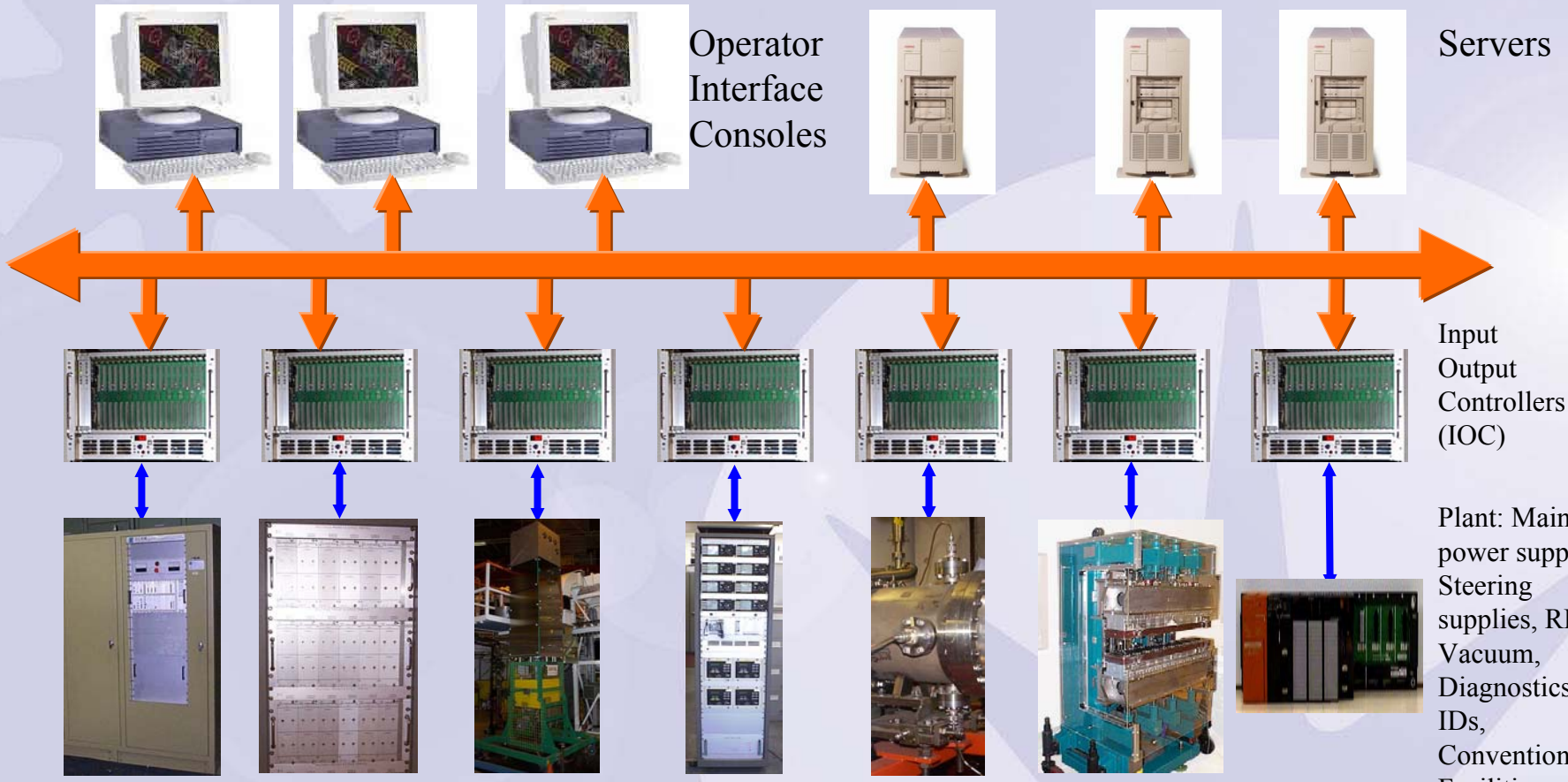
- Advanced Photon Source
  - Applied to accelerators, most beamlines and experiments
- BESSY II
  - Applied accelerators and some beamlines and experiments
- SLS
  - Applied to accelerators, all beamlines and experiments
- Canadian Light Source
  - Applied to accelerators
- Advance Light Source
  - Applied to some accelerator systems with an upgrade to EPICS planned
- SSRL
  - SPEAR3 upgrade to EPICS

EPICS: Architecture



- EPICS embodies the standard client server model for a distributed control system
- The Operator Interface (OPI) is one class of Client which receives and processes data
- The Input Output Controller (IOC) is the Server which interfaces to the equipment being controlled
- The OPIs and IOCs are connected using a network and communicate using the EPICS protocol Channel Access (CA)

EPICS: Architecture



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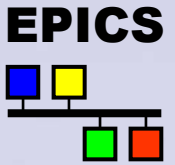
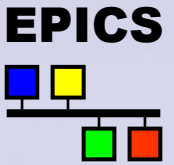
EPICS: Channel Access (CA)



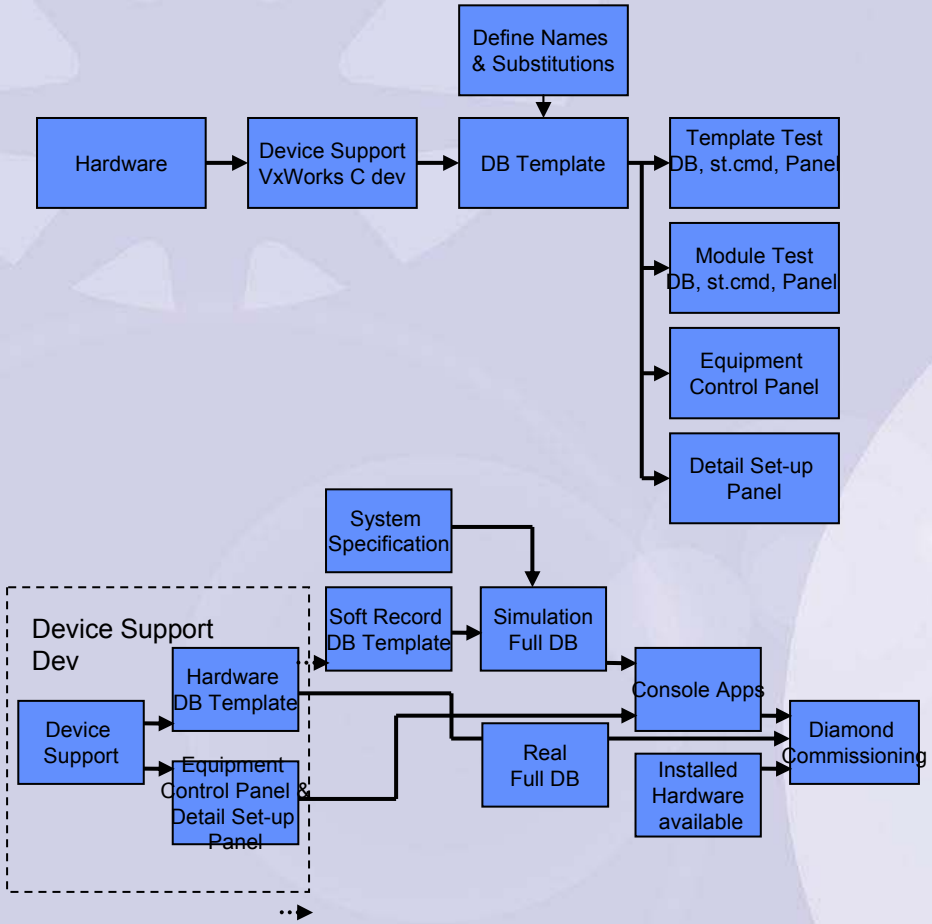
- CA is the protocol for communicating from the IOC
  - Communicates with OPI and user applications ie display screens archiver, alarm handler
  - Communicates with other IOCs to pass data from IOC to IOC
- CA resolves channel names using broadcast
- Three communication mechanisms
  - Put : The client sends the data and an acknowledge is received from the server
  - Get : The client request the data which is returned by the server
  - Monitor : Client requests the server to supply the data.The server updates the data to the client, periodically, on change, on out side limits.
  - Gets and Puts are available in sync and async calls from the client

Generic Work: Development Standard



- Standards have been produced to support development
  - Device Naming Conventions
  - Control System Application Development Environment
  - Diamond Control System Development Process
  - Naming Convention for Substitutions
  - Numbering Convention for VME & IP Cards
  - Human-Machine Interface (HMI) Style Guide
- A standard installation of EPICS component on Linux system
  - Standard development systems used by all staff
  - Systems loaned to developers

Generic Work: Software Development Model



- Hardware Support
  - Defines the software components to be produces for each hardware module at the IOC level
  - Develop template for each module and Test DBs and applications
- Application Development
  - Creates simulation of device using Soft records
  - Create substitution as per real system to create full set of soft records
  - Add a limited level of simulation
  - Application are develop communicating to soft records

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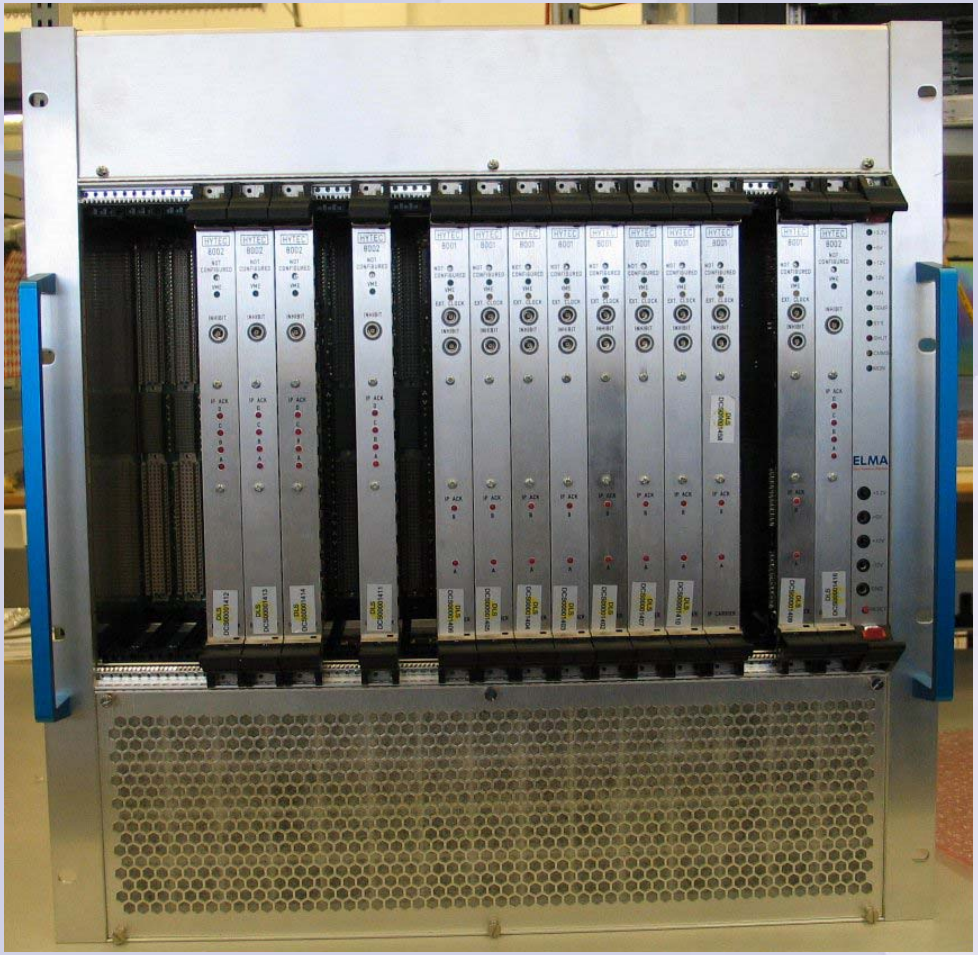
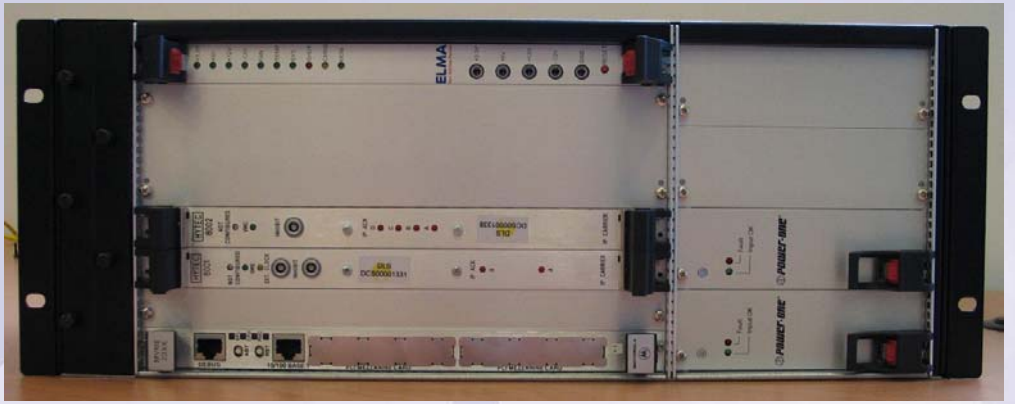
Hardware: VME Crates





- Provides the interface layer of the controls system
- Connects to the equipment being controlled
- 190 off 7 slot and 60 off 21slot VME64x standard crates.
- Include plug removable PSUs and fans, and remote monitoring

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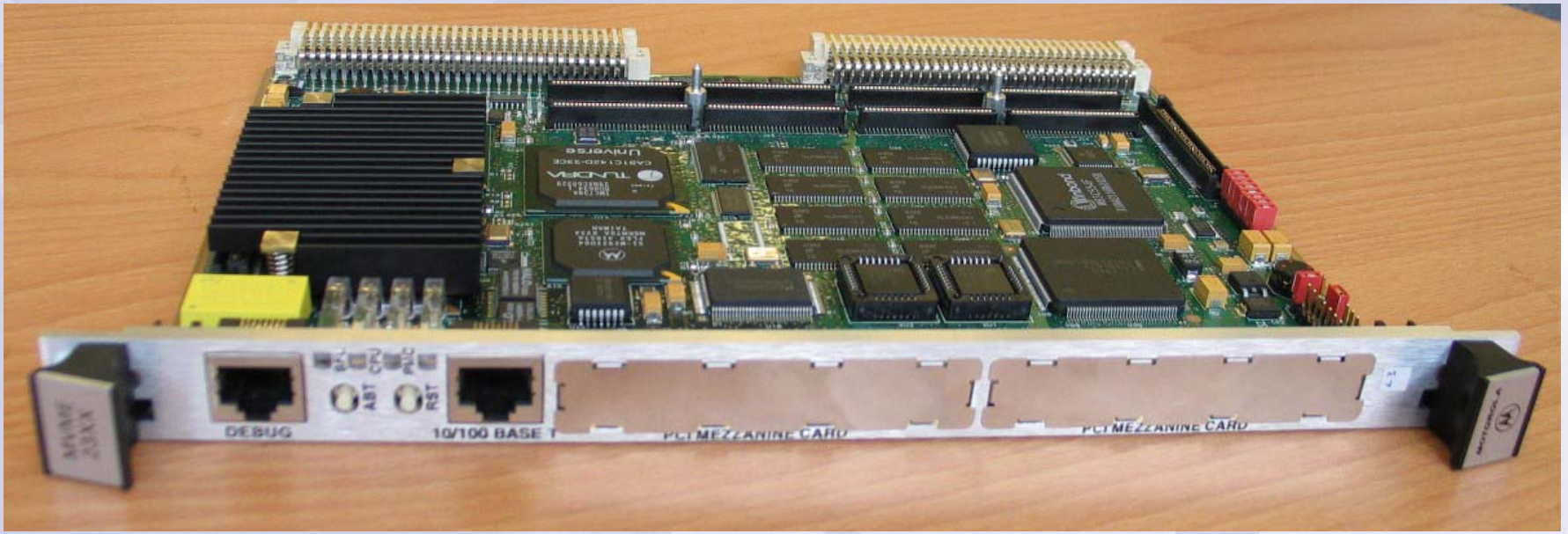
Hardware: VME Processor



- MVME5500 VME64x processor Card
  - Uses PPC processor as used in Apple Macs
- Provide the computing power in the IOC
- Processor board have no physical disks but are booted over the network

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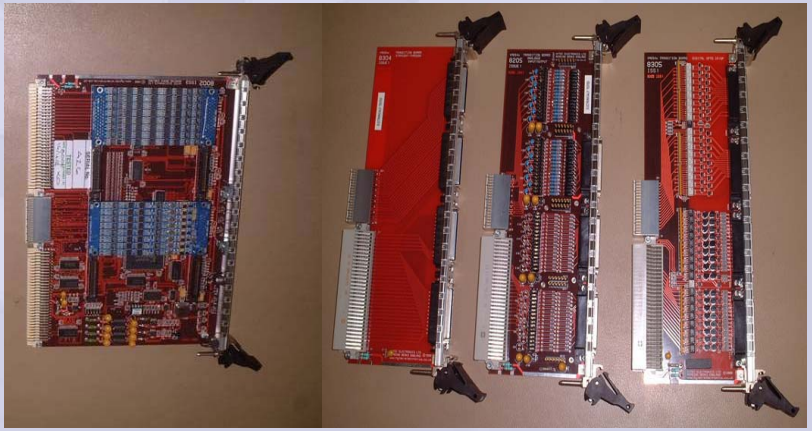
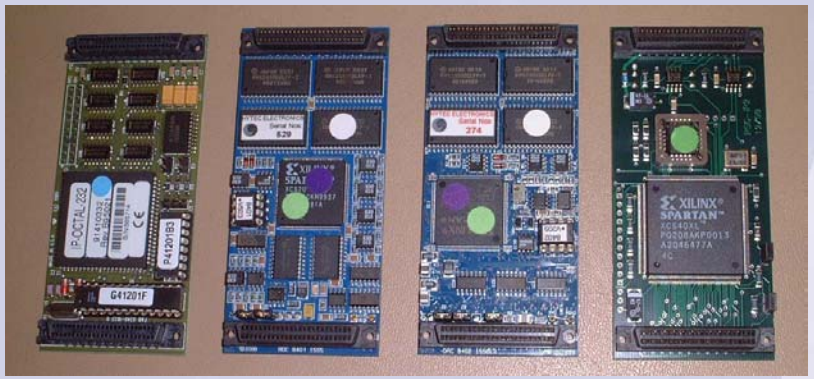
Hardware: IO Modules





- VME modules provide range of IO solutions to interface from equipment being controlled to the IOC

VME64x IP Carrier	550
Transition Boards	350
IP Module 16 Bit ADC	300
IP Module 16 Bit DAC	50
IP Module Digital Input	100
IP Module Digital Output	50
IP Module Octal Serial 232	280
IP Module Octal Serial 422/485	5
IP Module Quad Stepper	5
IP Module Scaler	5
IP Module FPGA	5
Cable	750
Plant interface modules	750

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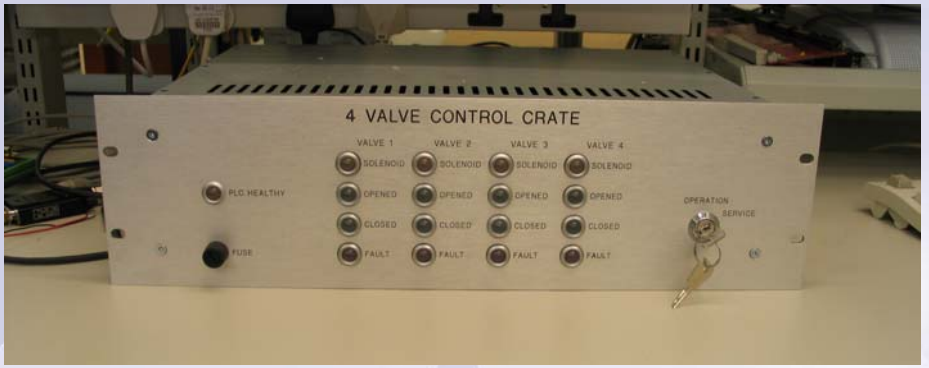
Hardware: PLCs



- Programmable Logic Controllers (PLCs) are used below the IOCs for process control and interlocking applications
  - Siemen S7 for high-end ie process control applications
  - Omron CJ1 for low-end applications ie interlocking
- Effect way mean to realise interlock logic
- Design standard products for Vacuum Valve Control and Interlocking by encapsulating PLCs in 19” crates
  - Will help to manage obsolescence

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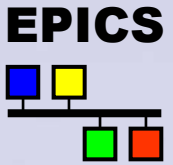
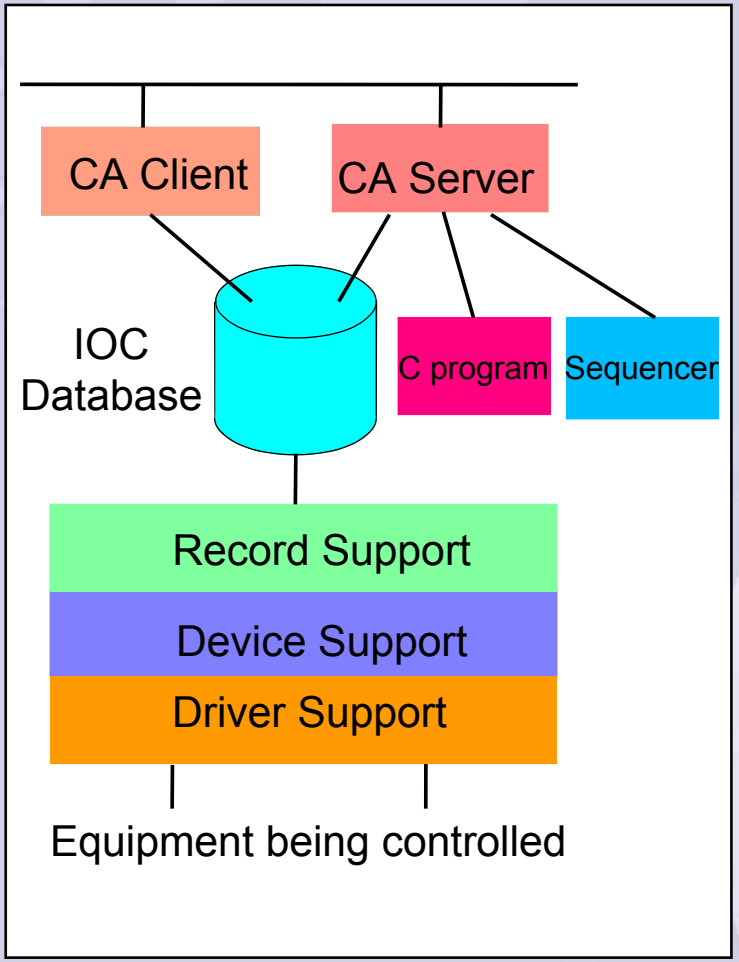
Software: Applications



- IOC Software Development
  - GCC for device driver support
  - VisualDCT for EPICS DB
- Synoptic editors, generators and viewers
  - EDM Display manager
  - Control Desk
- Alarms
  - Alarm handler
- Archiver
  - Channel Archiver
- Visulaization
  - StripTool, IDL, web interface
- Programming
  - C, C++, Java, Jython, Matlab

Software: IOC Software Development



- Software in the IOC is at two levels
  - Define the functionality using the Database (see next slide)
  - Writing C code and Sequence code
- C code is used for
  - Device\Driver Development to support new hardware.
  - C and development to support complex processing
- Sequencer is used to write finite State Machines for State based applications

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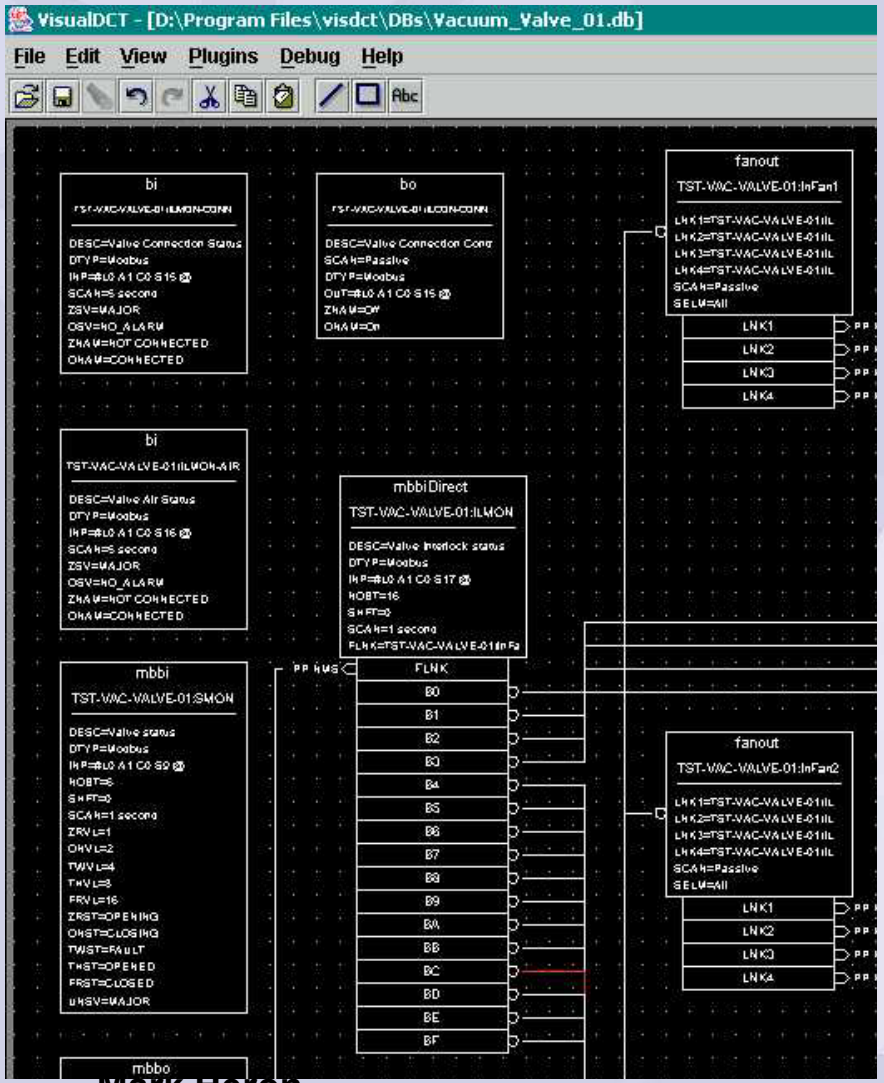
Software: IOC Database Design



- The EPICS Database is memory resident in each of the IOCs
- Provides the interface to hardware and a means to process signals
- Described by text files which can be created using an test editor but also using VisualDCT a tool to design the DB graphically by placing functional blocks and interconnecting them

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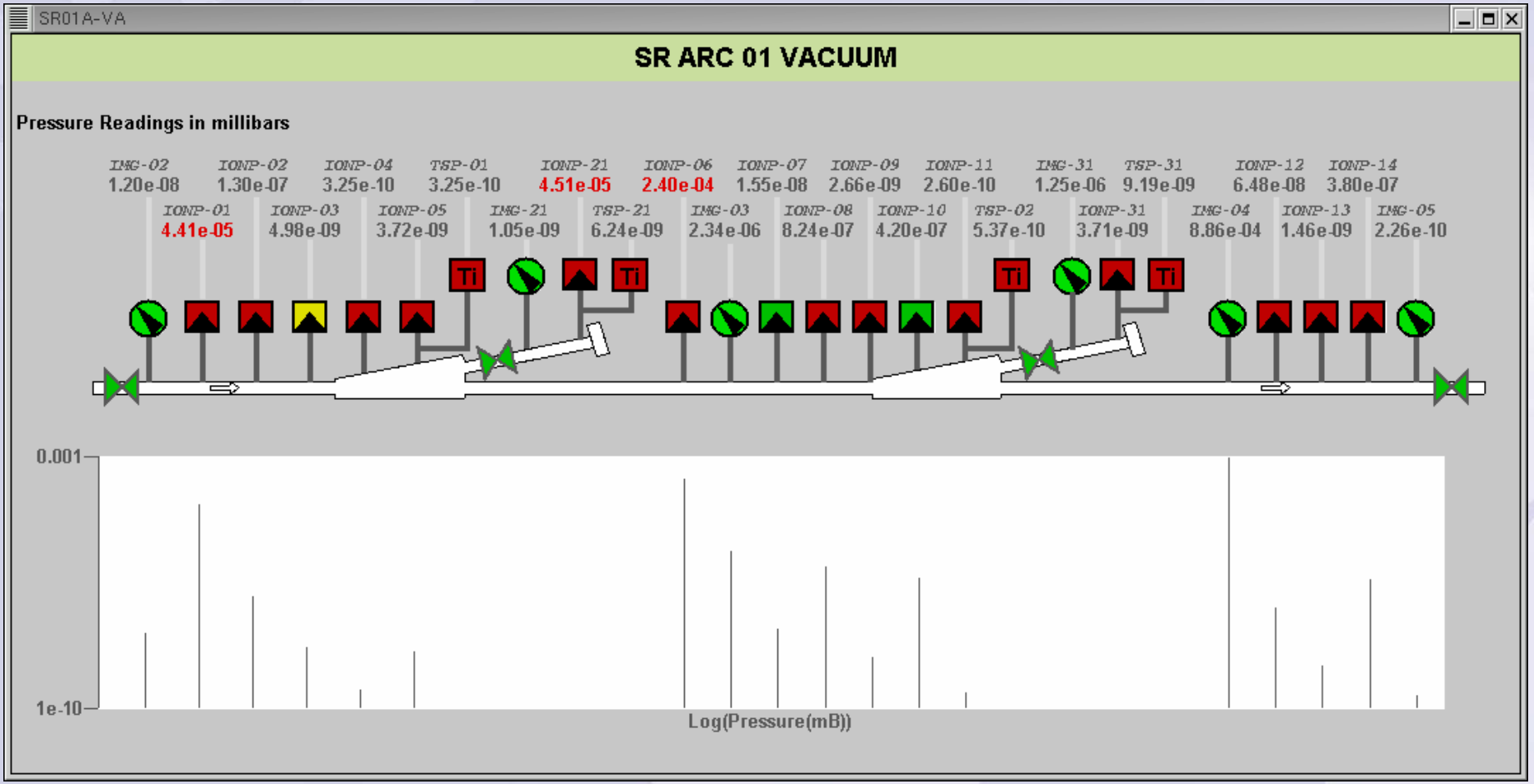
Software: Display Manager Diamond Arc Vacuum



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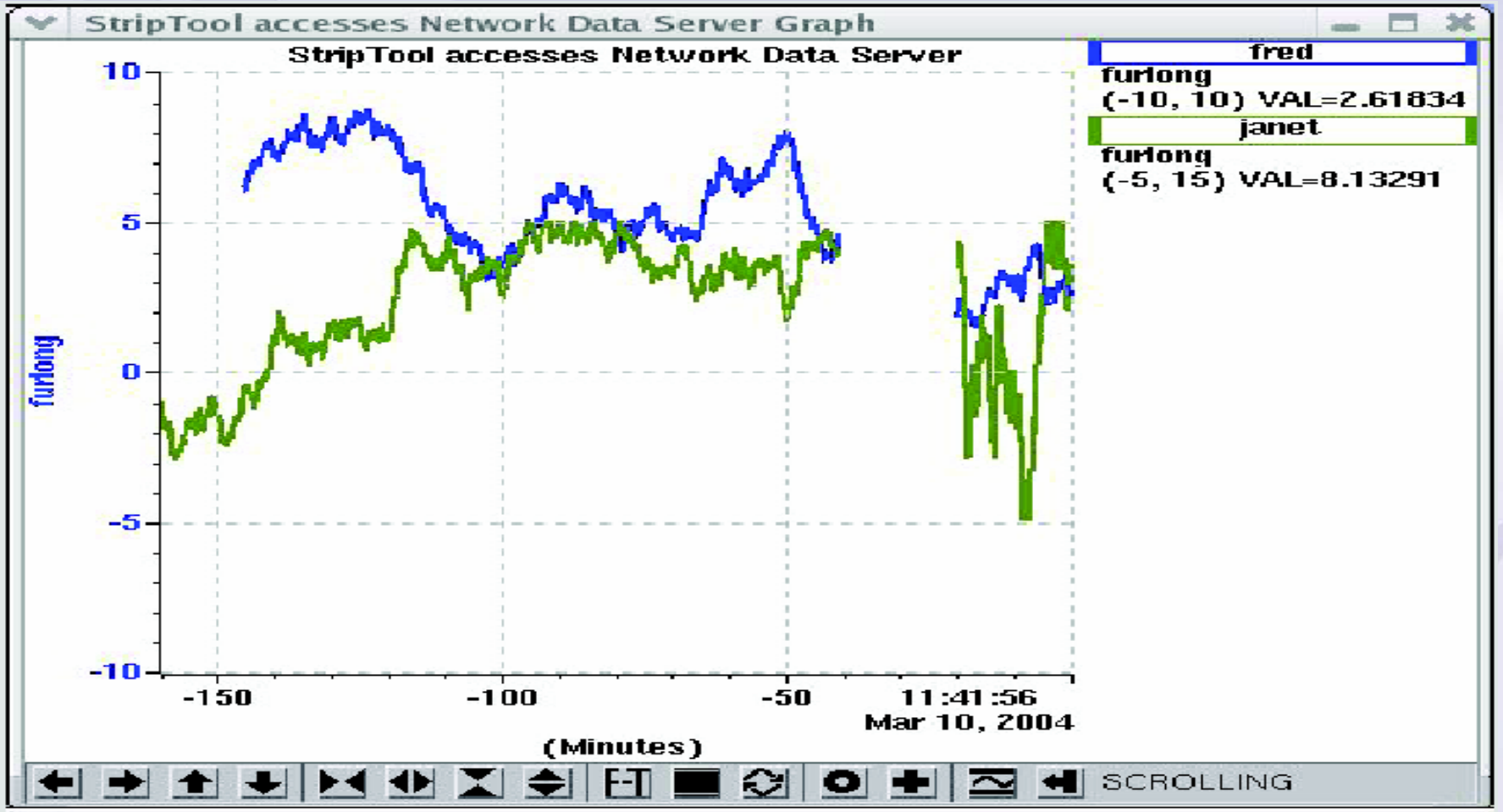
Software: StripTool



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Software: Archiver interface

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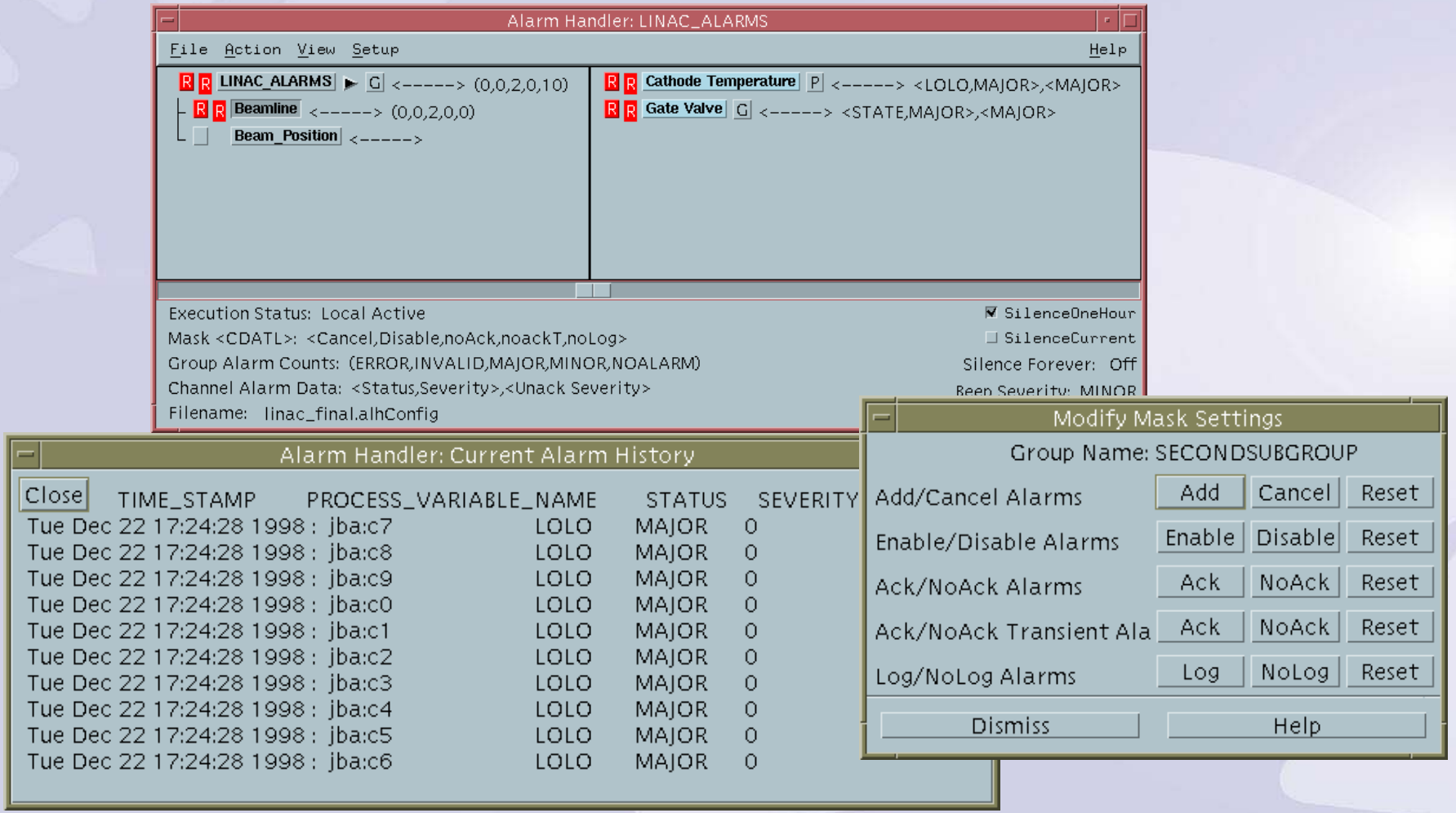
Software: Alarm Handler



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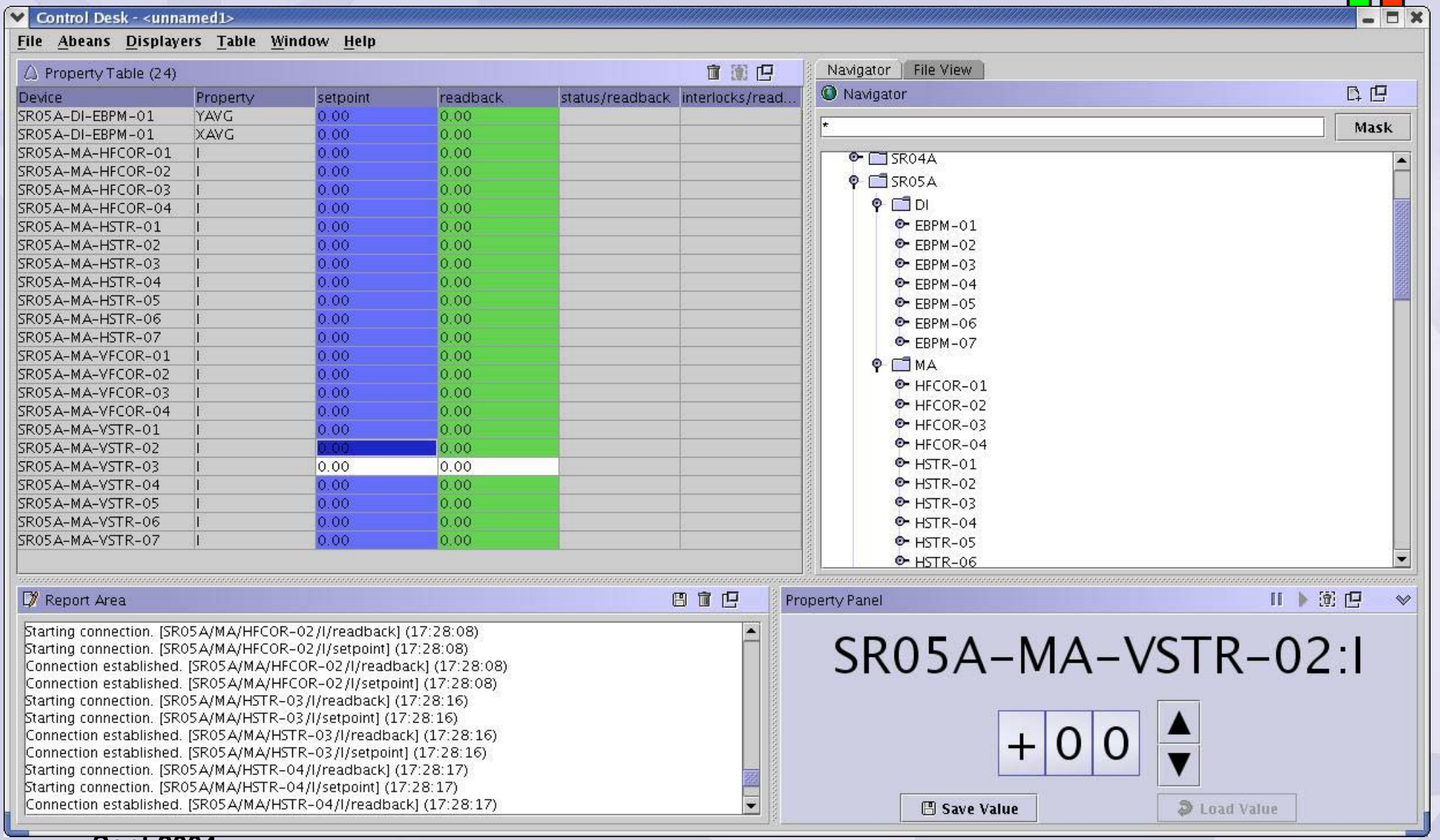
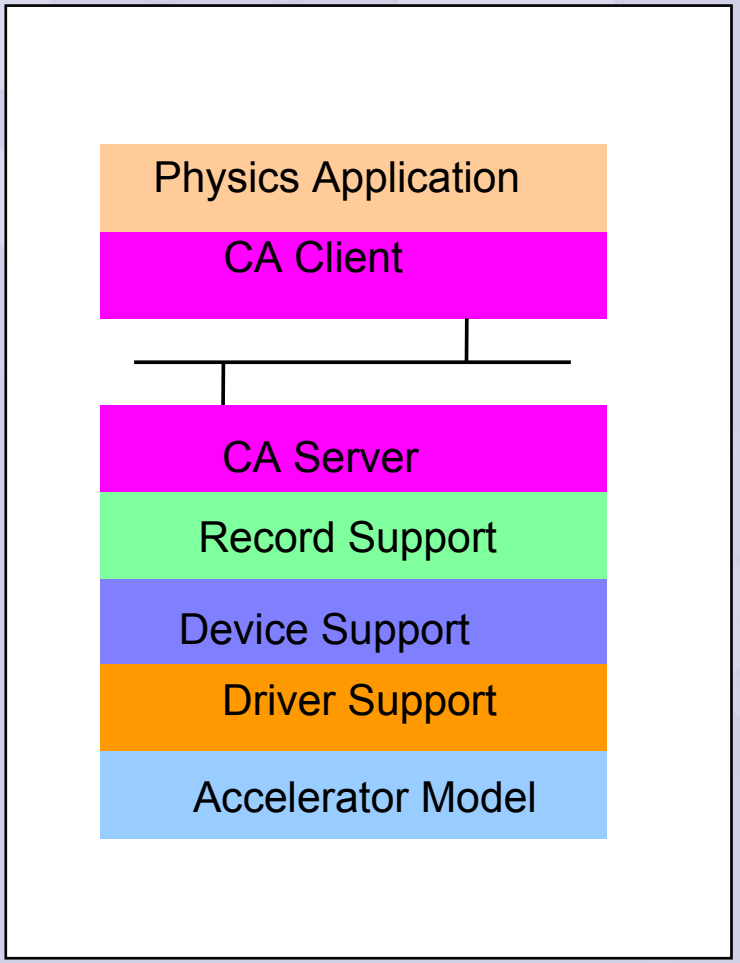
Software: Control Desk



Software: Virtual Accelerator in EPICS



- We need to develop physics applications with AP group early
- Realising this by building a model of the accelerator under EPICS
  - This ensures the communications from the model to the real machine will be transparent
- The model is realised using Tracy Libraries under EPICS device support
  - This reads a description of the machine lattice
  - EPICS provides the channels then to control magnet and read beam information BPMs
- Physics applications are being written in Matlab, IDL and Java
  - Use the Accelerator Toolbox for MatLab

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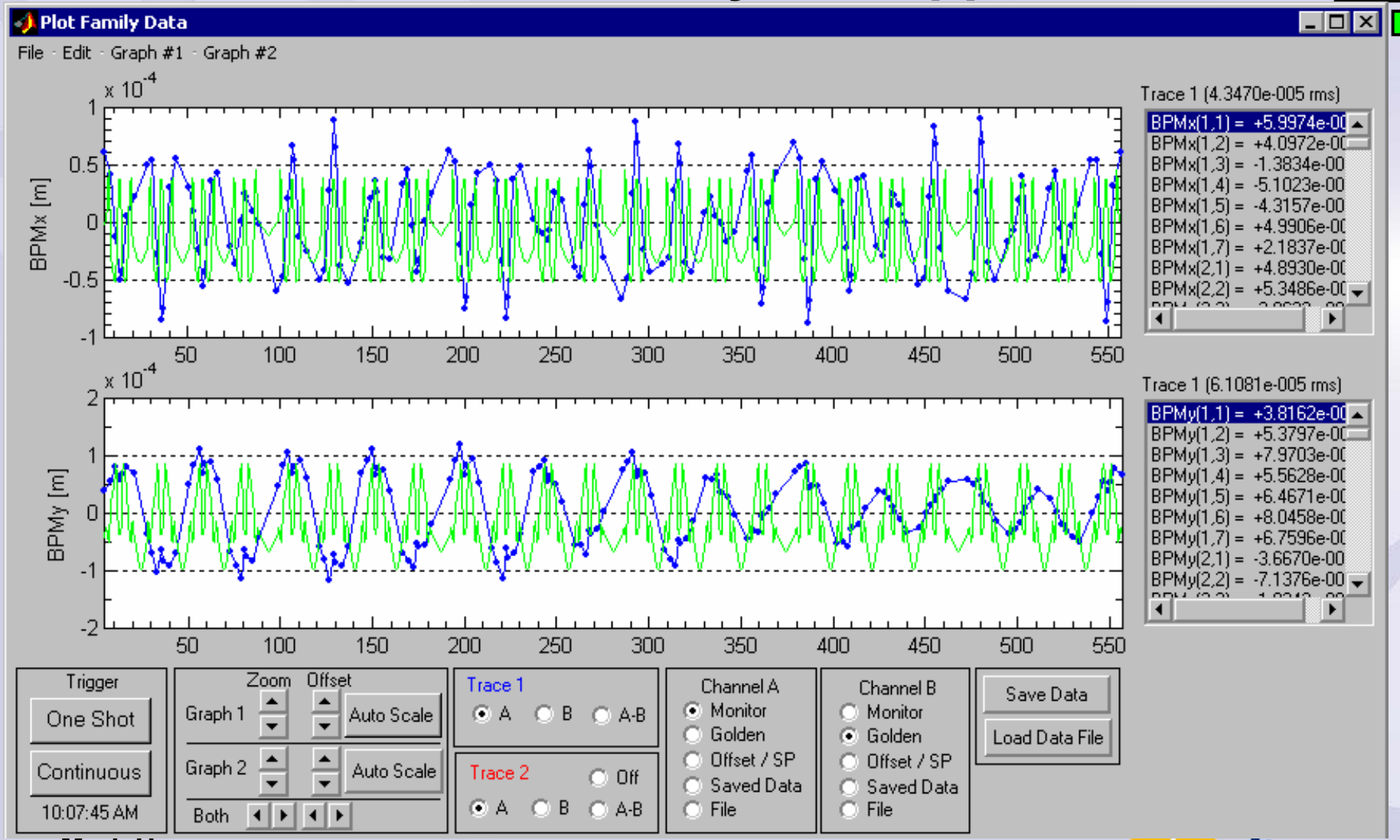
Software: MatLab AT Physics Applications



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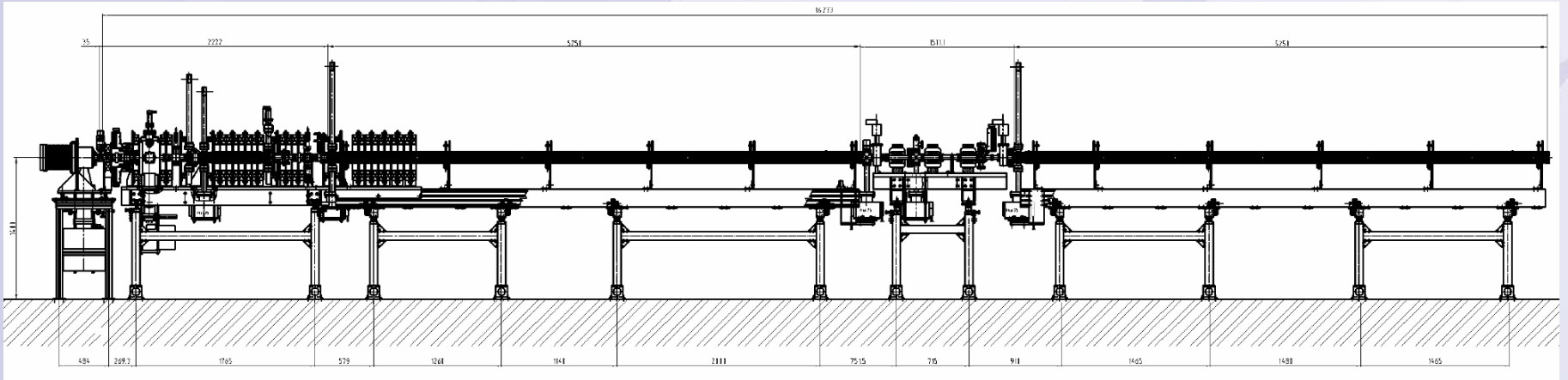
Technical Systems: Linac

- **Technical Solution**
  - Gun and Modulators controlled through Siemens S7 PLCs interfaced to IOCs
  - Solenoid PSUs will use DLS standard PSUs interfaced direct to IOCs
  - Vacuum will use DLS design issued to ACCEL using PLC for valves and instrument on serial interfaces to IOC
- **Procurement Model**
  - Turn-key solution from Industry based on EPICS, excluding PSUs
- **Progress**
  - Contract placed
  - Control System requirements reviewed
  - EPICS development system and standards issued Sept 03
  - Controls hardware and vacuum control system design will be free issued Feb 04



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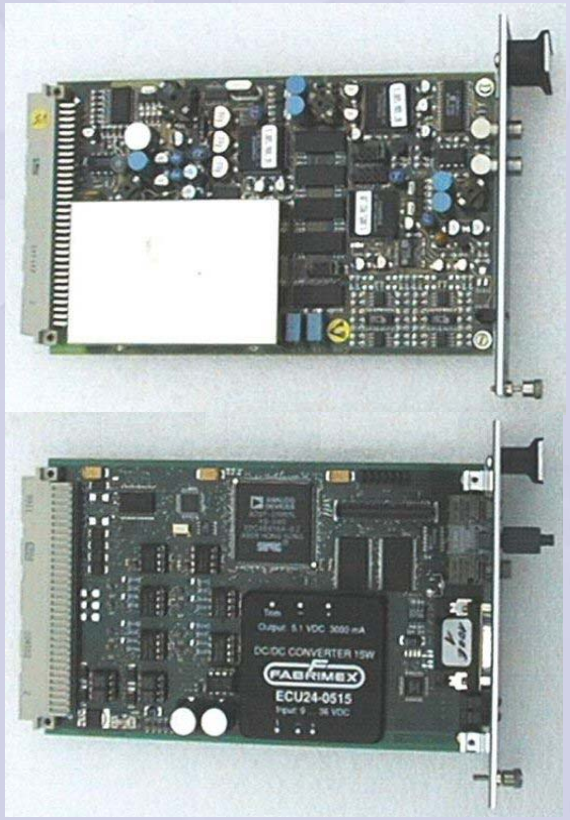
Technical Systems: PSUs



- 4 large and 434 medium and 780 small PSUs all controlled by the PSI designed PSU controller.
- PSUs interfaced to VME IOC by high speed point to point link and IP modules
- Procurement Model
  - DLS will design EPICS IOC functionality
  - Large PSUs will be integrated into controls by DLS
  - Medium supplies DLS will free issues IOCs, to be integrated at part of contract
  - For Small Supplies DLS will design PSUs and integrate PSU controllers and IOCs

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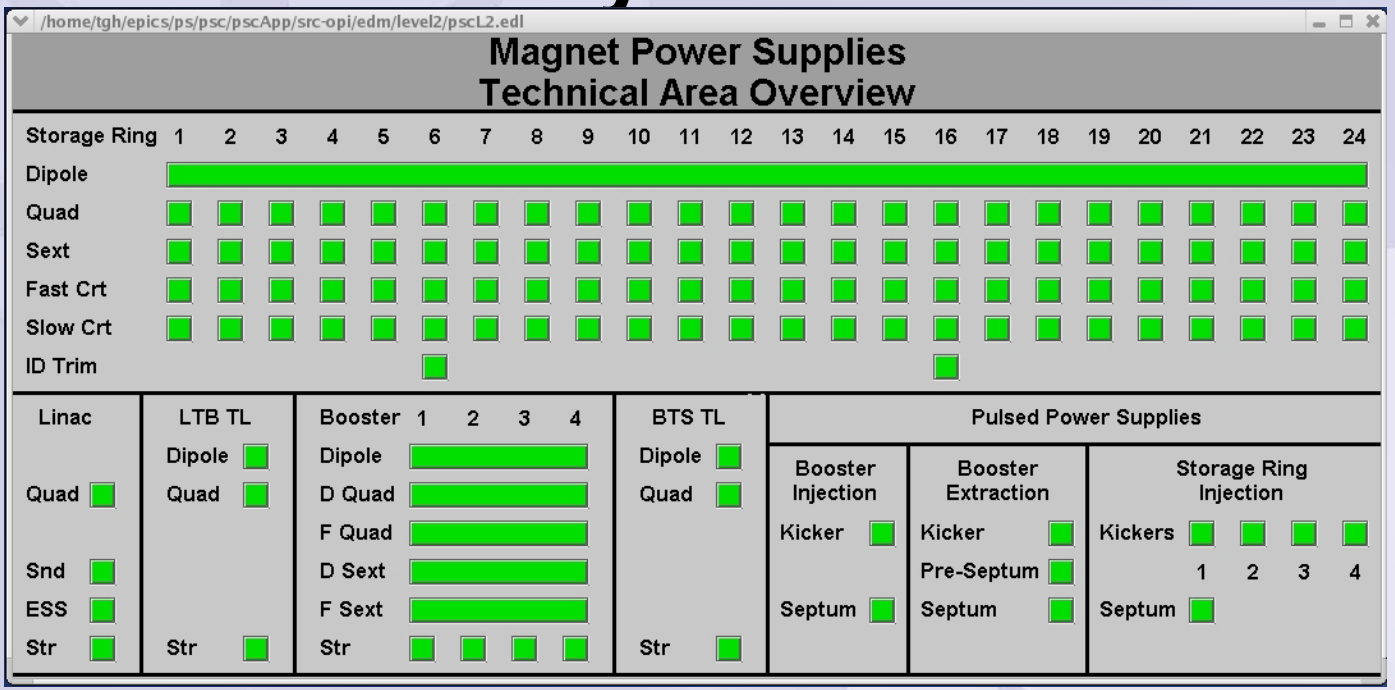
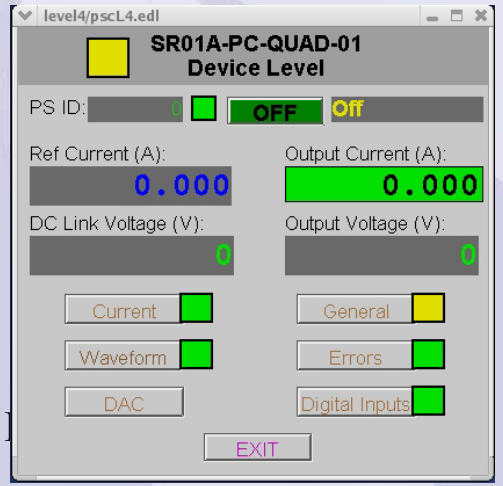
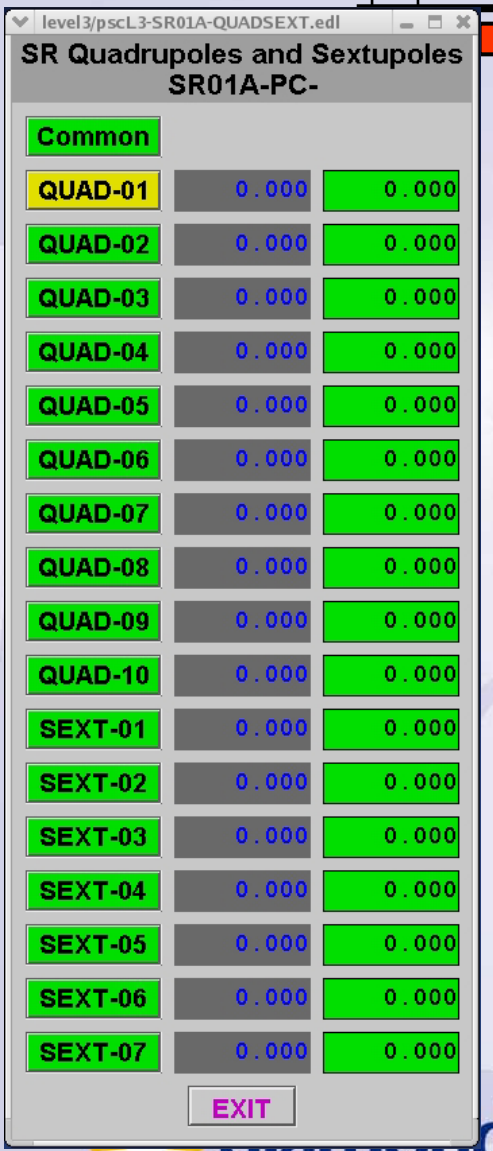
Technical Systems: PSUs







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Technical Systems: Diagnostics (1)

- Electron Beam Position Monitors
  - 207 EBPMS using Libera EBPM Detectors form Instrumentation Technology
  - Sample BPM signal and use digital detection and signal processing within FPGAs to give beam position information
  - Gives multiple data paths, trading off resolution and BW
  - Embedded ARM processor board running Linux and an EPICS server
  - Network interface for general control functionality and other diagnostics and high speed SPF modules for global feedback system
- Other Diagnostics Includes Current transformers and Loss Monitors

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Technical Systems: Diagnostics (2)

- CCD Camers
  - Auto beam alignment
  - Injection optimization
  - Pinhole array analysis
  - Emittance measurement
  - Auto sample centering
- Interface is 1394 Firewire bus
  - 400Mbit/sec
- API through DCII Lib
- Provide BW output at 640x480 at 30fps
  - 10Hz update 640x480 mono uses ~5% of 2.4G P4 through CA
- Developing EPICS device support for VxWork and Linux

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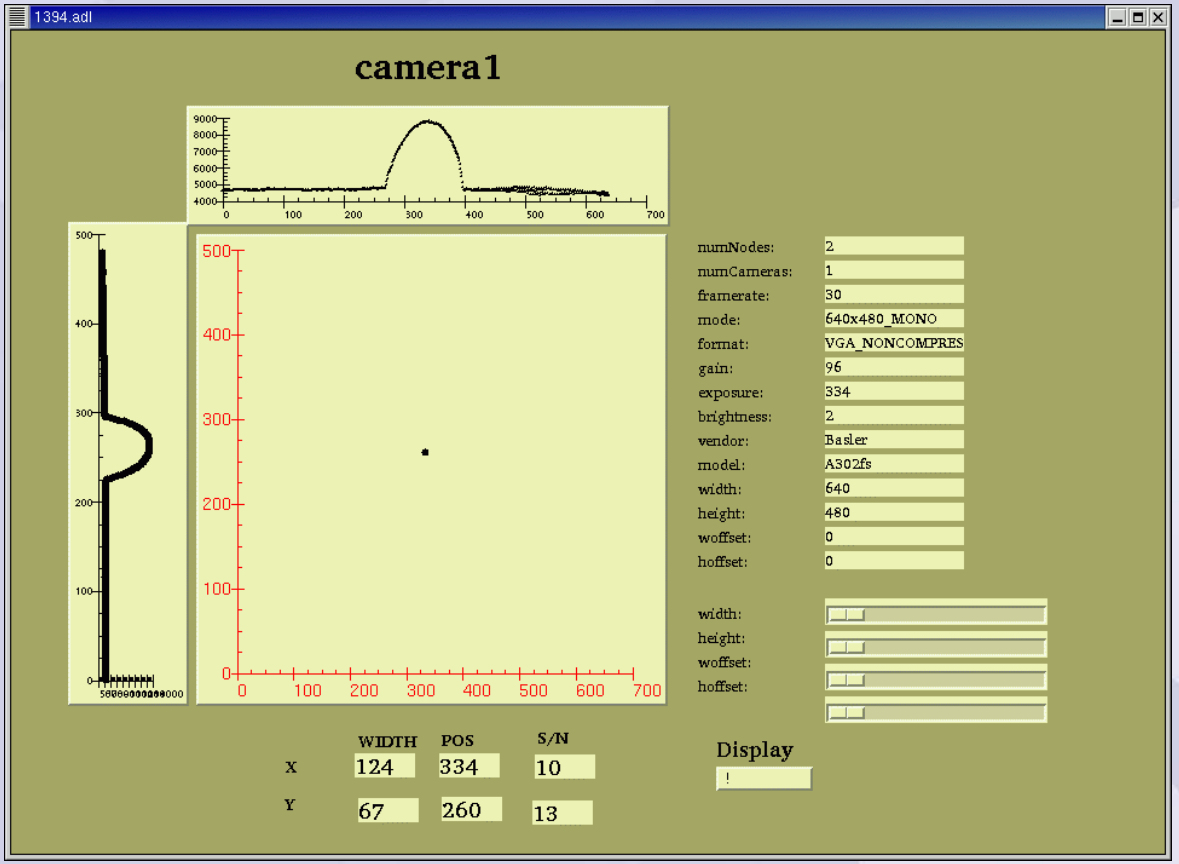
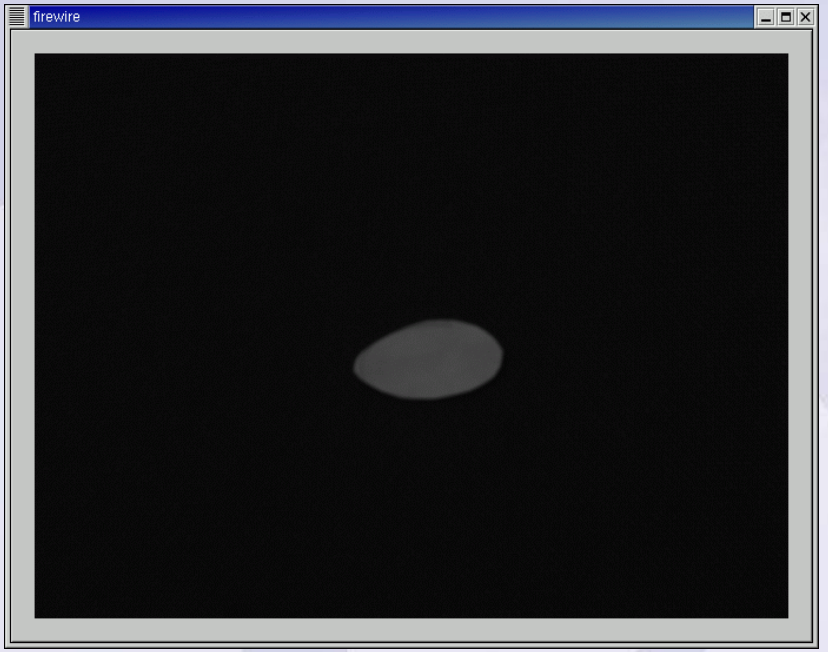
Technical Systems: Video example Apps





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Technical Systems: Vacuum

- 528 Gauges MKS937A Interfaced through serial connections using Stream Device
- 624 Ion pumps and 60 TSPs controlled by MPCs from Gamma Vacuum, interfaced through serial connections using ORNL Serial
- 139 vacuum valves controlled through Omron CJ PLC based valve control units
  - Valve Control Units provide vacuum protection and interlocking
  - PLCs interfaced through serial connections using ORNL Serial to support protocol CRCs
  - Same PLCs used for MPS

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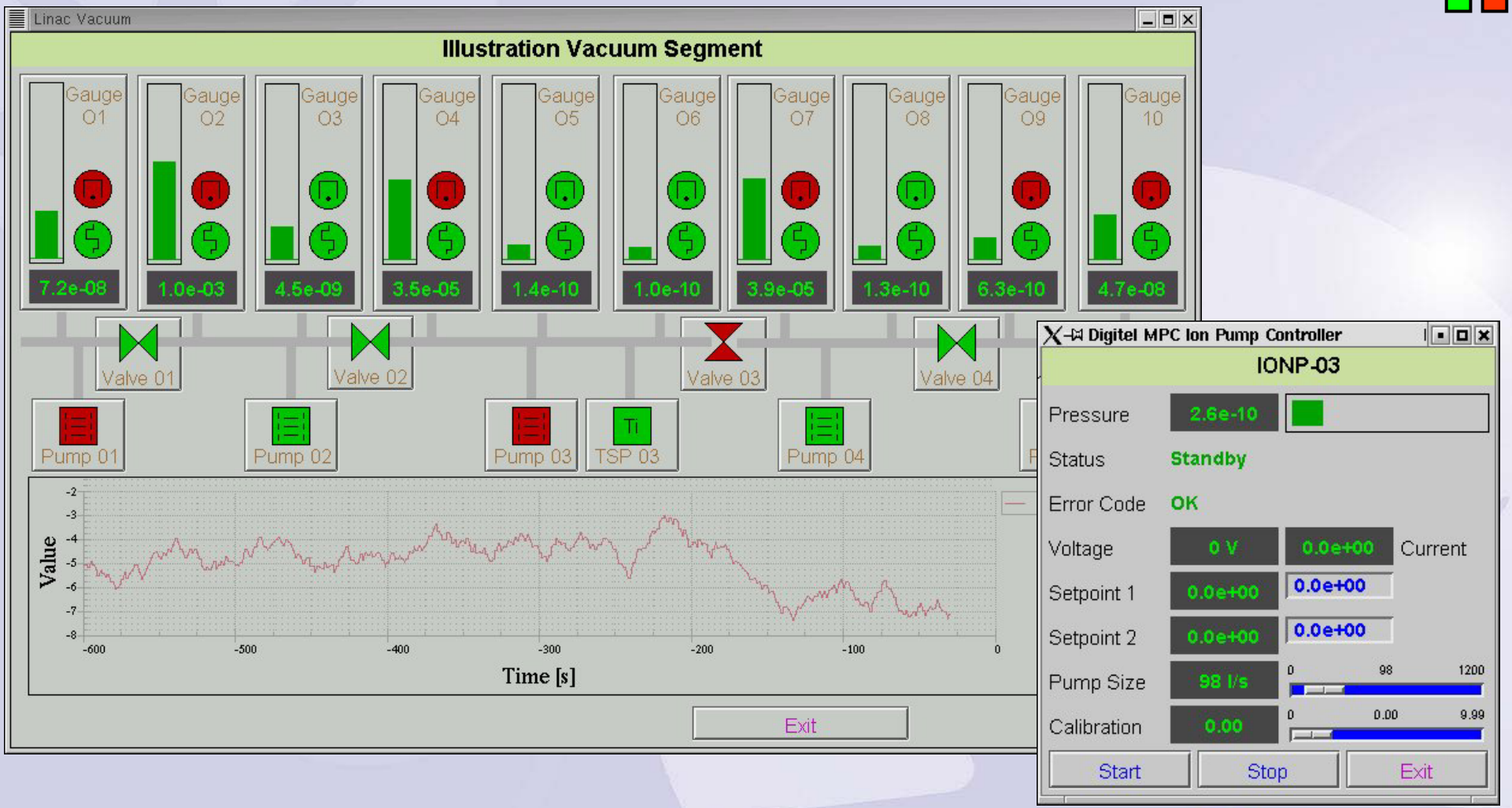
Technical Systems: Vacuum



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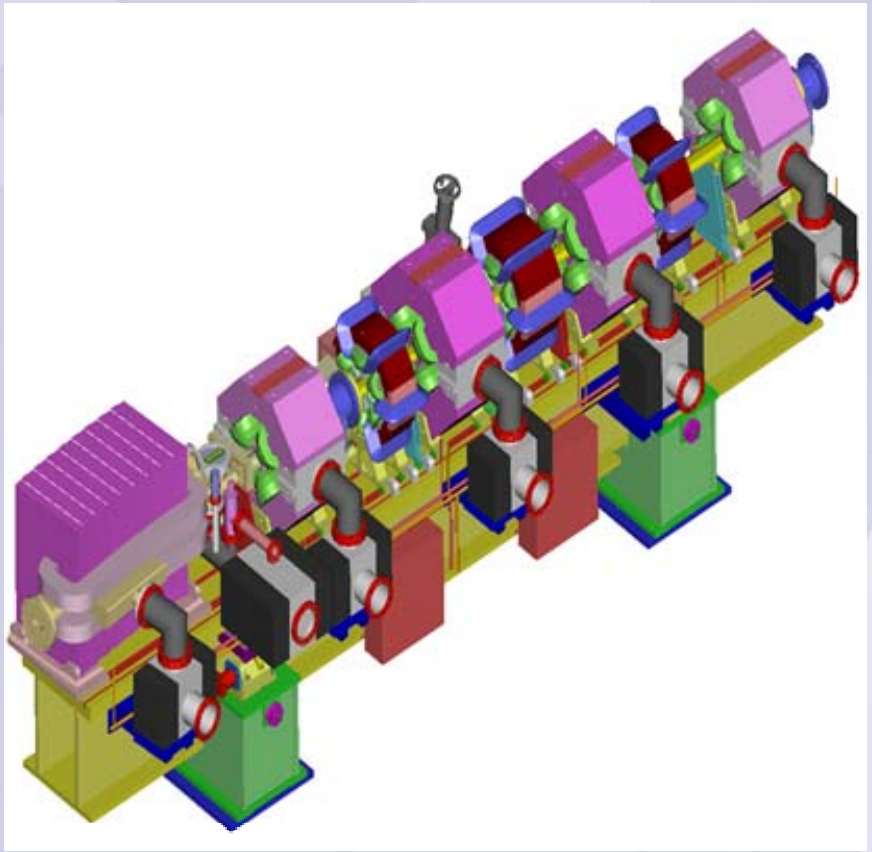
Technical Systems: Girder Motion Control



- 72 Girders for Storage Ring
  - Each girder has motorised Kinematic mounts to provide 5 degree of freedom so enabling auto alignment
- 360 axes of motion control driving concentric cams
- Each cell
  - Three Girders or 15 axes
  - Controlled by two OMS VME 58 controller cards in one IOC
- Procurement Model
  - Turn-key solution from industry based on EPICS with industry delivering functionality to control each axis and manage protection
  - DLS implements high-level algorithms and tools for girder alignment

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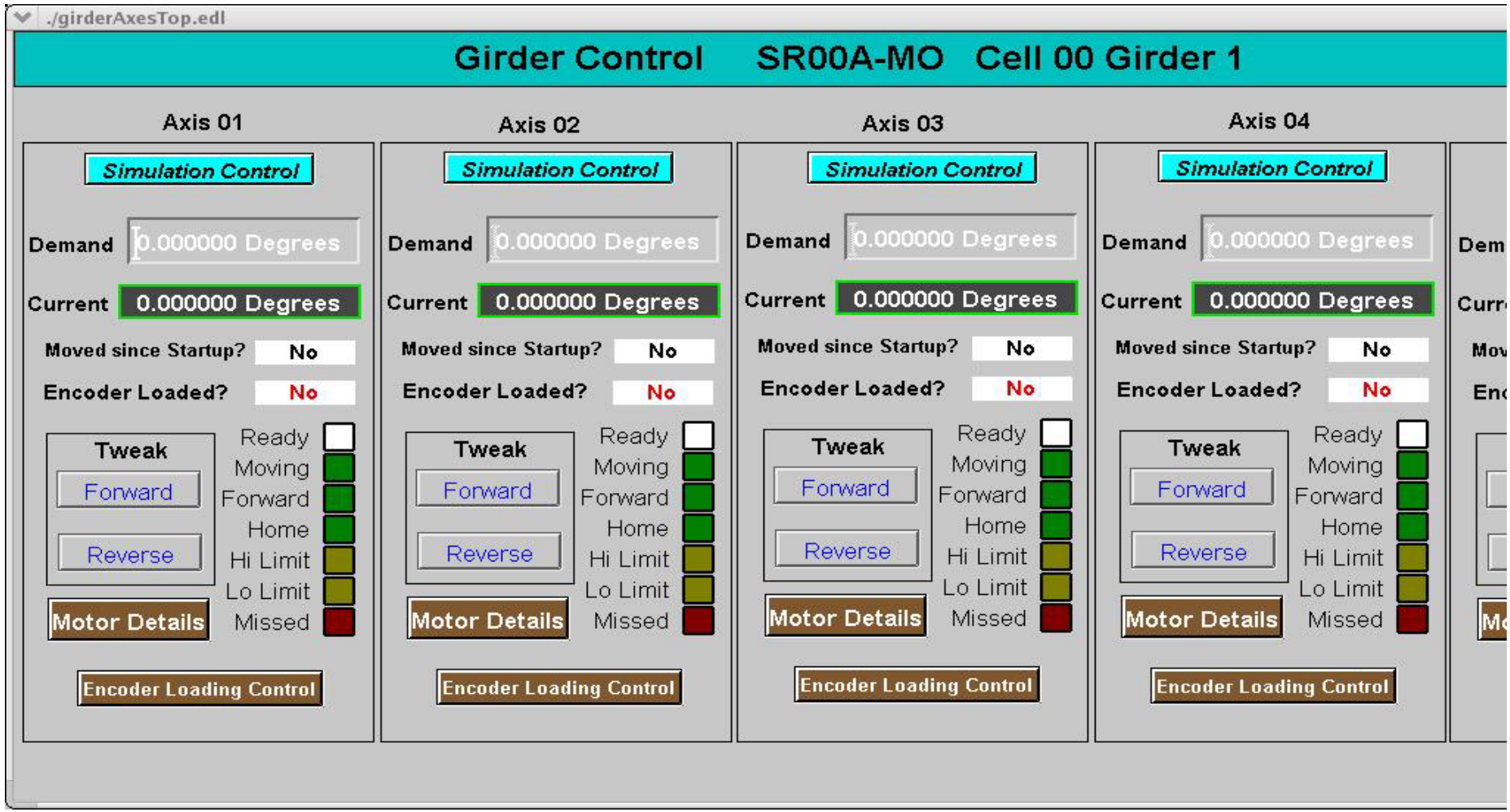
Technical Systems: Girder Motion Control



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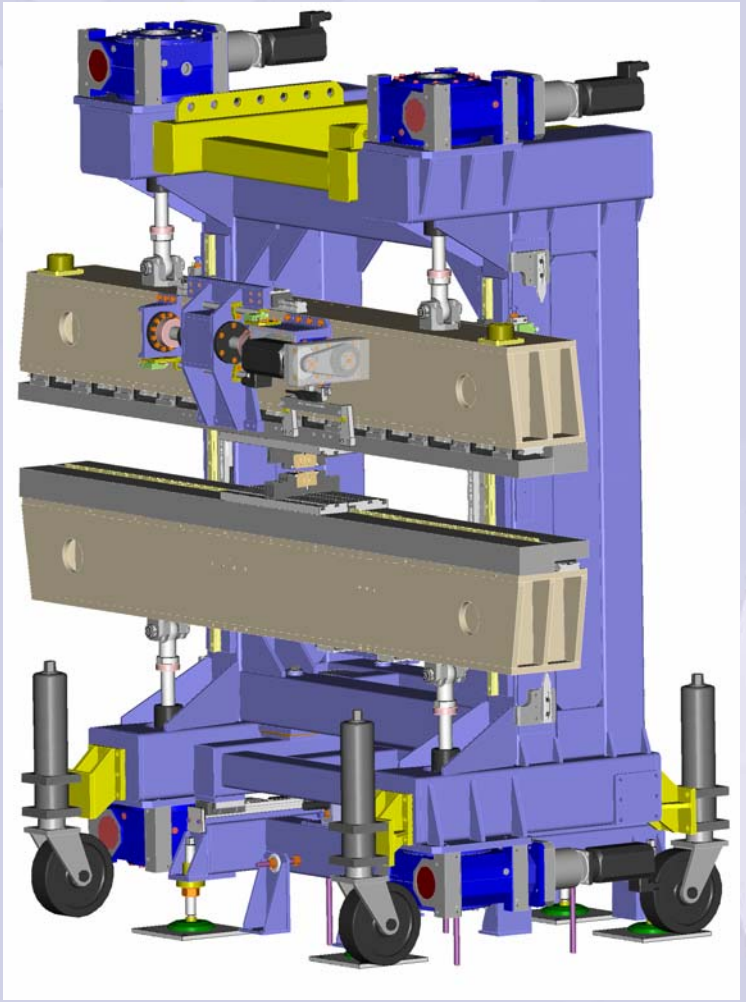
Technical Systems: Insertion Device



- Common motion control system for all permanent magnet IDs
  - In-Vacuum and Ex-Vacuum
- 6 axis motion control
  - Each beam two independent jacks
  - Each beam has Phase change of magnet array
- 4 or 8 DC PSUs
- Synchronous operation of Axis and PSUs
  - Synchronous operation of ID with BL mono
- Omron CJ PLC based protection sub-system manage safe operating window
- Procurement
  - Contract design of prototype control system by industry based on EPICS controls system
  - Manufacture of production control systems for all In Vac and Outer Vac devices by industry, against build to print
  - DLS will provide detailed EPICS controls to synch ID to SR Magnetic elements and BL Mono

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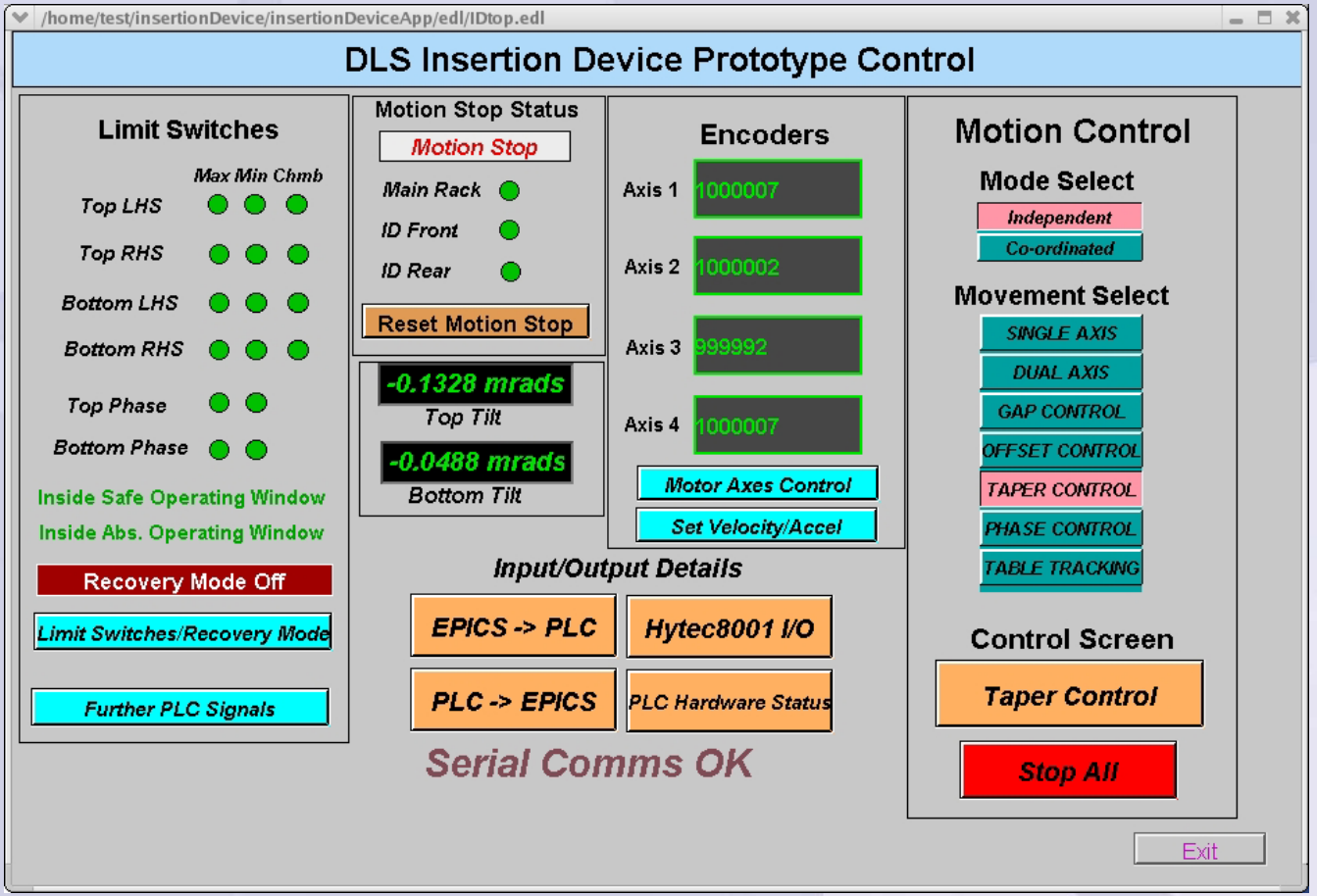

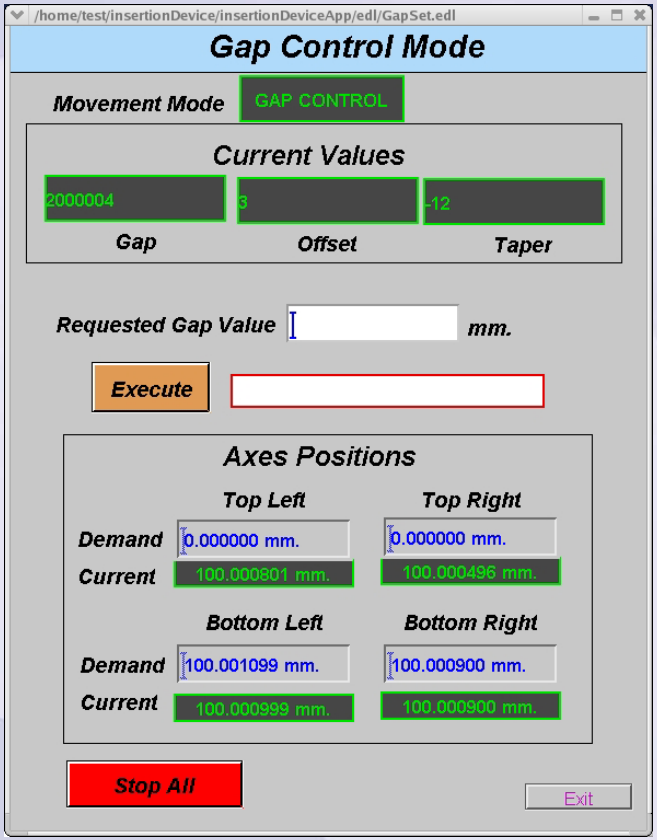

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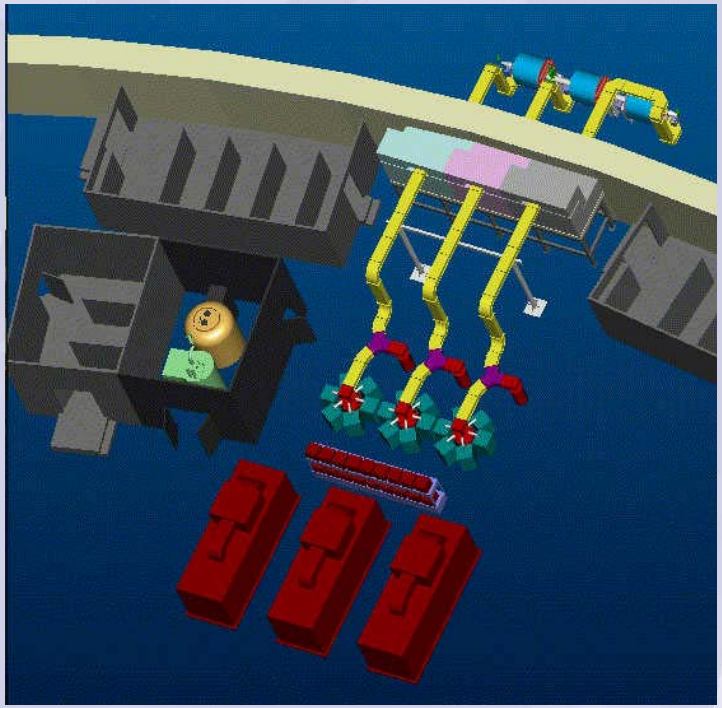
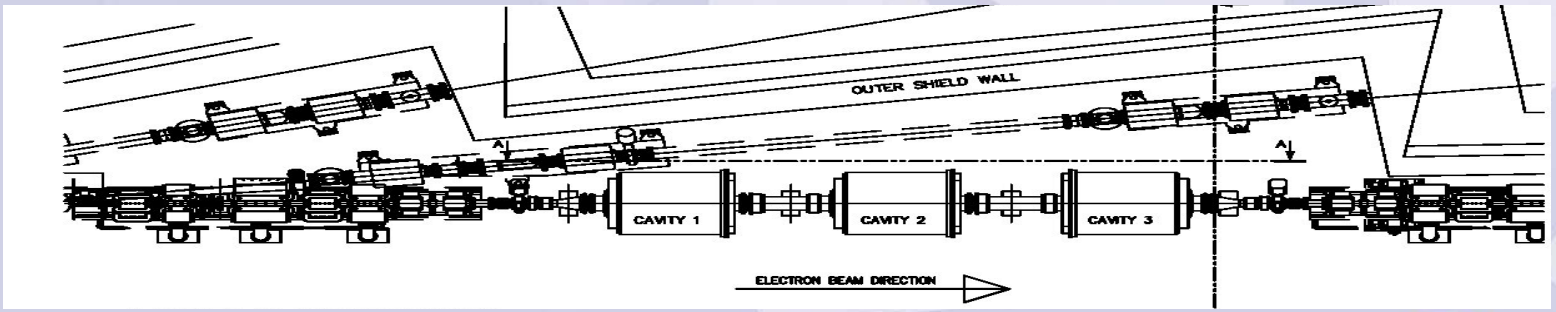
Technical Systems: SR RF System



- 3 SC RF cavities use Siemens S7 PLCs for Cavity Cryogenic Control
- 3 RF amplifier using combined output of Inductive Output Tubes and controls based on IOCs
- Single cryo-plant Siemens S7 PLC



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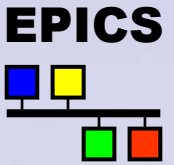
Technical Systems: Timing System

- The timing system is required to
  - Provide a means of generating and distributing timing fidicuals to technical systems
  - Enables Synchronous control and monitoring across multiple IOCs
  - Maintain real-time clock in each IOC

Distribution Network	**Differential error, location to location**	**20 ns**
	Long term stability	**10 ps**
Events to technical systems eg BPMs	**Resolution of Events**	**10 ns**
	RMS jitter of decoded events	**< 20 ps**
	Delay range	**> 1 s**
	Delay resolution	**< 10 ns**
	RMS jitter of recovered RF clock	**< 5 ps**
Linac timing to give bunch selection	**Delay range**	**> 1 s**
	Delay resolution	**20 ps**
	RMS jitter of delayed pulses to RF Clock	**2 ps**

Technical Systems: Choice of Timing System



- Reviewed the various options for a timing system
- Particularly the use of an Event based system to realise the APS and SLS timings systems
- SLS Event modules are available commercially, from Micro Research,
  - Considered procuring this design
- Obsolesce in transceiver requires a redesign, which created the opportunity to look to improve the performance
- Developing the design of the APS\SLS timing system

Technical Systems: Evolution of APS SLS Timing Systems

EPICS

		APS	SLS	DIAMOND
Event	Event Size	8 bit	8 + 8 (Distrib. Ext. bus)	8 + 8 (Distrib. Ext. bus)
	Event bit rate	100 Mbps	1 Gbps	2.5 Gbps
	Event rate	10 MEvent/s	50 MEvent/s	125 MEvent/s
	Delay resolution	100 ns	20 ns	8 ns
	Jitter of decoded Event	100 ns (peak-to-peak)	< 20 ps (RMS)	< 10 ps (RMS) expected
Beam Synchronisation	Clock distribution	Special cable	Decoded from event stream	Decoded from event stream
	Clock precision	A few of ps (peak-to-peak)	< 10 ps (RMS)	< 5 ps (RMS) - expected
	HW Beam Synchronization	Different types of modules for linac, injection and extraction	Event Receiver	Event Receiver
	HW fine time tuning	DG535 generator: Resolution – 5 ps, RMS jitter – 60 ps Range – 1000 s	TD4V timer (VME) Resolution – 2 ns RMS jitter – 4 ps (in respect to clock) DG535	4-CH. Timer (VME) Resolution - < 20ps RMS jitter - < 2 ps (in respect to clock)
Software support		EPICS		

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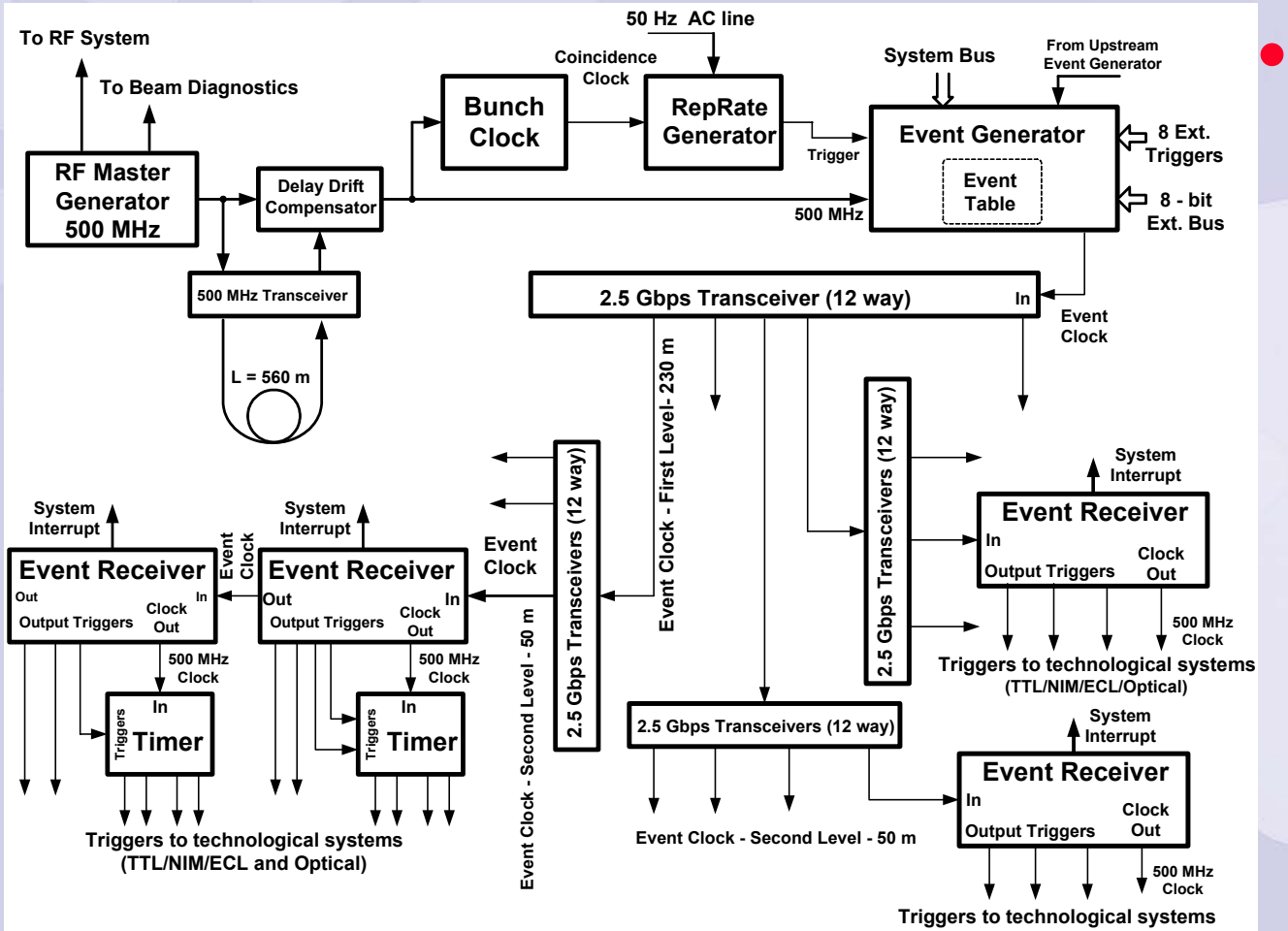
Technical Systems: Timing System Structure



- Structured as
  - Distribution network
  - Event Generator
  - Event Receiver
  - 4-Channel Timer
  - Delay Drift compensator
  - Bunch Clock
  - Rep. Rate Generator

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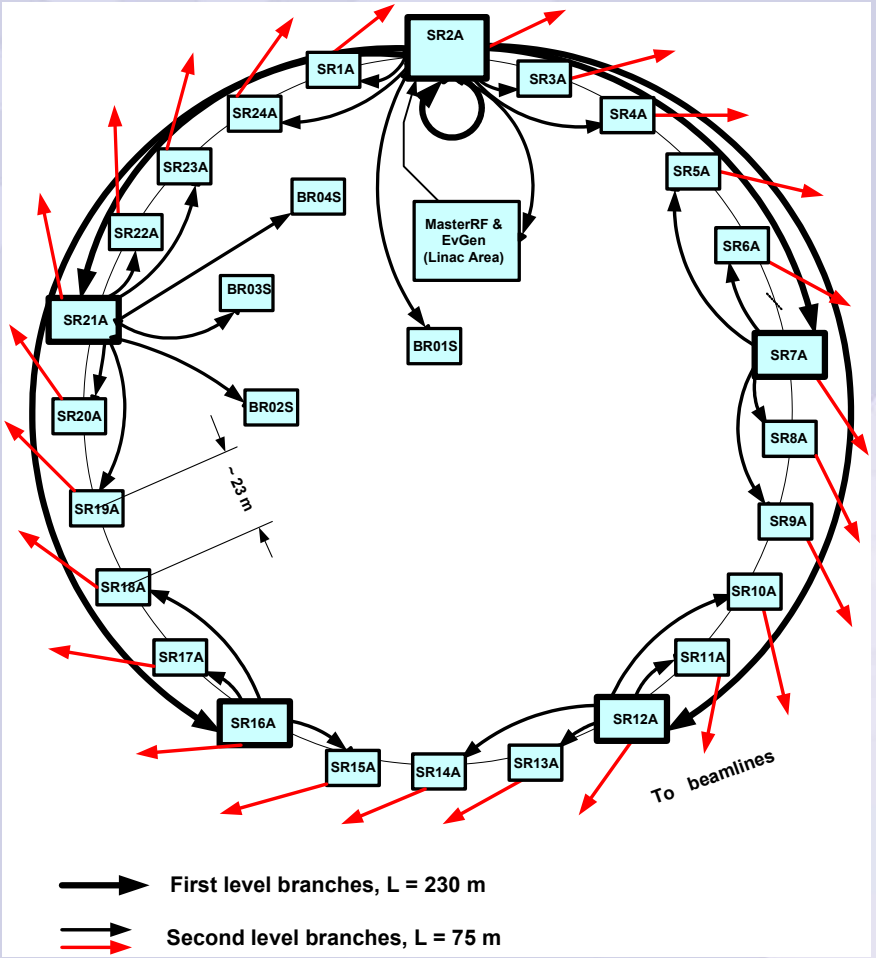
Technical Systems: Timing System Network



- Geographical
  - 70 destination locations
  - 250 event receivers
  - 120000 square meters area
- Distribution as multi-star topology
  - 5 branches of 230 m
  - Up to 8 branches of 75 m in locations
- Transmission media
  - OM3 multi mode fibre
- Data Rate
  - 2.5 Gbps

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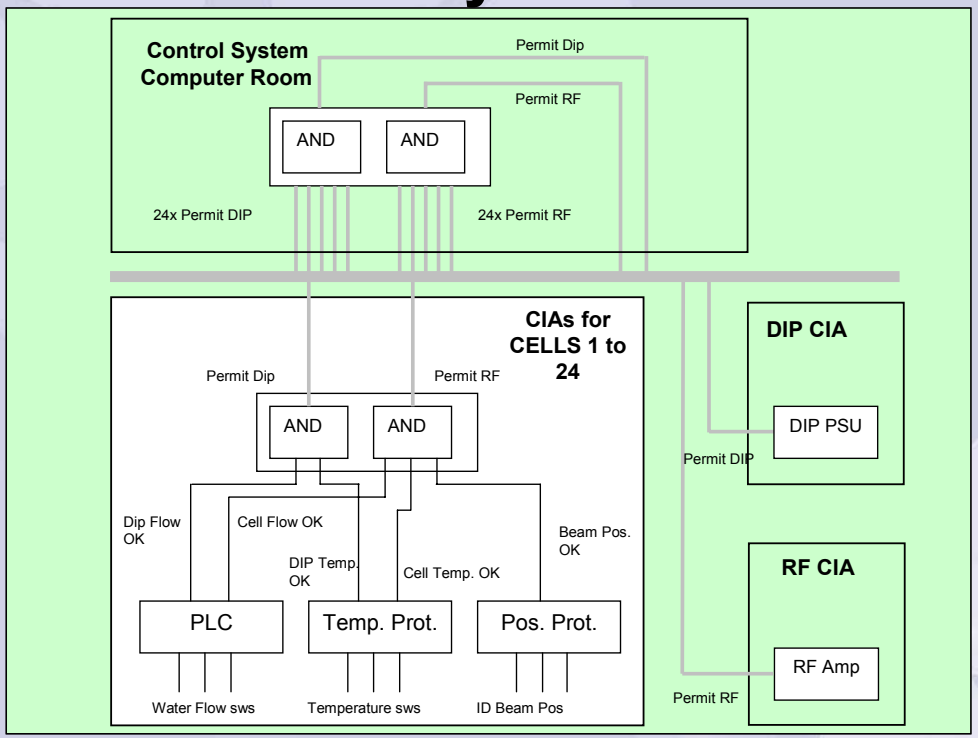
Technical Systems: Machine Protection System (1)



- Machine Protection System manages interlocks on a global basis to protect components from damage caused by
  - Stored beam in the case of
    - loss of cooling
    - loss of vacuum
  - Obstructions in beam path
  - Mis-steering of the beam
  - Other potentially hazardous situations
- Storage Ring two protection circuits
  - Vessel and Dipole
- Booster four protection circuits
  - Vessel, Dipole, FQuad and DQuad
- Local protection uses PLCs
  - Temperatures and water flows
  - Enable filtering

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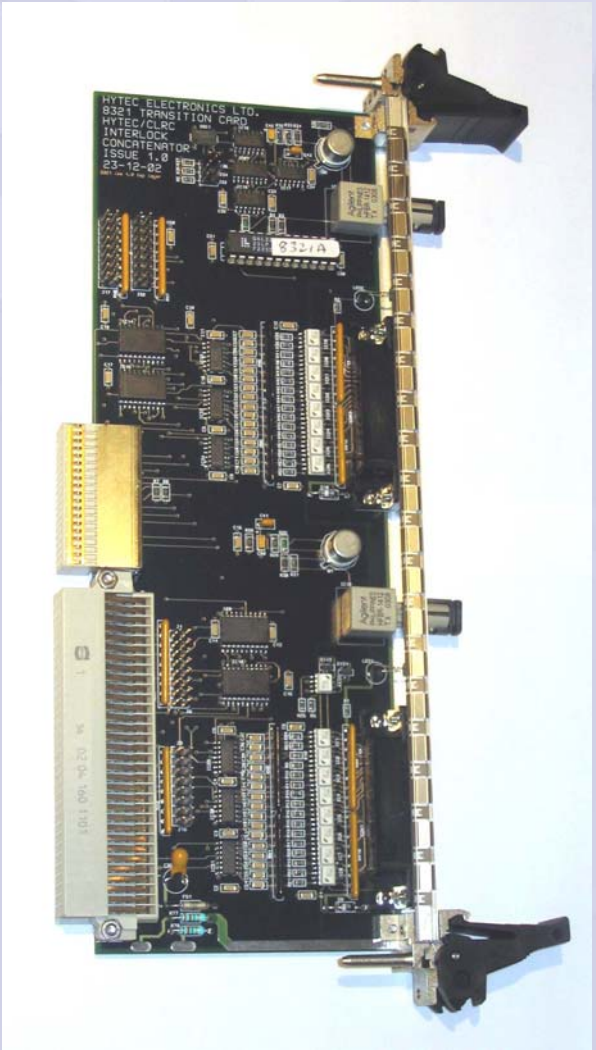
Technical Systems: Machine Protection System (2)



- Based on CEFAB FSD design
  - Tree structure
  - Uses a 5MHz pulse stream over Fibre Optic to TX the Interlock
  - No encoding
  - Simple TX and RX circuit defined with reference designs
  - Defines fail to safe in fault mode,
    - loss of signal, or signal forced high or low
  - Defines propagation delay IL failing
- DLS modules realised as VME64 Transition boards monitored by EPICS
- Will use FO infrastructure provided by the Network contract
- Water flow etc monitored by PLC sub system which feed into Local MPS module
- Progress
  - Functional spec approved
  - Detailed electrical design ongoing
  - Local module designed
  - Global module to be designed

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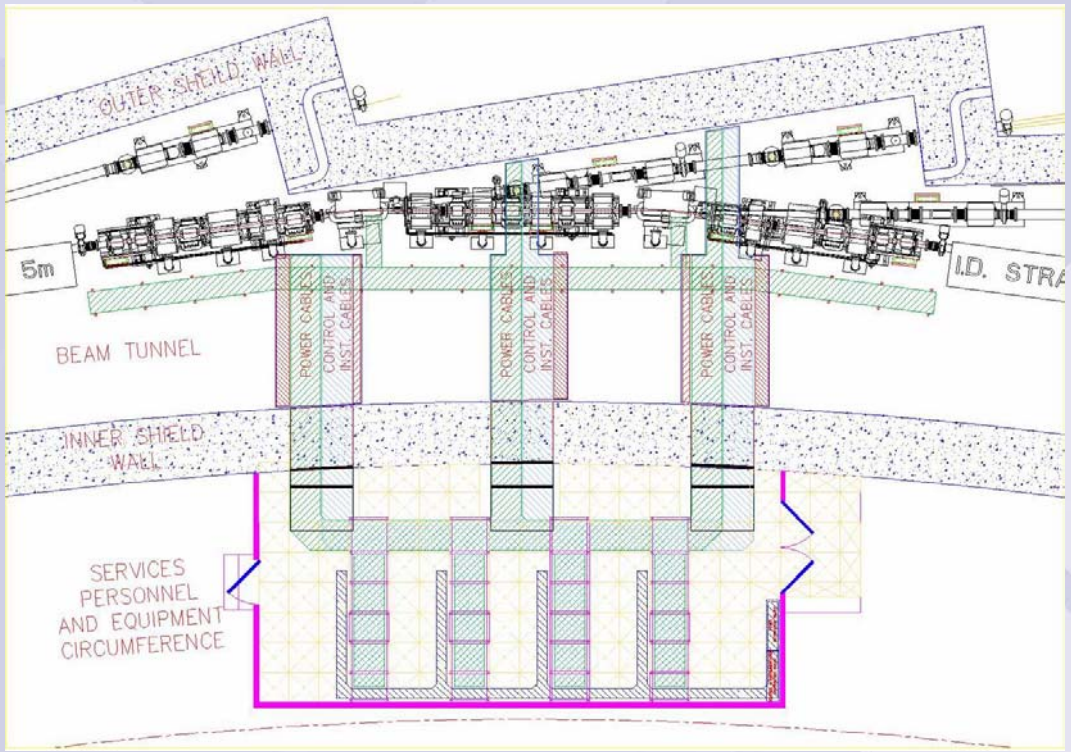
Technical Systems: Control Instrumentation Areas (CIA)



- CIAs house instrumentation racks and provide
  - A clean, temperature controlled environment
  - Manage cooling of racks
  - Contains the noise from high speed fans in the instrumentation
  - Define cable routes and labyrinths into accelerator enclosures

1 Linac, 4 for Booster, 1 for BTS, 24 for SR, 4 for misc and 7 on beamlines

For SR there is space for 20 racks per cell

- Quad/Sext PSUs, Steerer PSUs, BPMS, Vacuum, MPS, Girder Alignment, 2x Front Ends, 2x IDs, and PSS

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Technical Systems: Actual CIAs Quadrant 1 Sept 2004

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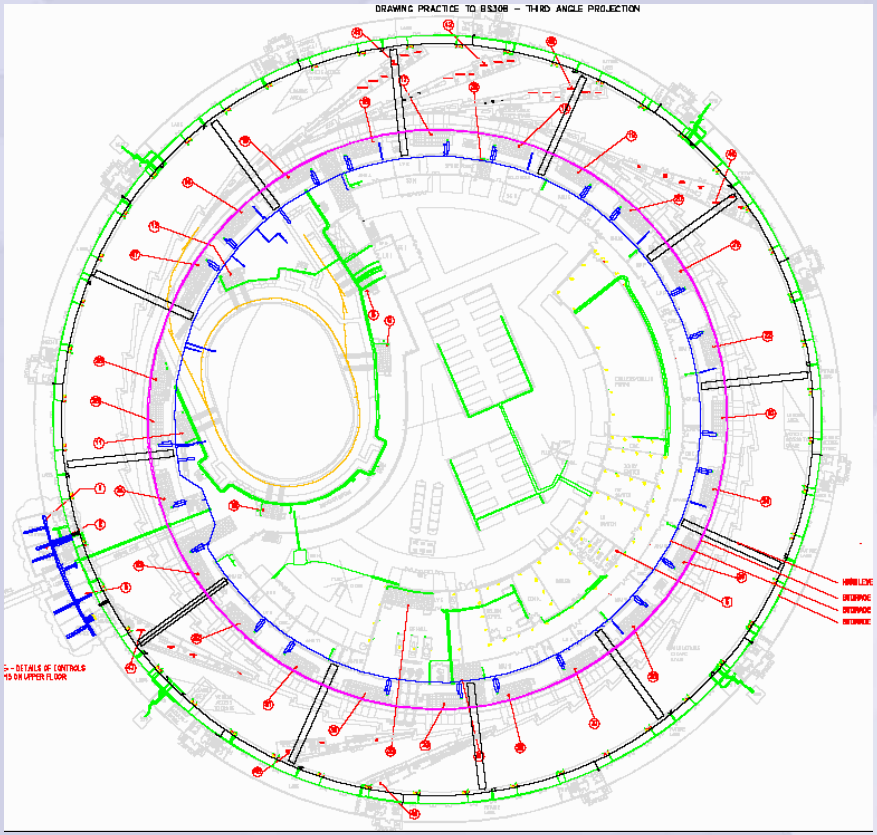
Technical Systems: Network(1)



- Fibre structure to support multiple networks and protocols
- Controls computer network
  - EPICS control and monitoring
  - Private network
- Secondary computer network
  - Video-over-IP cameras
  - Maintenance and configuration traffic
  - Make site network available around the Accelerator
- Event timing system
  - Challenging network design
  - ±0.5m fibre lengths
- Global Feedback
  - Either Reflective memory or FPGA serial interconnects for Fast Corrector System
- Machine Protection
- Analogue signals
  - 3GHz bandwidth per fibre back to Control Room

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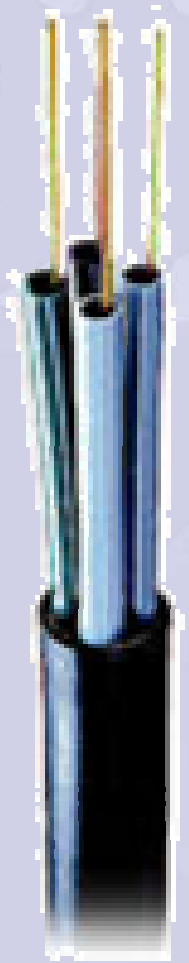
Technical Systems: Network (2)



- All fibre from CIAs to Control System Computer Room
  - Mixture of Multi mode and Single mode fibres to every CIA
- Fibre and CAT6 copper from CIAs to Racks and Tunnel
- Selected Blown Fibre for FO infrastructure
  - Flexible design
  - Easy to add more capacity
  - Easy to upgrade to new technology
- Progress

Specification prepared	Oct 03
Tender	Dec 03
Contract Issued	March 04
Installation phase 1 (Linac & booster areas)	January 05
Installation phase 2	October 05

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Technical Systems: Personnel Safety System (1)

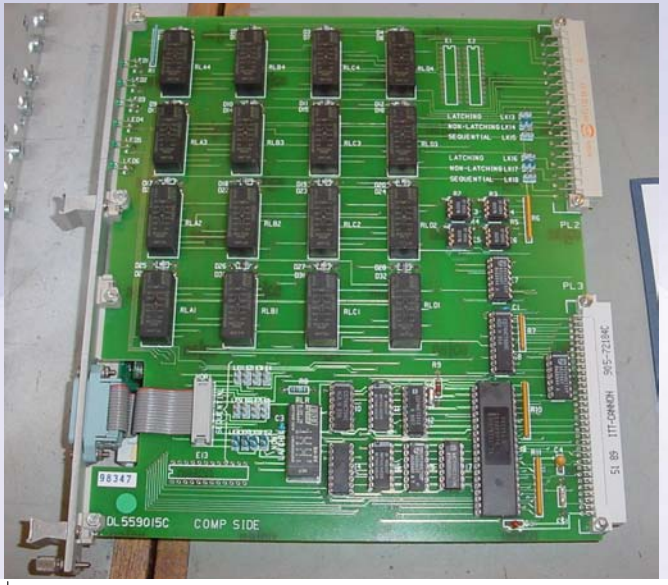
- The Personnel Safety System (PSS) will manage the Hazards associated with prompt radiation and electrical
- Need to Comply with Ionising Radiation Regulation 1999 and Approved Code of Practice
  - These were not written with light sources in mind
  - Need to consider future changes in legislation
- What is safe ?
  - Health and Safety Executive calling for ALARP
  - Defined for Diamond a safety figure for Staff and Public
  - PSS is being designed to a reliability figure
    - Need to test design assumptions by failure mode analysis ie Fault Tree analysis
    - Designing against a standard for safety systems IEC61508

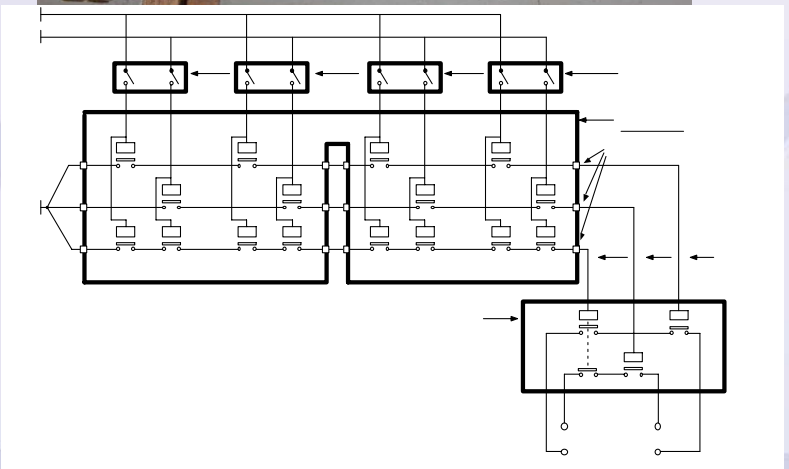
Technical Systems: Personnel Safety System (2)

- Realised through system of control measures managed by hardwired system
  - Keys, key allowing access or beam operation
  - Safety-switches on doors as interlocks
  - Search required prior to operation
  - Annunciators outside doors, indicating vault status
  - Blue lights in vault when access is not allowed
  - Signs in vault indicating danger
  - Beam Off buttons throughout the vault and outside the access doors
  - Time delay between search completion and enabling the beam (to allow someone to respond to the blue light warning)
  - An audible warning, or recorded announcement
- Selected a hardwired relay system over PLCs
  - Simple failure modes
  - Establish design in Daresbury PSS, also applied to ESRF
  - Long term maintainability
  - No Safety Critical software to development
  - Many of PLC feature easy of change etc are not required in a PSS

Technical Systems: Personnel Safety System (3)

- Logic Hardware
  - Based on the Daresbury SRS PSS design, also applied to ESRF
  - Dual guard rail interlock system
  - Protection logic realised as relays in a redundant configuration
  - All inputs and outs are monitor, independent of the protection logic, by VME processor card which provided EPICS software interface
- Permits
  - Provided to enable production of radiation or electrical permit
  - Redundancy, Diversity, Fail Safe, Feedback to PSS,
  - Independent of normal controls and control fundamentals





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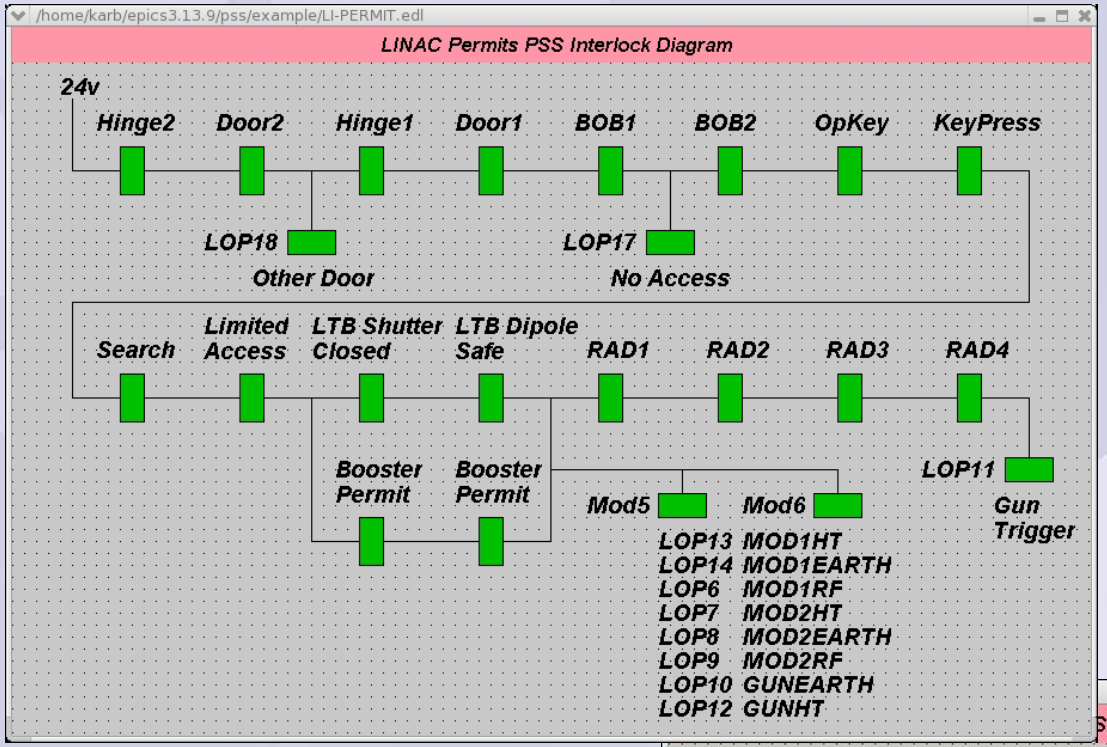

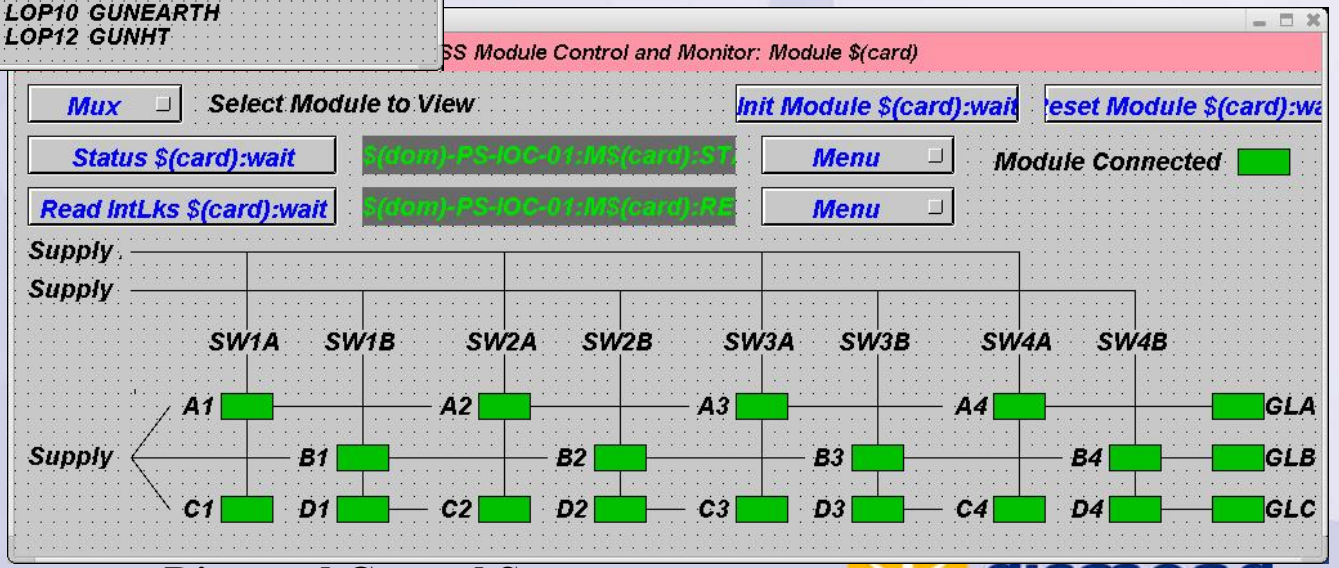

- EPICS supervision of PSS status
- Monitor of Linac vault
- Monitor of single PSS module

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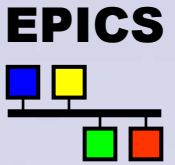
Design Decisions to Review for a new project

- Choice of EPICS
  - Very difficult to do a real comparison with commercial SCADA or a paper designs for new control systems
- Choice of VME
  - Still a good choice, increasing market share
  - cPCI would have advantages with Linux as OS
- Choice of Embedded OS
  - VxWork still valid in benefiting from exiting support but for a clean start I would consider RTEMs or Linux
- Serial Interfaces
  - Concerns raised by Diamond TAC but with tool based approach is becomes manageable
- Network Attached Devices
  - Minimised the number on Diamond
    - S7 PLCs and XPS motor controllers
  - A number of Scopes and IP camera on doors will use proprietary applications
  - Need to understand and have good tools to develop protocol support to be able to integrate effectively
  - Industry needs to adopted standards

Statistics for the Diamond Control System



Racks	450
IOCs	260
PLCs	~100
VME processors	290
Electronic modules	~4500
Computers (PC)	120
Network switches	94
Network fibre	198 km
Network copper	29 km
Plant Cables No	~15,000
Capital Cost	£9 M
Staff	90 S/Yrs

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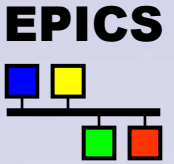

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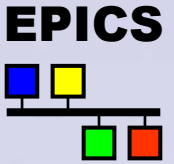

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