

Status of Indus-2 Control System

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This talk is dedicated to the entire team of Indus-2, who have made country's first and essentially indigenously made SRS work well. And efforts continue...

Status of Indus-2 Control System

- Introduction- RRCAT, Indus Facilities & Indus-2
- Overview of Indus-2 Control System
- Various Improvements in Control System
- Some Recent Additions
- Looking ahead
- Summary

Introduction

- Raja Ramanna Centre For Advanced Technology (RRCAT) under Dept. of Atomic Energy has focus on
 - Accelerators (SRS, Agricultural, Proton, SNS, ...)
 - Lasers (shifted from Bhabha Atomic Research Centre (BARC))
 - Cryogenics
 - The centre was setup in 1985 and now has 450 MeV SRS (Indus-1) & 2.5 GeV SRS (Indus-2).
 - Plans ahead for high brilliance SRS and SNS

Schematic View of Indus Complex

**RRCAT is the home to TWO Synchrotron
Radiation Sources: Indus-1 & Indus-2**



Indus-2

**Operating at 2.5 GeV, 200 mA
since June 2014**

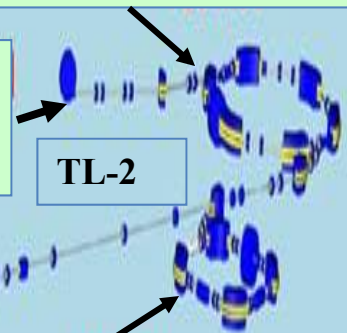
**Microtron
(20 MeV)
(Commissioned in 1992)**

TL-3

**Booster Synchrotron
(700 MeV)
(Commissioned in 1995)**

TL-2

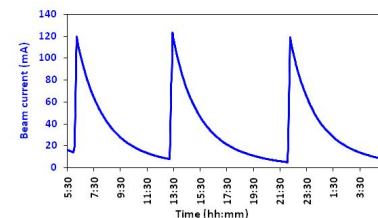
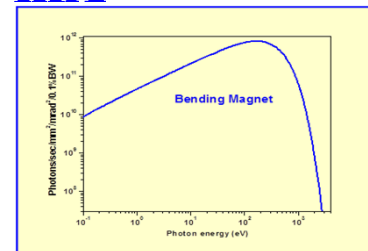
**Indus-1
(450 MeV, 100 mA)
(Operational since 1999)**





Booster
450/600 MeV

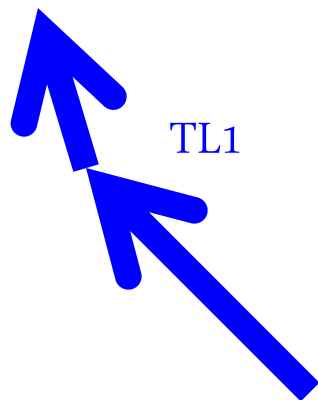
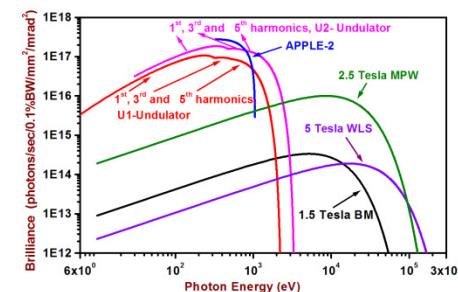
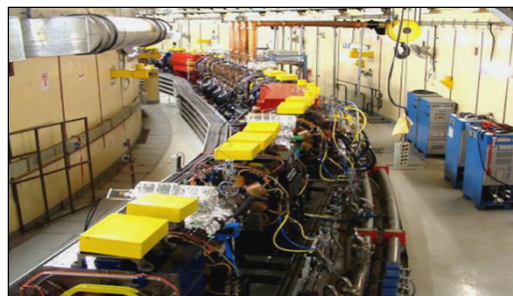
Indus-1
450 MeV, 100 mA



TL2

TL3

Indus-2
2.5 GeV, 200mA

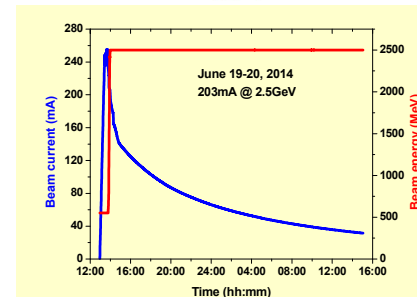


TL1



Microtron
20 MeV

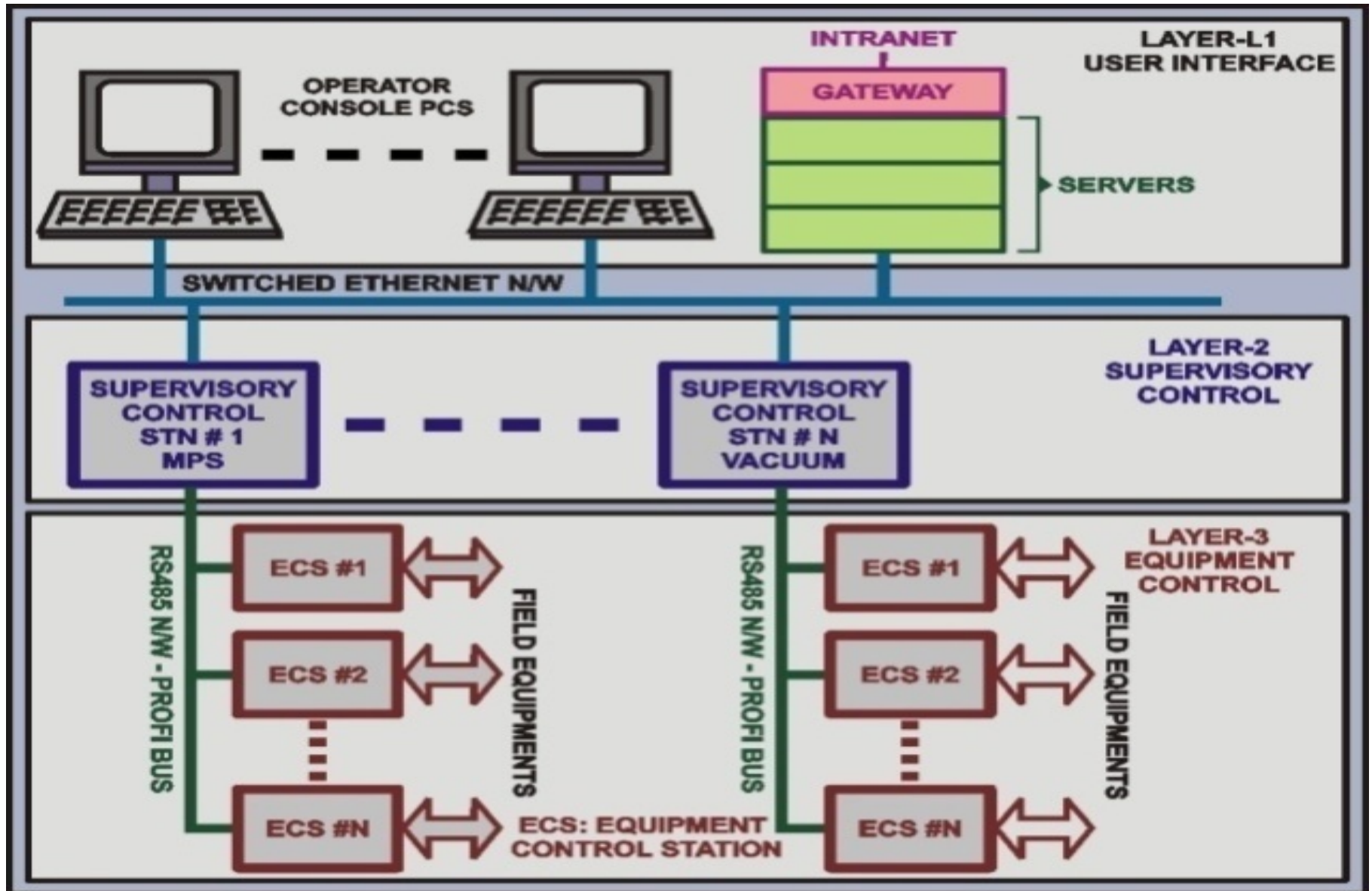
Circumference	18.97 m	172.47 m
Critical wavelength	61 Å	1.98 Å
Harmonic number	2	291
RF	31.613 MHz	505.812 MHz



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Indus-2 Control System Architecture



Indus-2 Control System ↔ Machine Sub-systems

- Magnet Power Supply Systems
- RF Systems
- Beam Diagnostics Systems
- Vacuum Systems
- Timing Systems
- Radiation Monitoring Systems
- Beam Line Front End Systems
- Interlocks
- Aux Systems (Integrated) – LCW, Pneumatic,
- Aux Systems (Isolated) - AHU, Access Control, Electrical SCADA, Power Conditioning Systems, etc.



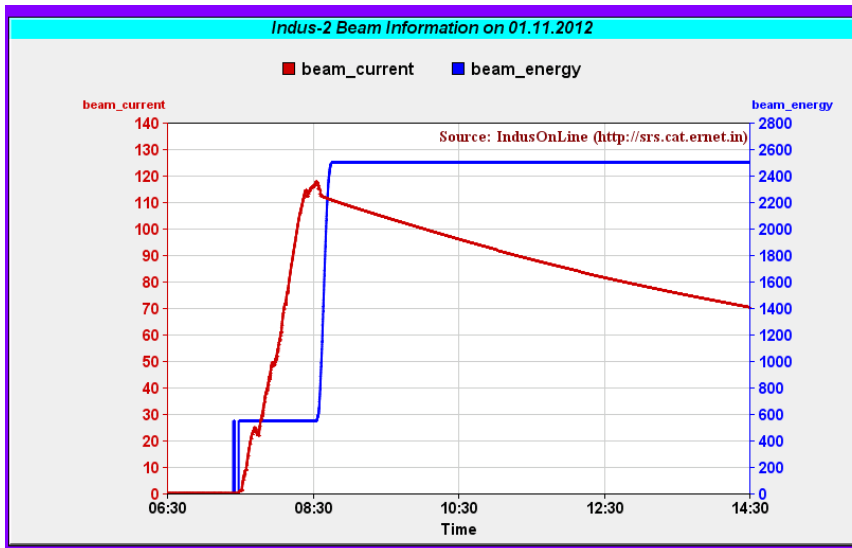
Indus-2 Control System : Salient Features...

- I/Os - $\sim > 10,000$
- Overall data refresh rate - ~ 1 sec
- MPS reference stabilities – < 50 PPM
- Timing jitters - ~ 2 nsec



Indus-2 Control System – Salient Features

- Commercial SCADA (WinCCOA) For Overall Process Supervision and Control
- RDBMS for Parameter database
- (MS SQL)
- Web Based Machine Information system over campus network
- Machine Safety Interlock System
- Alarm Handling System



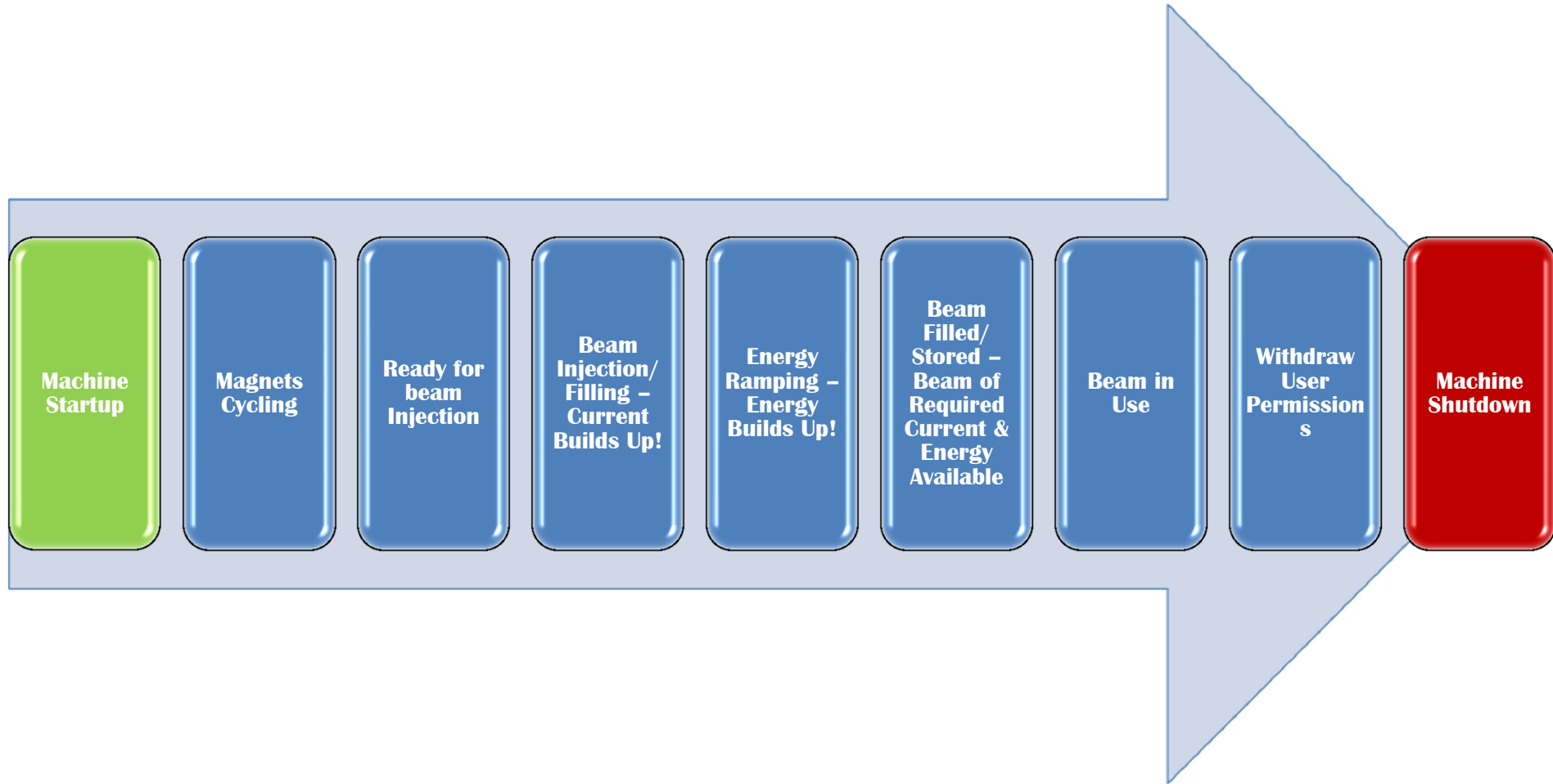
Machine Activities Facilitated by Control System

- User Authentication, Machine startup, pre condition checks
- Loading of required system parameter files
- Generate stable and precise reference signals for various devices
- Magnet Cycling, Sub-system tuning & optimisations
- Preparation of Ramp Files for various power supplies (1 DP, 28 QPs, 2 SPs, 40 HSC, 48 VSC, RF Cavities)
- Selection of Filling Patterns – Single bunch, Equal-spaced, Multi bunch
- Filling: Injecting e- bunches from injector and building up (accumulating) current
- Ramping

Machine Activities Facilitated by Control System

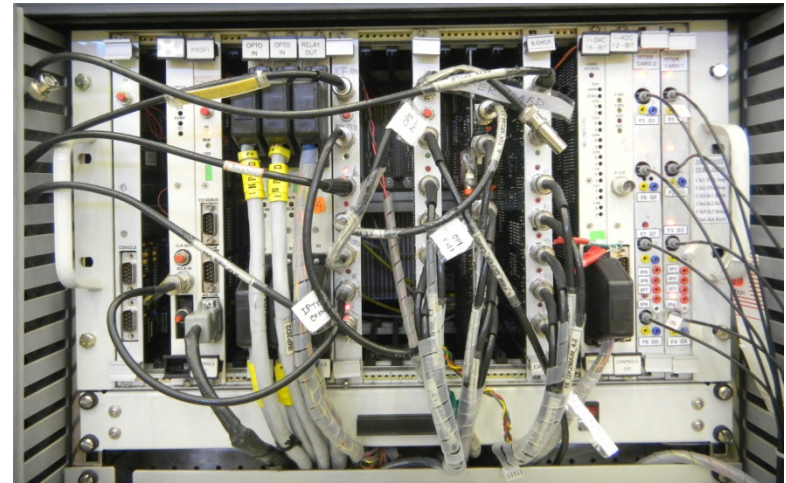
- Tune feedback
- Applying bumps –orbit correction
- Beamline Front Ends – Coordination & Control :Permitting & regulating users on the beamlines
- Machine safety, radiation surveillance, general services
- Whole system is on Check - Alarms and Interlocks
- Data logging, machine history
- Machine Diagnostics
- Safe, orderly shutdown

Machine States

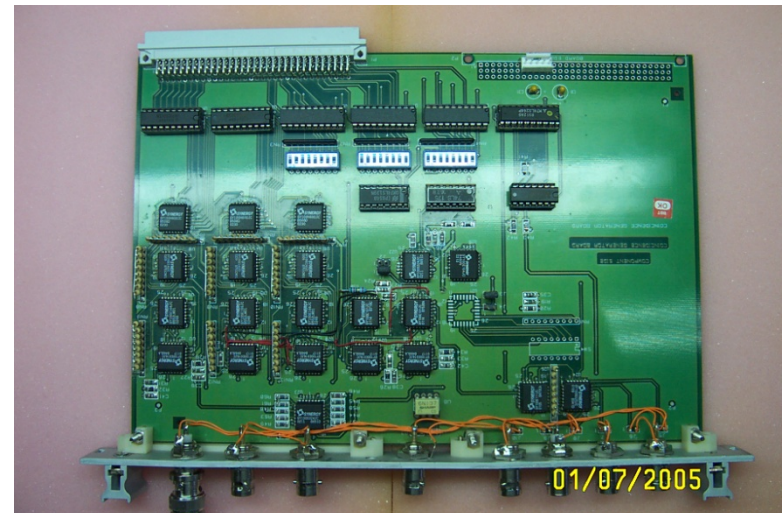


Salient Features Indus Timing Systems

- Extraction and Injection (Microtron, Booster, Indus-1 and Indus-2)
- Generates low jitter (<2 ns) timing pulses, isolated trigger signals synchronized to RF clock, with programmable delays in ms, μ s and ns ranges with 1 ns resolution
- Control and setting of all pulsed magnet power supply currents
- Programmable triggers to different sub systems like Magnet power supply and Beam diagnostics systems
- Bunch filling modes - single bunch, multiple bunched and three symmetric bunches



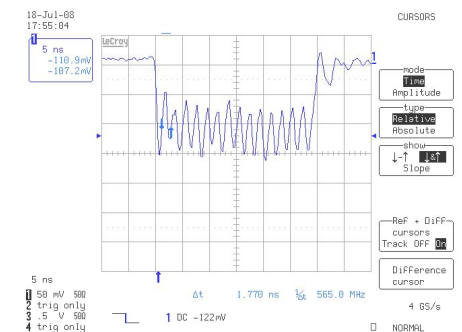
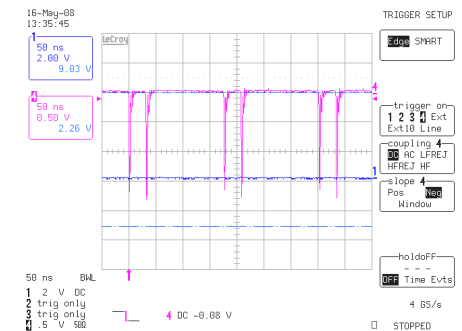
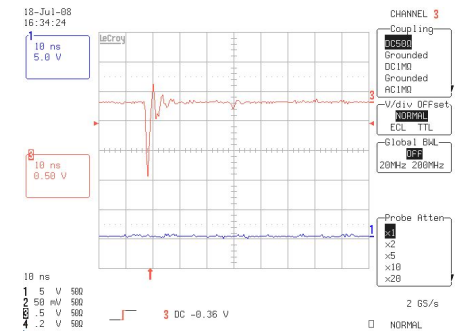
Equipment Controller for I-2 Timing Control System



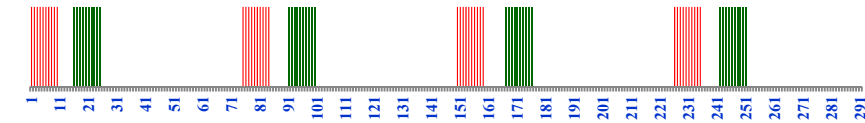
Coincidence Generator Board for I-2 Timing Control System

Indus Timing Control System: Improvements

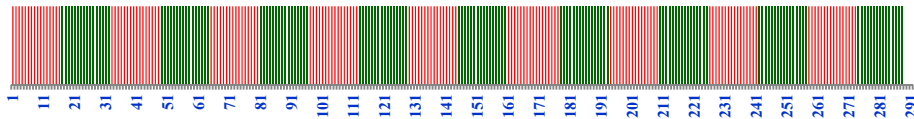
- New **FPGA based** delay generator boards developed with provision of delay read back
- **Optical fiber based** reference generation system deployed
- **Low jitter revolution clock** provided for beam diagnostics experiments
- **Several new bunch filling modes** provided as per requirements



New Bunch Filling Patterns



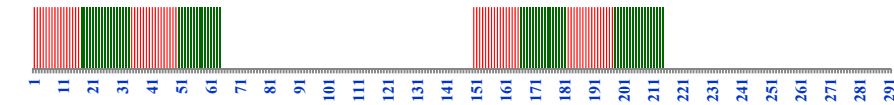
Variable width and gap between the trains



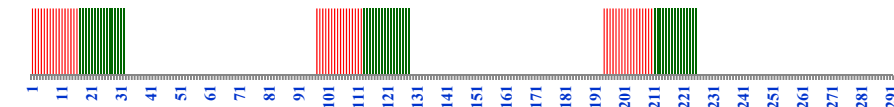
Continuous filling without overlapping



Single train



Two trains

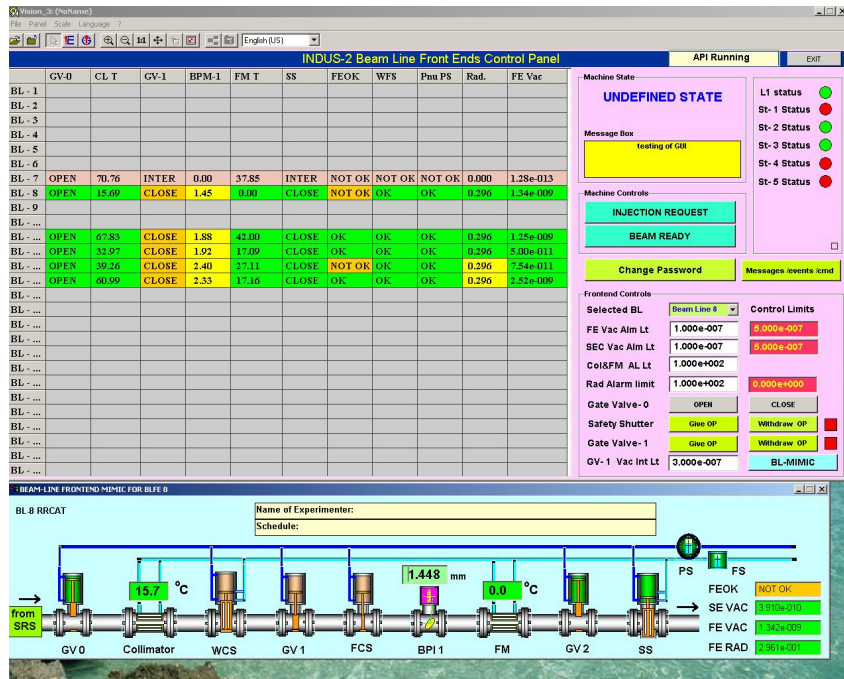


Three trains

Indus-2 Controls: Beam Line Front Ends

A beam line front end (BLFE) is typically the part of beam line which is inside the inaccessible, shielded ring area and connects the actual beam line to the ring with needed regulating and controlling mechanisms for synchrotron beam and vacuum.

Gate valves, named GV0s and located at the periphery of Indus-2 ring separate the machine vacuum envelope from those of the beam lines. These are installed at the beginning of beam line front ends (BLFE).



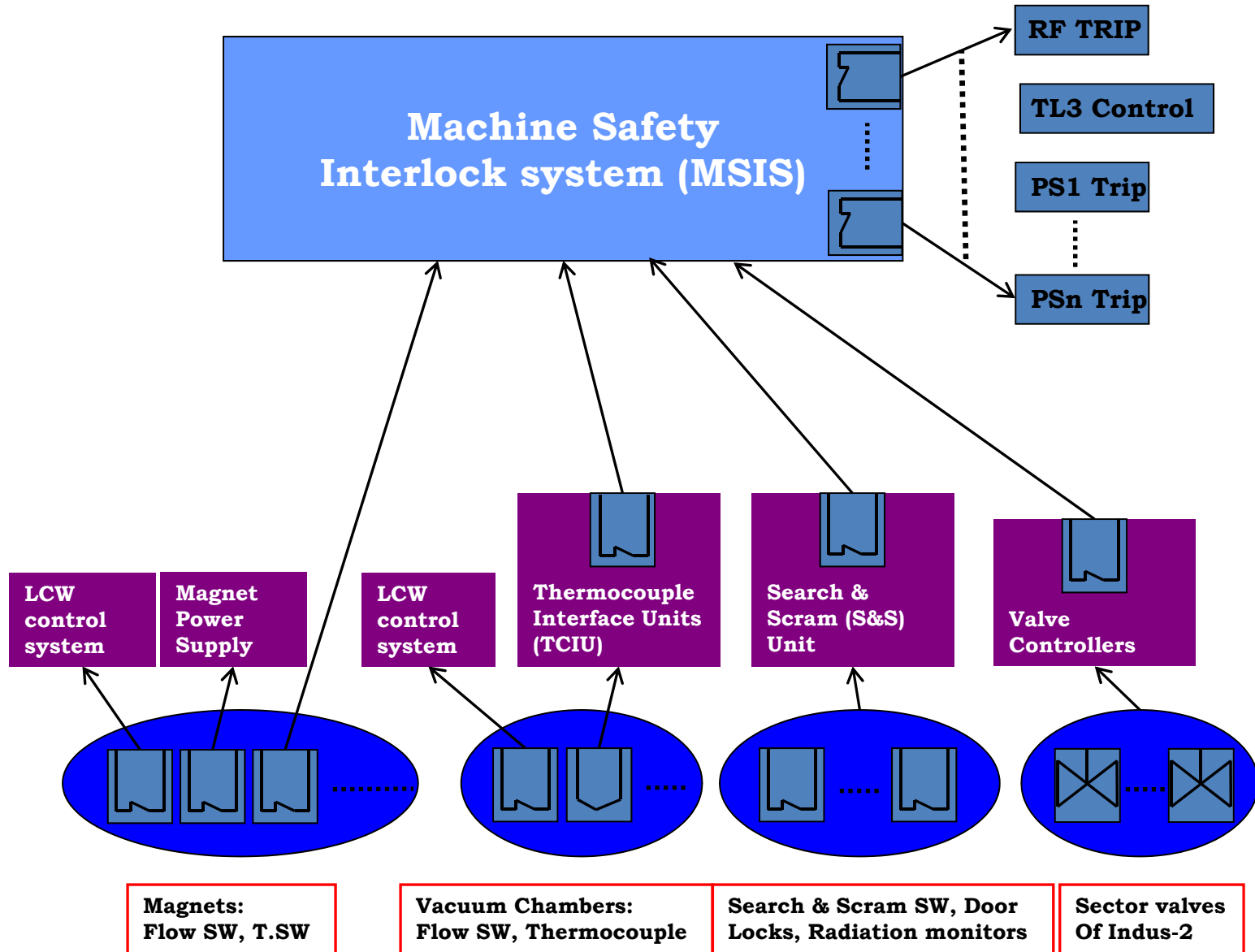
- Starting with BL-12, front ends for various Beam Lines are now integrated with machine controls.
- **Pneumatic gate valves**
- Strategic for machine vacuum protection
- **Sensitive to heat flux due to synchrotron radiation**
- Valve control, status monitoring, interlocks, alarms and data logging
- **Access Control - Any action taken on GV0s is authenticated and logged**
- Critical actions are authenticated and arbitrated by control room through handshaking

Beam Line front ends are added gradually, in course of time. So, control and integration should allow adding new FEs without affecting normal machine operation

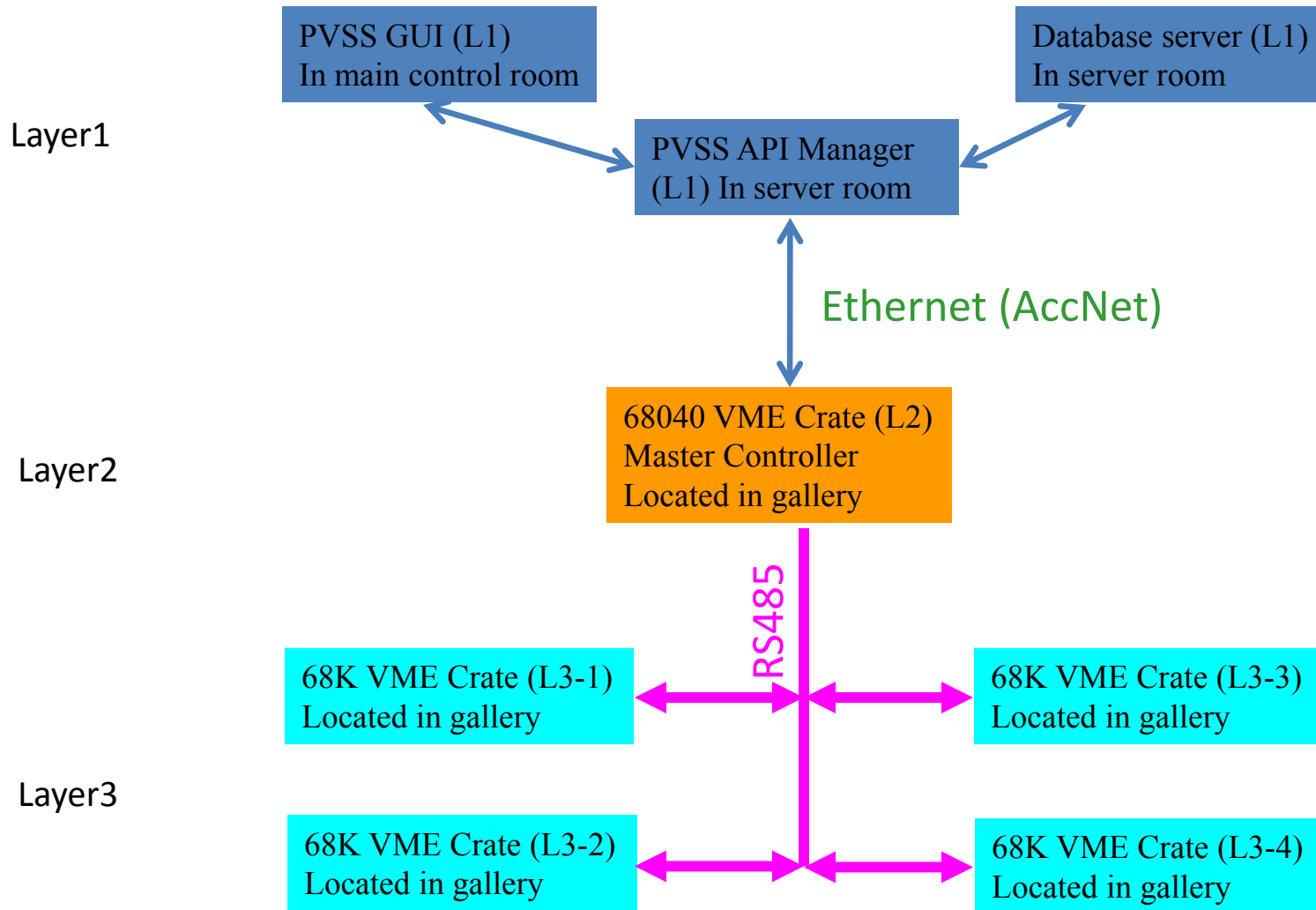
Indus-2 Machine Safety Interlock System

- Centralized interlocking for whole Indus-2 ring
- Protects critical Indus-2 machine components
- Fail safe operation
- Conditional bypassing of any faulty status or device
- Runs in 24x7x365 mode
- Working flawlessly for many years

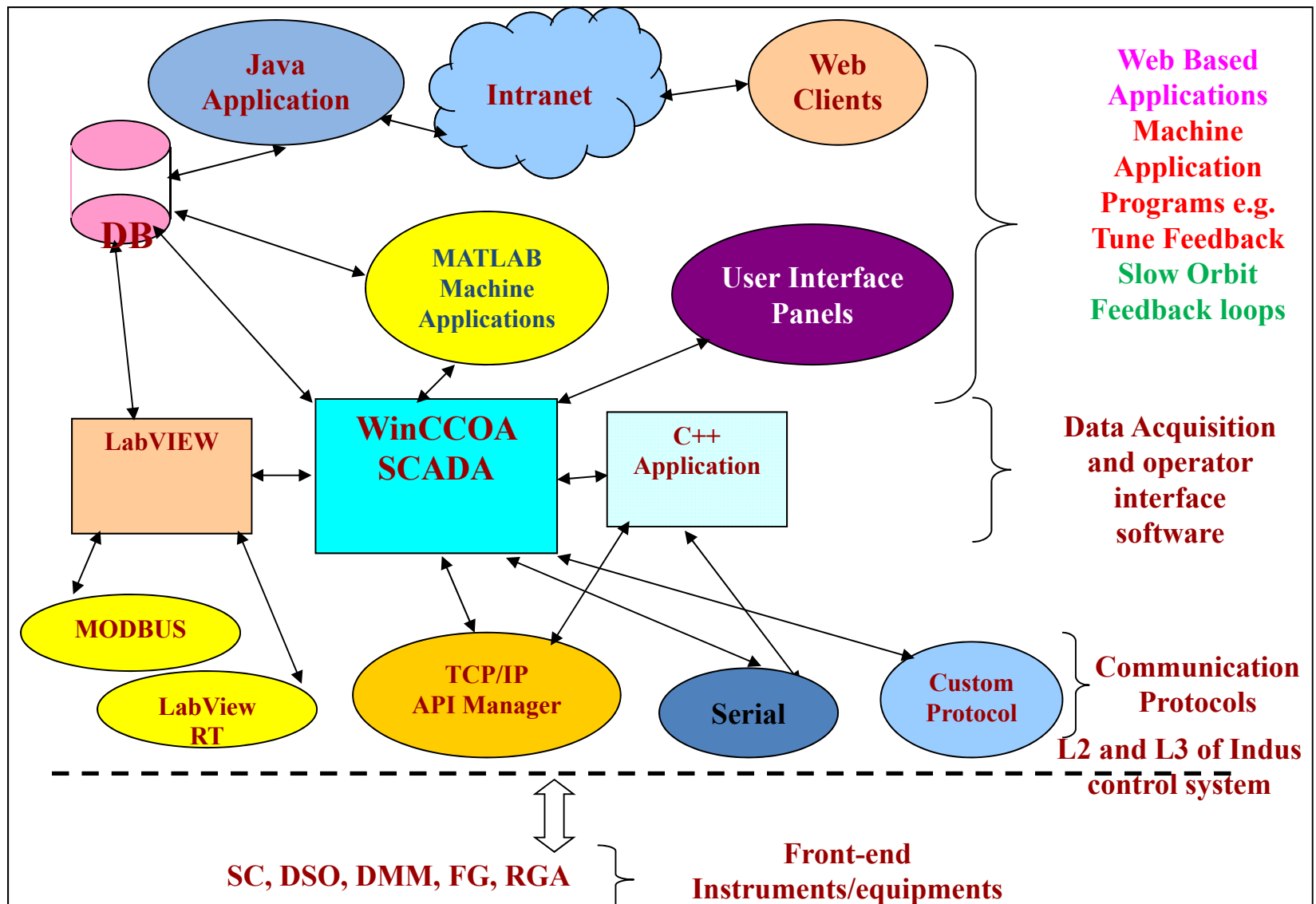
Overall interlock scheme of Indus-2

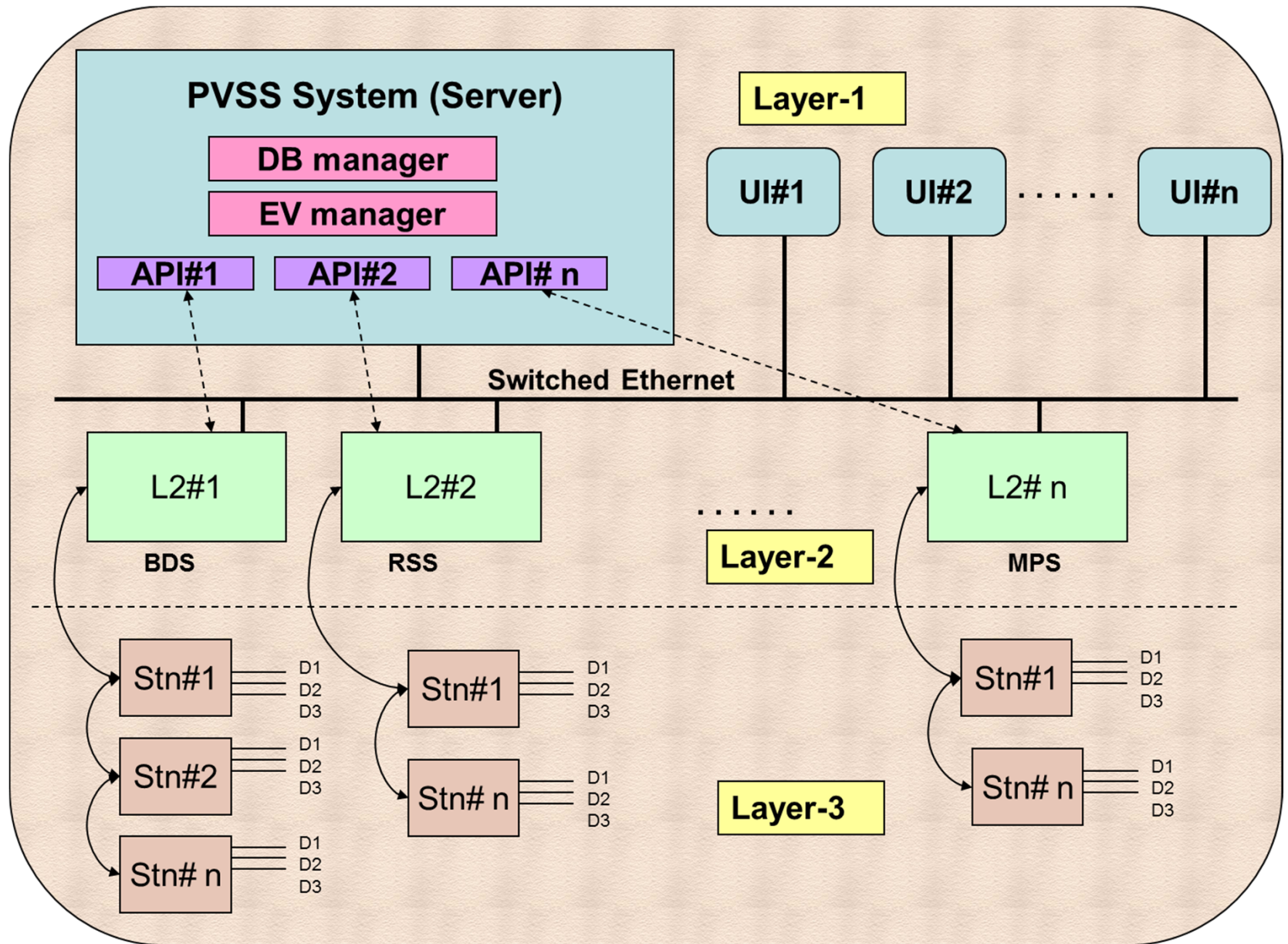


Architecture of Indus-2 safety Interlock system



Software Architecture of Indus-2 Control System





Experience with SCADA (WinCCOA)

- The usage of WinCCOA SCADA system has resulted in a well-organized and managed control system
- Ease of operation, maintenance and scalability
- Integrates various sub-systems located in the field area into one supervised control
- With ~14 clients connected at a time the CPU utilization of server is ~2-5 % maximum and peak memory used is 2.2GB. The network load is maximum 10 Mbps
- Diagnostic information made available by PVSS like resource utilization, clients connected, manager states etc., has been used extensively
- WinCCOA API has been used to interface VME supervisory control layer over Ethernet
- Rapid development of GUI panels could be done with the graphic editor having drag and drop facility and various widgets

PVSS SCADA – Performance & Figures

System Name	~ No of Signals
MPS	4200
Vacuum	1600
RF	400
Timing	100
BDS	500
RSSS	300
BLFE	300
Interlock	700
LCW	1200
Orbit Correction	200
Total	~10,000

SCADA Configuration

Physical I/Os ~ 10,000

data points ~ 20,000

Alarms ~ 4,000

Events ~ 900 per sec

Dynamic Performance Parameters

Events per sec ~ 900

Data log rate ~ 10, 000

parameters /sec

**Data is logged to external
RDBMS (MS-SQL server)**

System Upgradation - 1st Stage

- Centralized Alarm handling system for Indus-2 was made functional. The alarm information was made available from WinCCOA based systems, Labview systems , EPICS based systems
- Data logging of all device parameters to centralized database server was made operational
- System diagnostics were made available in the main control room with information like- VME stations health status, API managers states, card status, temperature, communication status etc
- With time new systems like Beam line Frontend, MSIS, Tune –feedback were integrated with the Indus-2 control system
- General purpose data server was implemented to make available the sub-system data to external applications like MATLAB based beam lifetime, decay rate, tune measurement etc, java based Bam orbit display etc. This is a multi-threaded C++ API defining a customized protocol for receiving and transmitting data

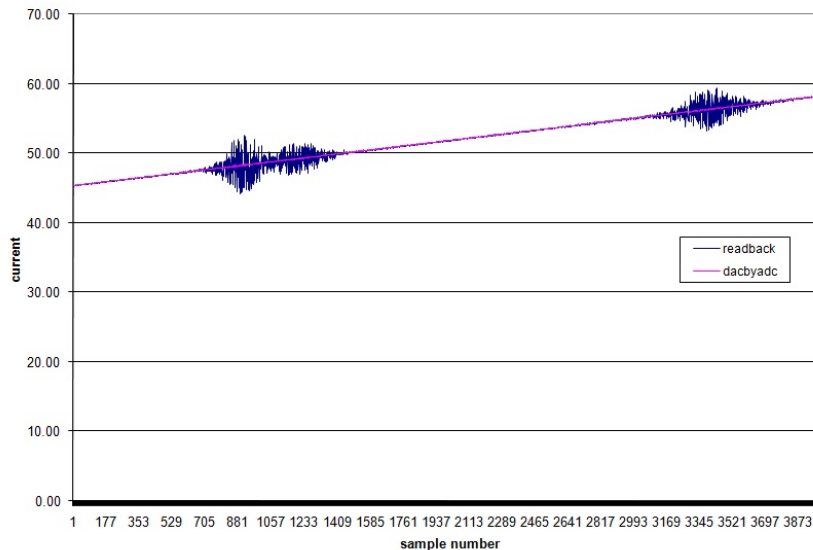
System Upgradation – 2nd Stage

- Parameter Deviation Alarms were introduced- This is a configurable system with alarm generation based on the machine state
- Beam Orbit display & alarm system
 - Whenever the difference of present beam orbit from the specified reference is beyond a specified maximum value the alarm is generated.
 - The maximum deviation is specified from injection energy and full energy and for each plane.
- Magnet cycling process verification module was put into function
- Auto injection stop after required beam current is reached
- SCADA upgradation
- 1 second data logging

System Diagnostics

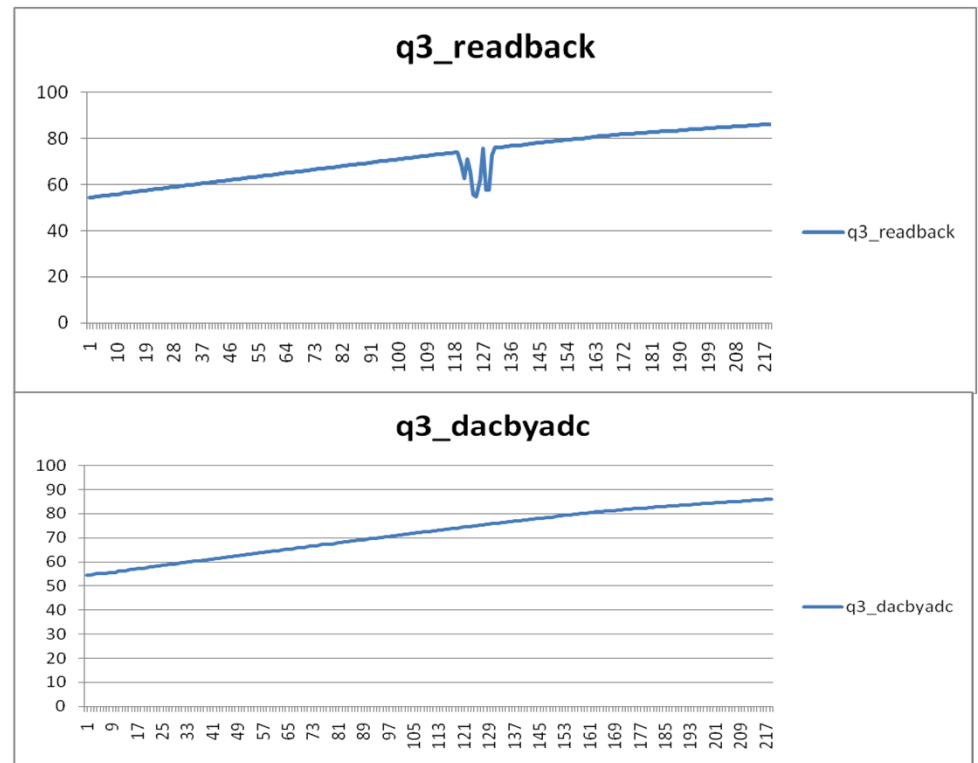
- L-3 station status at L-2 and L-1
- L-3 CPU running state at L-2 and
- Bus-error status of L-3 cards at L-1
- L1-L2 communication status at GUI
- API running status at GUI
- DAC readback by ADC for end-to end confirmation (in MPS system)
- Cycling verification system
- Synchronous Ramp data capture
- Transient Data Capture System
- Web based data diagnostics from history data

ls8q3d rdbk and dacbyadc



Data Diagnostics

- Web data browsing
- Uses normal history data logging of machine parameters
- Detects beam current fall by selectable value
- On those time stamps, finds suspected systems whose Set – R/B values might have changed by more than a certain value
- Graphical and textual display



How the system has performed

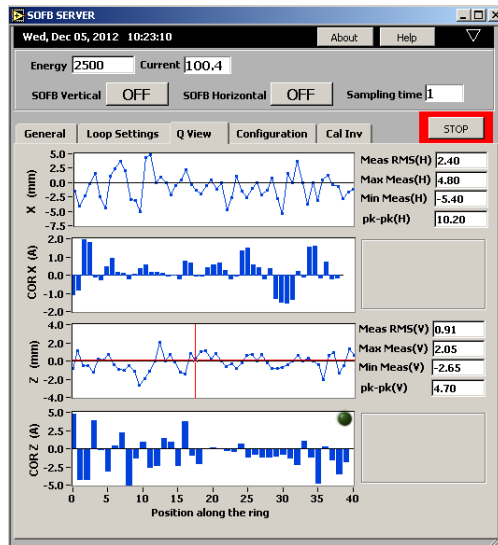
- Good hardware reliability
- Improved system diagnostics
- Few software bugs
- Very few machine trips on account of control system
- Machine Safety Interlock System
- Heavy use of database and web resources - increased drastically
- Rising Security concerns
- Continuously evolved – performance, resource utilisation, reduced down time

Major Recent Enhancements

- Global Slow Orbit Feedback System
- Global Fast Orbit Feedback System
- Tune Feedback Correction System
- Data logging and database
- Security measures
- Diagnostics – PDA, Beam Orbit Alarm & Display System, Cycling Verification System, Ramping data verification - Transient Data Capture System

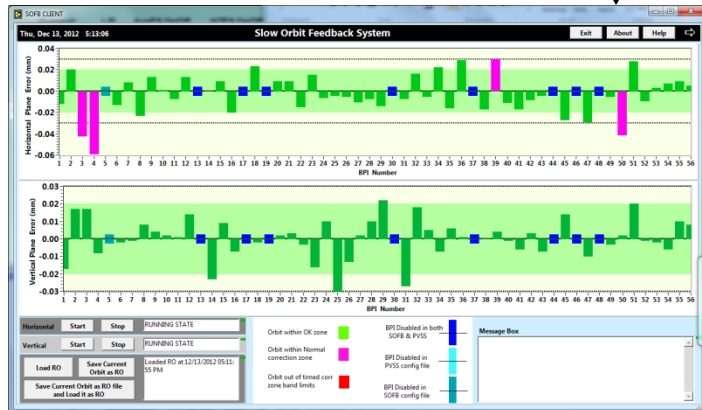
Slow Orbit Feedback Control System for Indus-2

- Slow orbit control system in Indus-2 serves the purpose of actively controlling the electron orbit in Indus-2 within the $\pm 30\mu\text{m}$ band over reference orbit (Golden Orbit) both in horizontal plane as well as in vertical plane



SOFB Server

SOFB Client

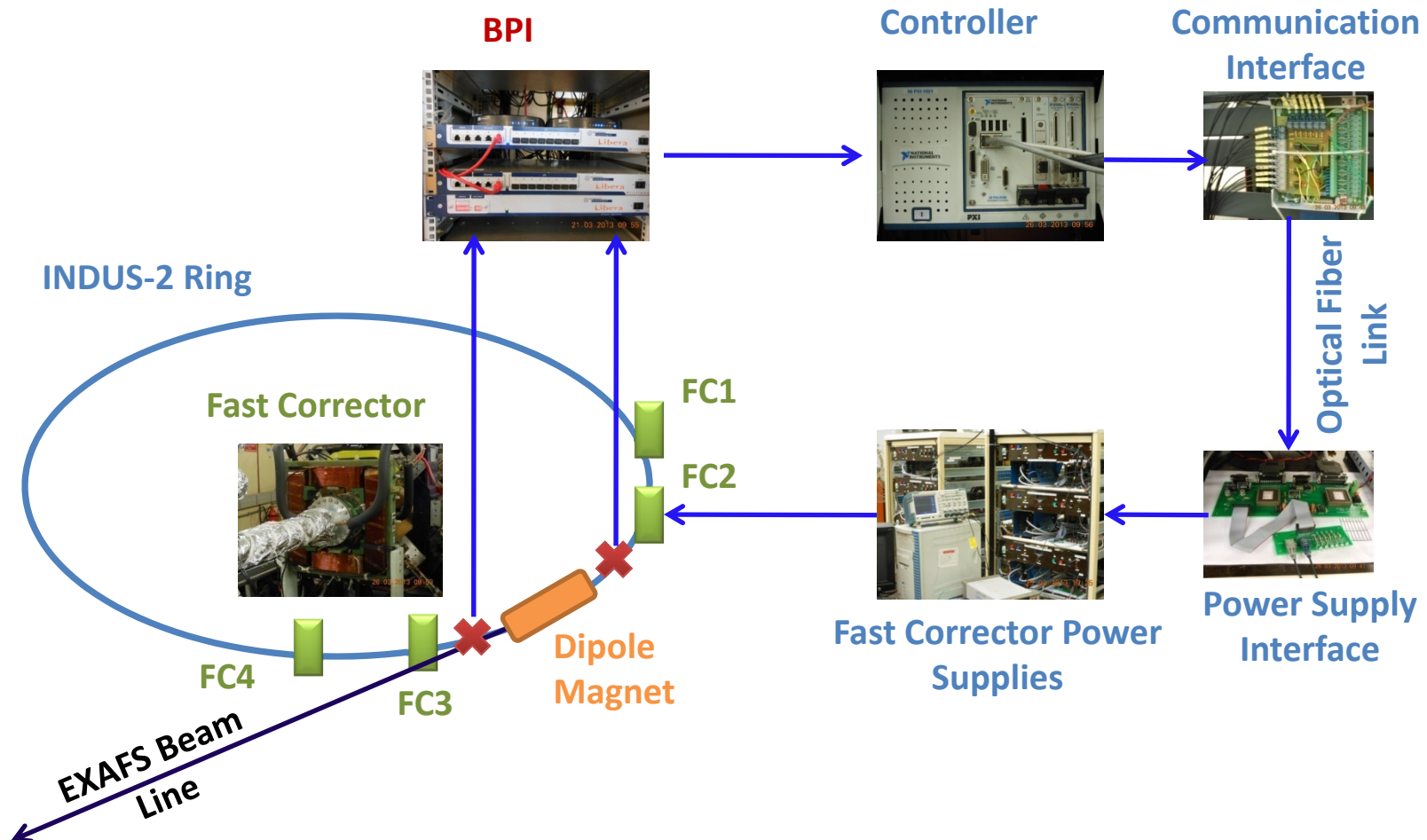


Multivariable active feedback control system implementation

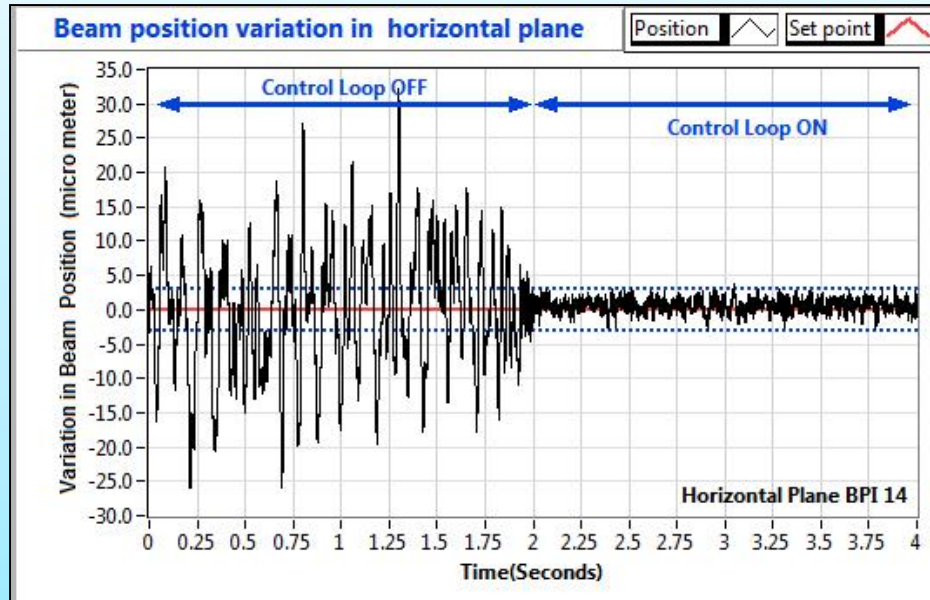
- Sensors: 56 Beam position indicators (BPI) distributed all over the INDUS-2 ring provide beam position in both Horizontal (x) as well as vertical (y) plane.
- Actuators: 40 Vertical and 48 Horizontal correctors distributed all over the INDUS-2 ring.
- correction rate: Once in 15 seconds.
- PID controller with Singular Value Decomposition based correction algorithm with auto fault detection and system recovery/restoration features.

Scheme of Local Fast Orbit Feedback Control System for Indus-2

Demonstration of LOCAL Fast Orbit Feed Back (FOFB) System - proof of concept on BL-8 as a first step towards implementing GLOBAL FOFB for Indus-2



Local Fast Orbit Feedback Control System for INDUS-2

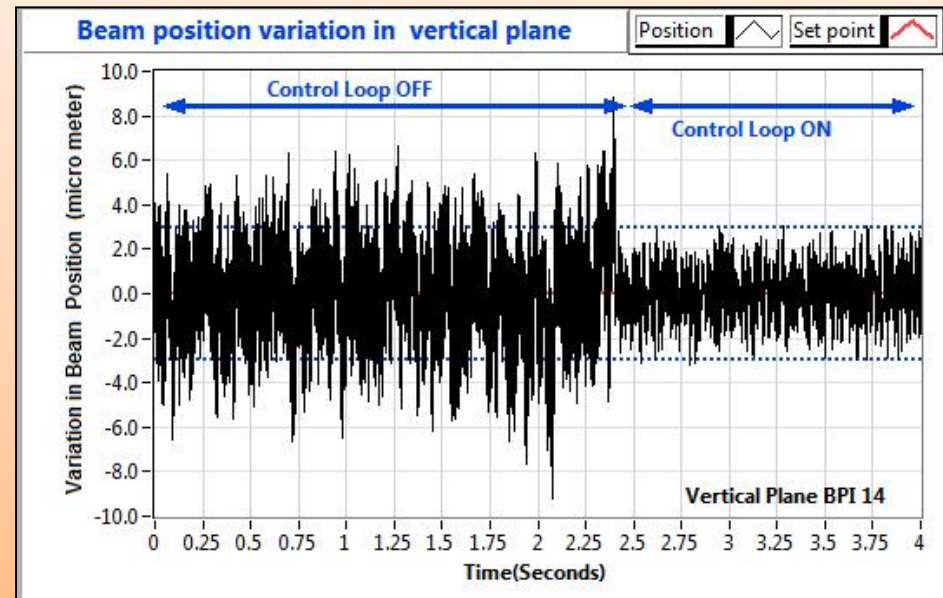


Beam position variation in horizontal plane

Orbit variations	Uncorrected	Corrected
Peak to Peak	$\pm 30 \mu\text{m}$	$\pm 3 \mu\text{m}$
RMS	$13.0 \mu\text{m}$	$1.2 \mu\text{m}$

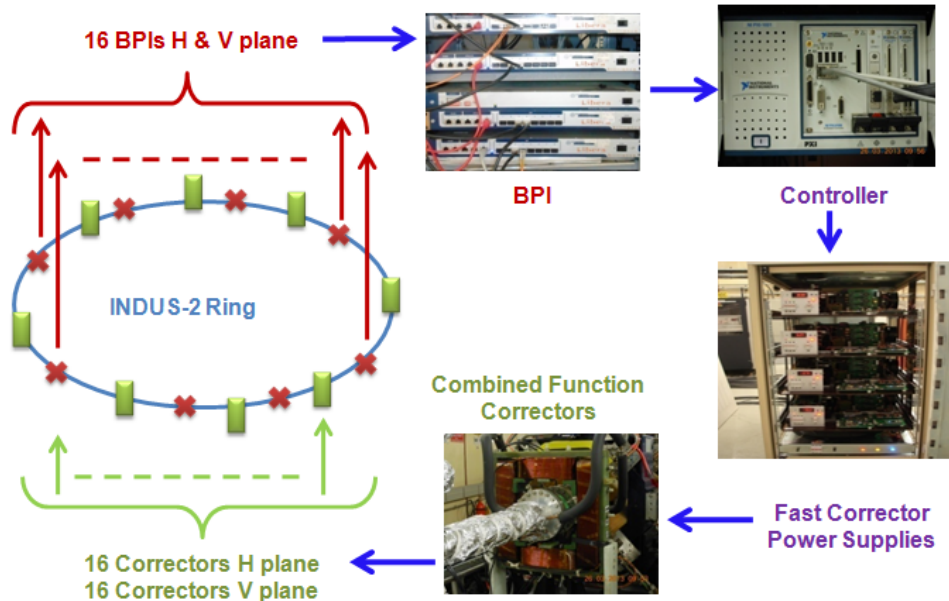
Beam position variation in vertical plane

Orbit variations	Uncorrected	Corrected
Peak to Peak	$\pm 9 \mu\text{m}$	$\pm 3 \mu\text{m}$
RMS	$1.23 \mu\text{m}$	$1.0 \mu\text{m}$

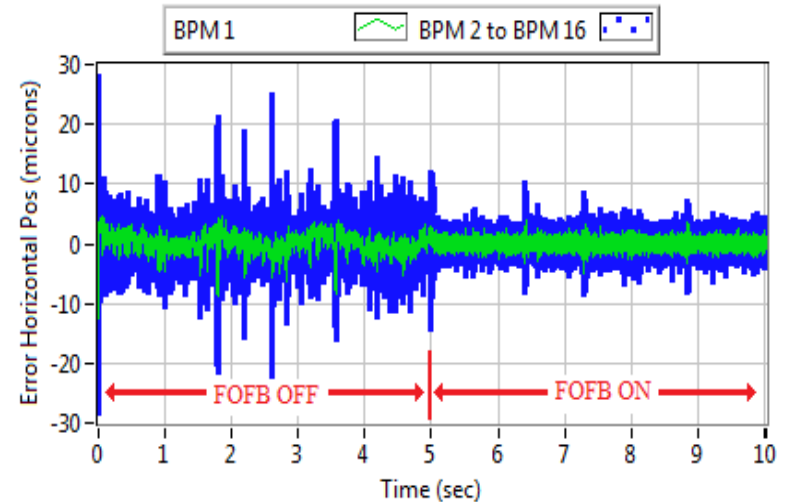


Global Fast Orbit Feedback Correction in Indus-2

Global FOFB Scheme



Horizontal Plane Beam Position variations with and without FOFB Corrections



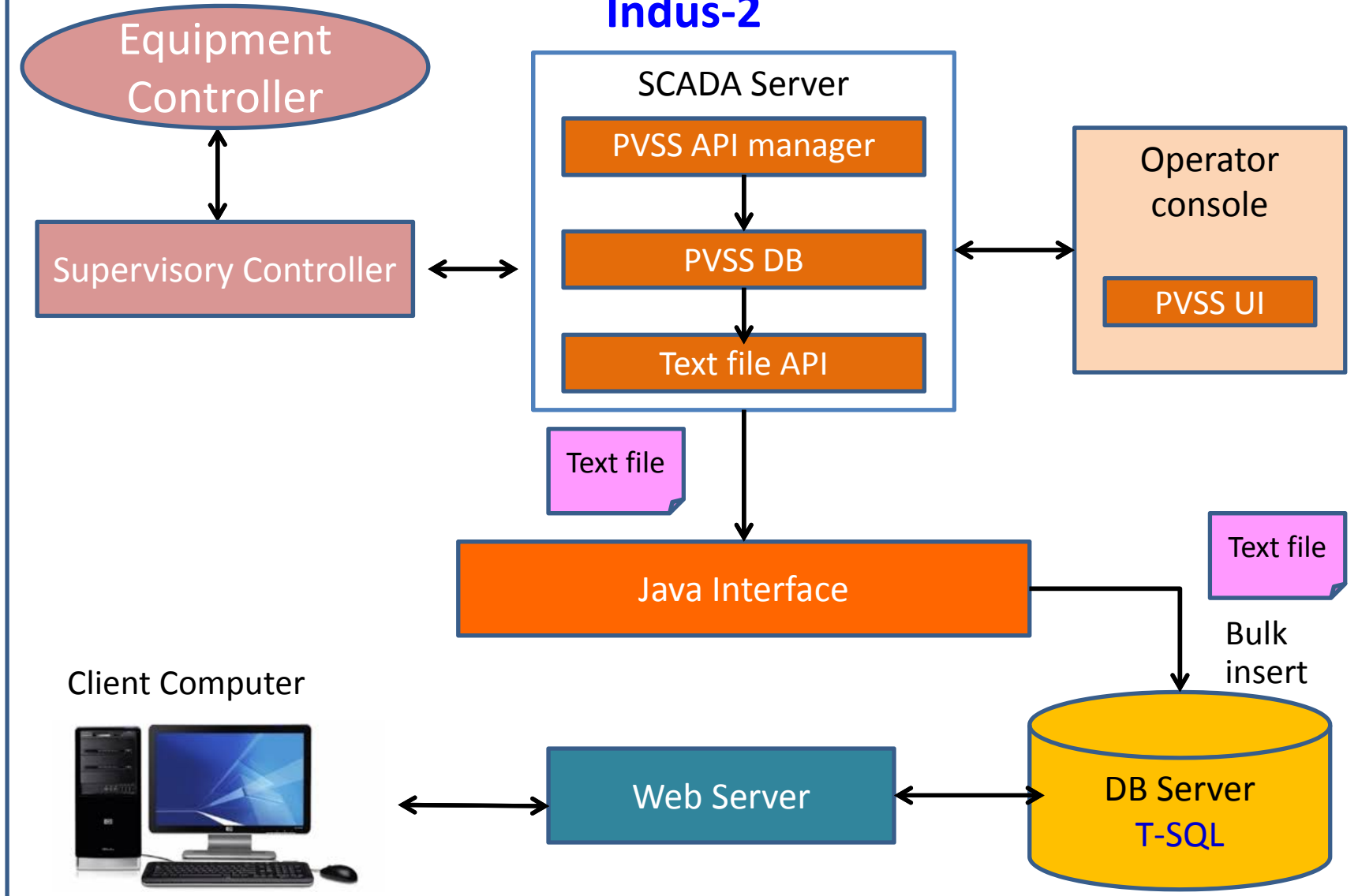
Beam Position Error (microns)	Horizontal Plane		Vertical Plane	
	Max	RMS	Max	RMS
Uncorrected	40	15	20	9
Corrected	12	3	6	2

- The initial trials showed the attenuation of 50 Hz component in beam orbit signal by approximately 5dB.
- Further controller tuning and advance control algorithm is expected to improve the results.
- The next challenge is to integrate global FOFB with the SOFB which is already implemented and in regular use during machine operation.

Fast data logging

- Nearly 10000 parameters are being logged at the rate of 1Hertz.
- Database schema is based on the theme of “**one data table per data type**” for each subsystem.
- Text file is parsed and Bulk Insertion is done to load the data into database.
- Recent one hour available data is kept in separate table termed as Intermediate table. This table is partitioned at the interval of five minutes.
- Remaining all past data is residing in the separate table termed as Main table.
- Each subsystem has one configuration table and two staging table for each data type.
- Java interface manages the temporal synchronization and provides error handling capability.
- This scheme allows the WinCCOA to be disjoint from the database, allowing it to concentrate on SCADA job and free from changes in the database.

New Database System Architecture for Indus-2



Web Applications

- Indus OnLine - Live (Text/Synoptic), History (Tabular/ Graph)
- Machine Status Display System (Text, Graph)
- Fault Information System – Fault Tracking
- FLogBook – Online fault logging & email
- ePlanner
- Elog: Electronic Logbook – comprehensive machine and shift logs

Indus-2 – Current Status

- ✓ Regular Operation in 3 shifts @200 mA/2.5GeV
- ✓ COD Correction
- ✓ Slow Orbit Feedback operational
- ✓ Tune feedback operational
- ✓ Diagnostic Beamlines commissioned
- ✓ Local & Global Fast Orbit Feedback demonstrated
- ✓ Transverse Instability feedback - implemented
- ✓ Work started for ID based beamlines
- ✓ First trials of BBA done using a single QP magnet
- ✓ Reliable & Stable control system opern.

A View of the Indus-2 User hall with Beam line Hutches



Looking Ahead...

- Combined operation of Slow and fast orbit feedback systems
- ID integration
- BBA
- Faster diagnostics & postmortem analysis

Summary

- ❑ All sub-systems completely interfaced
- ❑ Three bunch filling modes qualified, recently some new filling patterns also accommodated and tested
- ❑ Power supply reference stabilities – qualified
- ❑ Cycling in place; recently cycling verification application developed
- ❑ Energy Ramping has been proven; TDCS for verification
- ❑ Machine safety interlock system working reliably
- ❑ Alarm handling system – proven; major tool in machine operation
- ❑ Major noise issues overcome
- ❑ All machine parameters are logged; now @1 sec
- ❑ All machine parameter data available over campus intranet
- ❑ Campus wide history data access
- ❑ Web based tools – MIS, Flogbook, Elogbook, Eplanner, Diagnostics
- ❑ Slow orbit feedback implemented and enhanced with advanced features such as 'agent based model assisted suspected BPI identification' and 'model assisted data prediction' to handle the situation of drift in BPI readings.
- ❑ Fast Orbit Feedback Demonstrated

Thank You.