9 CONTROL SYSTEM

9.1 Introduction and Scope

The control system for NSLS-II is designed to convey all monitor, control, model-based, and computed data from all accelerator, facility, safety, and operations subsystems to accomplish supervisory control, automation, and operational analysis. The scope of the control system extends from the interface of the equipment being controlled through to the designers and operators of the accelerator facility, as well as synchrotron beamline experimenters and staff. The control system includes all hardware and software between these bounds: computer systems, networking, hardware interfaces, and programmable logic controllers.

To provide this comprehensive monitoring, control, and automation, the NSLS-II control system must scale to support 100,000 physical I/O connections and 350,000 computed variables that can be correlated to analyze events and provide data for all control aspects. It must support 1 Hz model-based control, 110 kHz power supply control and readback, 500 MHz RF control, 100 Hz orbit feedback, and 5 millisecond equipment protection mitigation. It also must provide 5 Hz updates to operators of up to 1,000 chosen parameters, provide coherent turn-by-turn orbit data for up to $2^{10} = 1{,}024$ consecutive turns (for FFT), archive up to 6,000 parameters at a rate of 0.5 Hz continually, latch the last 10 seconds of data from all parameters in the storage ring when a fault is detected in the Machine Protection System (MPS), archive up to $2^{10} = 1{,}024$ consecutive turn by turn data for 1,000 parameters at a rate of 10 Hz, and provide pulse-to-pulse beam steering in the linac at 1 Hz.

Our proposed client-server architecture is depicted in Figure 9.1.1. Different levels of access and control reside at distinct layers. At the highest layer (layer 3), access is provided for activities that do not involve moment-by-moment control or monitoring of the accelerator. Layer 3 includes high level physics modeling, making use of live data and data stored in the site Relational Database (RDB in the figure). Experimental activities that do not require synchronization with the ring also reside at layer 3. Layer 2 contains accelerator operation and monitoring activities. Layer 1 contains dedicated equipment controllers, which in turn interface to specific equipment through point-to-point protocols (layer 0).

Communication between subsystems takes place via four distinct buses as indicated. Fast Feedback, MPS, and Global Synchronization buses supply information as implied for the needs of these control operations. Asynchronous information flow which does not require specific transfer rates is achieved by Channel Protocol. This is the most global communication standard in the system and, accordingly, most devices in every layer are identified as channel access clients, servers, or both.

The standard two-layer client server architecture ensures scalability and avoids performance limitations. NSLS-II controls must be built upon a proven tool kit with well-defined interfaces at both the server and client to enable integration and development. It should enable the use of hardware and software already developed for specific light source requirements. The core of the Experimental Physics and Industrial Control System (EPICS) has been chosen as the basis for the control system. Three options for the control system tool kit were reviewed [9.1]: EPICS [9.2], TANGO [9.3], and a commercial SCADA system [9.4]. We concluded that any of these options could be made to work, but with varying levels of functionality, support and cost. However, EPICS has advantages over the other options in three key areas: large user base in the accelerator community, functionality for accelerator-related systems, and support for the required hardware interfaces.

Specific technical requirements, identification of control system user groups, and further details of the system architecture and EPICS toolkit will now be elaborated.

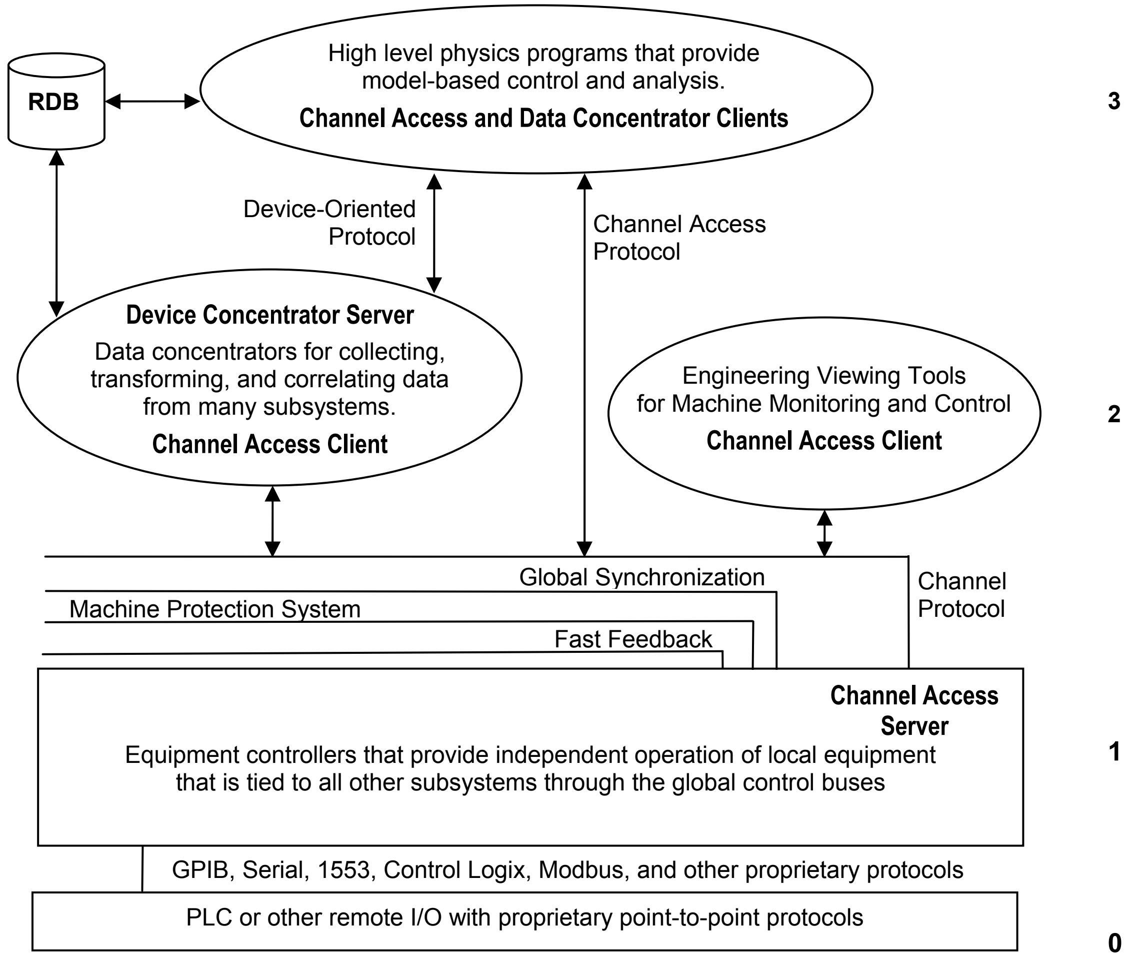

Figure 9.1.1 NSLS-II software architecture.

9.2 Control System Requirements

9.2.1 Technical Requirements

The control system must be modular, incrementally upgradeable, scaleable, and extendable. Expansion of the control system to accommodate the build-up of the accelerator and beamlines from early testing, through installation and commissioning, and during the life of the facility, should not impact the performance. The control system must be available to support all aspects of the project schedule, from component tests during prototyping to beam characterization and optimization at commissioning. To achieve this, the NSLS-II control system is based on open standards and commercial off-the-shelf equipment, whenever possible. Developments needed by NSLS-II are to be accomplished in a manner that meets the project schedule, budget, and performance needs, with consideration for knowledge transfer to the wider accelerator community.

Machine Control

Machine control supports linac control that is synchronized to the master timing system to fill the booster ring with 80 nanosecond pulse trains made up of 40 micro bunches of 2 ns length each. Pulse-to-pulse timing jitter will be less than 80 ps at the 1 Hz rate. The pulse is ramped up to the correct energy in the booster ring over 400 ms. It is then injected into the storage ring. The revolution rate for the booster and storage ring is 2.6 µs. Manual control of orbit trims, quadrupoles, sextupoles, and insertion devices is asynchronous. These are controlled by the operators, accelerator physicists, high level applications, or users. In particular, ~10 Hz write/read is suitable for "turning knobs" for a power supply. The only "fast" process is the fast orbit feedback system with ~100 Hz bandwidth (and feedback systems for coherent bunch instabilities of order MHz). To summarize, the beam bunches in the ring and the injection process are synchronous to the RF, but everything else has its own time scales. Model-based control is used to correct steering, the orbit, tune, linear chromaticity, optics, etc. in the storage ring at 1 Hz.

System Reliability

The control system must have 99.9% availability, 24 hours per day, 365 days per year. Control system modifications that add new functionality will be performed during scheduled down times. New functionality for the operational facility will be tested on equipment test stands before installation. The cryogenic control must achieve even higher standards. Failures or modifications to the cryogenic control system must not result in the loss of temperature control for greater than 15 minutes. Subsystems will be designed to meet system reliability goals using high reliability technology, where required. This includes the use of an uninterruptible power supply, programmable logic controllers, battery backup, and redundant power supplies for VME crates. All subsystems will be designed to achieve operational reliability goals.

Security and Integration across Operator Base

The system must manage access requirements for the different classes of user. It must also incorporate appropriate tools to guarantee security of its computers and network systems. The source of the data should be irrelevant from the point of view of any software designer or user. For example, it should be possible to display data from the control system, from the associated relational database and from an accelerator model on one full-screen synoptic.

9.2.2 Software Requirements

Control system applications must be designed to enable future upgrades to be incorporated economically. Wherever possible, application programs will be provided with command-line options, so that the functionality on offer can be increased by simply running the program with a different set of command line options.

Code Maintenance

All code, control system tools, and applications will be placed under source/release control. A standard tool will be used to control the version of software running and to keep previous versions and an audit trail for changes to released and commissioned software. Accelerator components and signal lists such as: magnetic lengths, min/max currents, calibration coefficients for currents vs. gradients, diagnostics channels, and configuration parameters also will be kept and their versions managed. The data that are also needed by accelerator models are to be kept in a similarly controlled relational database.

Open Standards, Integration, and Ease of Use

The control system will use open standards and an open architecture. The long life expectancy of an accelerator complex implies that the control system will need to evolve to incorporate upgrades and new technology. The control system must enable seamless integration of systems at both the server and client side through well-defined APIs. It is beneficial for the applications that comprise the NSLS-II control system to have a consistent look and feel. Related functions should be linked, to reduce the number of mouse clicks a user has to perform. For example, trends could be accessed by clicking on a process value hotspot displayed on a plant synoptic value. All control system facilities that need to be accessed directly will be accessible via menus, where the menu titles give a clear indication of the facility being called up. It should never be necessary for a user to remember the name of a program or of data files in order to use the system.

Context-sensitive online help facilities should be designed into the system, where feasible. Conscientious attention to common-sense ergonomics during application development will clearly pay dividends for long-term ease of use and will minimize familiarization and training costs for new operators. Production of a concise Style Guide document at an early stage in the development cycle of the project will provide a good ethos for addressing these issues.

9.2.3 Architecture Requirements

The four-layer EPICS-based client-server architecture illustrated in Figure 9.1.1 implies further design considerations for its implementation:

Network

The connection of the control system layers will use standard network components. These should be in a redundant configuration and include provision for network evolution, i.e., the development to GbE standards. Control system network security is to include physical security that limits access to the control network from outside, using gateways and firewalls. It requires appropriate types of password and key protection within the control network with access control to manage who is controlling which operation.

Operator Interface

The operator interface will be either workstations or PCs running Unix or NT, as these are the established standards. The control system should seamlessly integrate with office systems through a gateway process to maintain security.

Equipment Interface

The equipment interface will provide the physical connection to the equipment being controlled through a variety of interfaces. The preferred standards will include VME because of physical and electrical performance, Compact PCI where higher performance backplanes or lower point count make this more cost effective, and PLC I/O for applications where equipment safety is required and speed is not. The control system includes all VME crates and processors, any network hardware required for integrating instrumentation, the timing/event system, all hardware used for fast feedback, and all instrumentation that plugs into the VME crates. When intelligent devices or PLCs are used, it must be clearly stated if the equipment is to be provided by the control system. All cables leading out of the instrumentation at either end are the responsibility of the subsystem.

Relational Database

The control system must include a relational database as a central repository for all configuration information. This should include all static information about accelerator components such as coefficients to calculate field magnetic strength from current. Consideration should be given to extending the database to include all technical information to enable subsequent support and maintenance. At the application level, there should be a unified and seamless interface to both the static and dynamic data.

9.3 Identification of Control System User Groups

The control system must support several user groups, each with varying requirements.

Accelerator Operators

Accelerator operators are the principal managers and users of the control system. It must be a complete and consistent interface for them to perform any function in the accelerator complex. The data and interfaces must be consistent in how data is presented and how equipment is seen to behave. The operation of the accelerators requires real-time control and monitoring of the equipment, archiving, alarm handling, sequencing, backup and restore for routine operation. For these users, alarm and error messages should be supported by information regarding recommended courses of action. The control system should allow the automation of plant operating tasks. It should provide applications that encourage and facilitate the keeping and passing of operation logs, particularly from shift to shift.

Accelerator Physicists

The accelerator physicists' requirements for the control system include all the routine operations of the control system together with the ability to integrate programs developed to support different accelerator models. Functionality is required to allow easy acquisition of data produced as part of an experimental run, and to provide the ability to switch between different accelerator models. Data retrieved from the control system must be acquired with sufficient time accuracy to enable accurate correlation.

Technical Groups

The technical groups require diagnostics to enable maintenance such as calibration and fault finding. Access to the control system is required in the main Control Room, local to the equipment, and potentially in the offices, laboratories and off-site. Applications must provide all diagnostic information necessary to assist in commissioning and debugging of equipment. They must provide useful fault diagnosis facilities to assist with plant equipment maintenance and maintenance of the control system itself (both hardware and software). An easy interface to databases of equipment properties, manufacturers, documentation, cabling data and fault histories is required, as well as access to information clearly identifying the geographical location of equipment and a system of fault prediction facilities to allow for scheduled maintenance of components likely to fail.

Beamline Staff and Experimenters

The end users of the experimental station require a straightforward graphical interface to the control system. They also require good integration of control system parameters with the experimental control and data acquisition systems. This is particularly necessary in the case of synchronizing scanning of a sample with changing a parameter on an insertion device in the storage ring, e.g., the gap of an undulator. Experimenters require clear information on light source status, performance, and timing signals, and may require remote access (i.e., from off site) to experiments and beam-lines.

Control System Engineers

Control system engineers require current and archived data on the status and behavior of the entire control system. Information required includes CPU loading, network loading, application monitoring (for frozen/crashed applications), connectivity status, and reports of any control system faults.

Facility Managers

The control system should be capable of producing operating reports and statistics in a form that can then be imported into software applications (i.e., spreadsheets, web-based tools, etc.) used by management. Information required could include the number of hours of beam time supplied to users and unplanned beam dump statistics – how often these events occur, time taken to restore beam, reason for beam dump, and signs of common modes of failure.

Public Users and Staff

A wide range of other groups will require information from the control system. These include technical and scientific groups on and off site. These groups should be served through a web service as the user interface.

9.4 EPICS Toolkit

EPICS is the result of a collaboration of control groups, across a number of research organizations, to produce a tool kit to build distributed control systems. The resultant tool kit reduces software development and maintenance cost by providing: configuration tools in place of programming, a large user base of proven software, a modular design that is expandable, and well defined interfaces for extension at all levels.

Worldwide, EPICS has a very large user base for a variety of accelerators, detector systems, astronomical projects, and industrial processes. Most recently, EPICS has been successfully deployed at the Diamond Light Source, the Spallation Neutron Source at ORNL, and the Australian Synchrotron Project. It is being used for the LINAC Coherent Light Source at SLAC, the Shanghai Light Source, and the multi-faceted accelerator facility JPARC at Jaeri.

The use of EPICS on a diverse range of projects means that there is a large base of drivers and hardware support already available. The existence of these makes interfacing of the underlying systems less dependent on software development.

The EPICS tool kit is supported through the collaboration with software distribution and documented through the web. There are EPICS training courses run each year by many groups in the collaboration, and there are two EPICS workshops rotating through the U.S., Europe, and Asia each year; a number of individuals and companies are also available to provide support and training.

9.4.1 Structure of an EPICS Control System

EPICS embodies the standard client server model for a distributed control system, and shown in Figure 9.4.1. The user consoles are one class of client that receives and processes information. The servers are the source of information and in the general case, the interface to the equipment being controlled. The clients and servers are physically connected using network technology and they communicate with the EPICS protocol Channel Access.

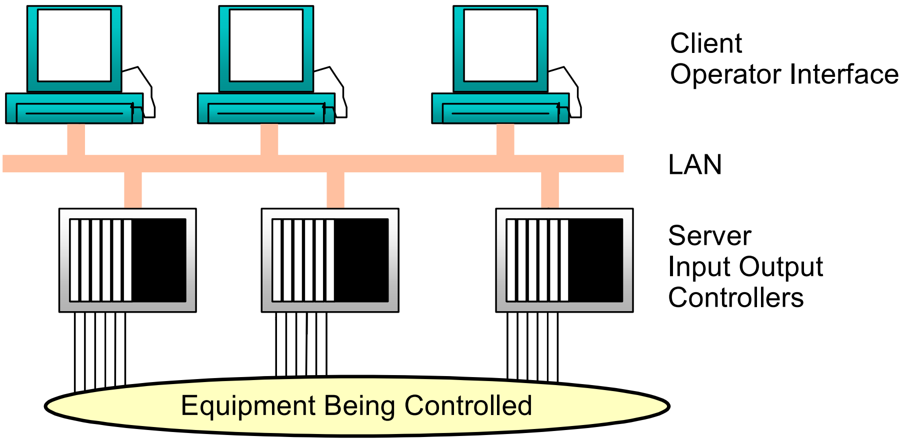

Figure 9.4.1 EPICS model.

9.4.2 EPICS Servers

The physical realization of EPICS servers is typically as multiple embedded VME systems, which are called IOCs, Figure 9.4.2. IOCs interface to the equipment being controlled, for which EPICS supports a large range of physical interface standards, protocols, and devices. IOCs also support the use of an event timing signal, to time-stamp transactions and enable synchronous acquisition or control across multiple IOCs.

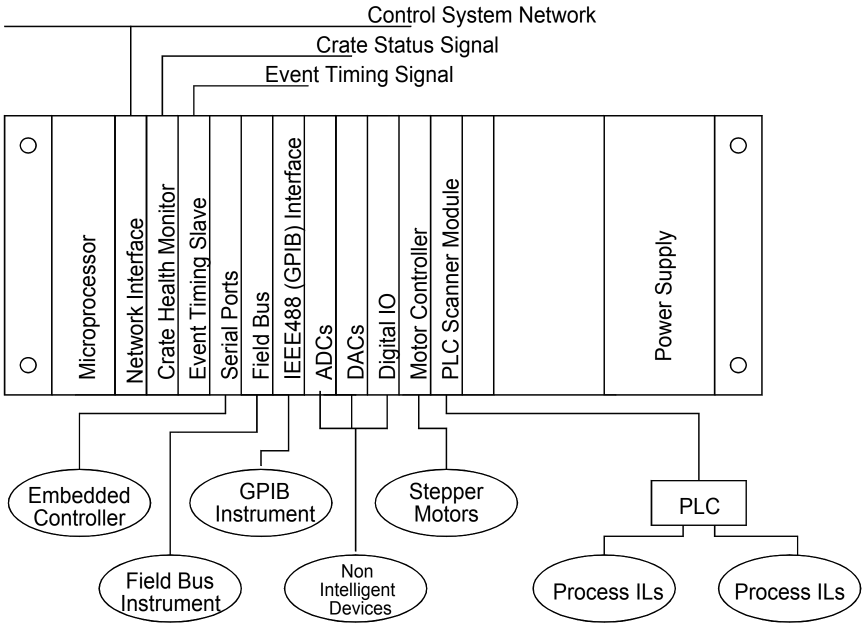

Figure 9.4.2 Example EPICS IOC.

9.4.3 Server Side Processing

Within the IOC, the CA server communicates with the Process Database, which uses the Record Support, Device Support, and Driver Support layers to interface to the plant, Figure 9.4.3. The communication from the EPICS client, over CA to the database, can be by synchronous call and reply or by the client establishing a monitor whereby the server asynchronously serves the data. The update of monitors can be on a periodic basis, on change of data, or on external event.

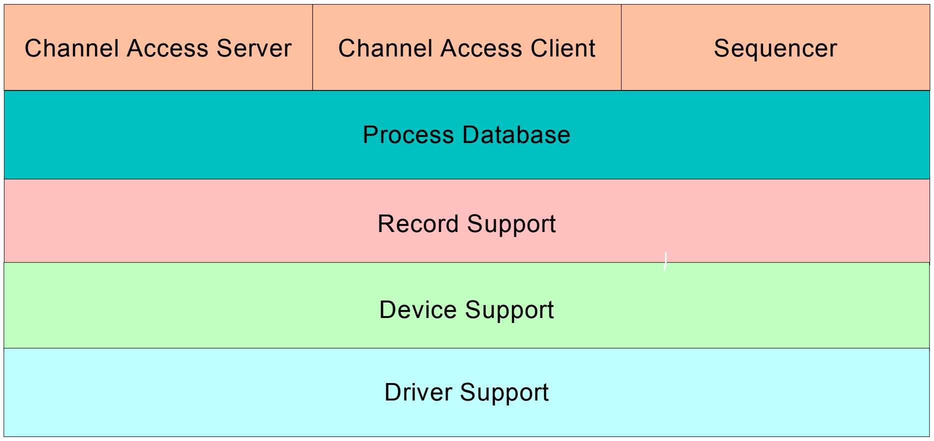

Figure 9.4.3 EPICS IOC data model.

The process database is a memory resident database that defines the functionality of the IOC. The database uses the Record Support layer to perform the processing necessary to access IO, perform data conversion, check alarms, and update monitors. The IO operations are carried out through the Device Support layer, which handles equipment specific protocols, and through the Driver Support layer, for the hardware interfaces. The structure provides support for interfacing to embedded controllers, field buses, IEEE488 (GPIB), DACs, ADCs, Digital IO, stepper motors, PLCs, power supplies, and a range of instrumentation.

Within the Input/Output Controller there is also a CA client to facilitate IOC-to-IOC communication. This is realized by linking process information from one process database to a process database on another IOC.

An IOC also contains a Sequencer to perform Finite State Machine control on the process database. The sequencer logic is defined as SNL, which is compiled to C code, then to an executable to run on the IOC. This allows for easy production on complex sequences, such as switching through the steps in bringing on a piece of equipment.

A standalone version of the CA server is available, which can be integrated into other systems without the process database and support layers. This facilitates integration of self-contained systems into EPICS, one example being the integration of LabView systems.

9.4.4 EPICS Clients

The client side of EPICS is realized on either Unix workstations or PCs running Windows and is called the OPerator Interface (OPI).

In the standard EPICS model, the OPI application programs interfaced directly to the CA client. This has limitations in that it only provides access to the dynamic control data through the CA API and so limits seamless integration of data from other sources, e.g., a RDB. The EPICS toolkit provides a suite of applications for the OPI. Among the choices for the core tools are: a synoptic user interface for control and monitoring (EDM), an Alarm Handler, an Archiver for recording and retrieving the historical state of the control system, a backup and restore facility to take snapshots of parameter settings, a knob manager to provide attachment of physical knobs to parameters and a parameter plotting tool. There is support within EPICS for the scripting languages Jython, Matlab, Tcl/Tk, Perl, and LabView. Data can be further served up to web pages through a CGI server.

9.4.5 EPICS Development Environment

The functionality of a control system built with EPICS is defined in three places: the Operator Interface, the Process Database, and the Sequencer logic. EPICS provides a number of tools to develop each of these which do not require software development. The OPI applications can be produced by a number of interface-generating tools, one of which is EDM. These tools allow for control objects to be placed on pages and animated with a connection to the control parameters. There are both text and graphical tools to produce the Process Database, which involves selecting records and drivers, and linking them to process data and alarms. The Sequencer logic is produced from SNL, which can be defined as text or, more recently, in a graphical form.

9.4.5.1 Distributed Development

Each developer will work on either a Linux PC or a Windows PC. These will be networked to a development file server providing read-access to all the necessary development tools and applications (VxWorks, RTEMS, Matlab, XAL EPICS base and extensions, configuration and database files, etc.), see Figure 9.4.4.

Modifications will only be made to local copies of applications, which will then be checked in to a branch of the CVS repository to enable any changes to be backtracked. When the application has been fully tested and is stable, this branch will become the main development branch for the control system.

A central boot server will be used to provide all the necessary files required by the local IOCs for booting. These files will be generated from the CVS repository. This will ensure that all IOCs are running a consistent and stable version of the control system. The contents of the central boot server will be mirrored on boot servers located in the control room, which will provide local booting of the IOCs.

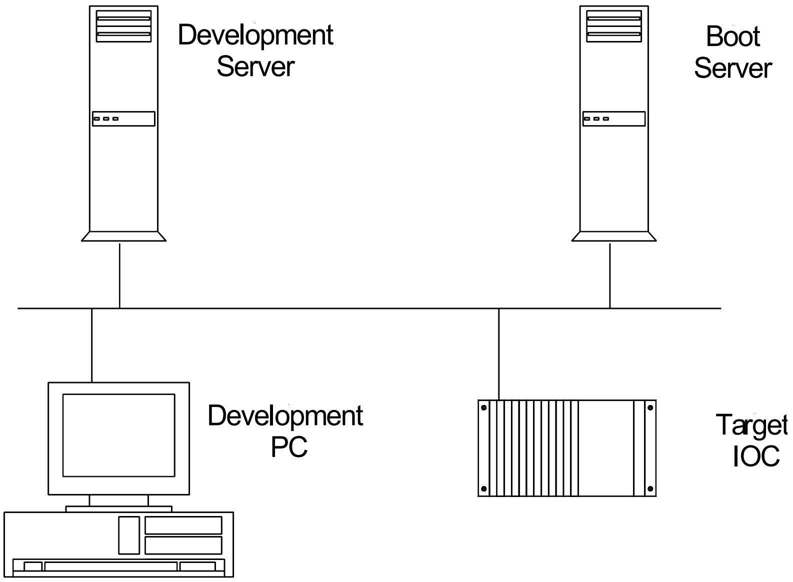

Figure 9.4.4 Distributed development structure.

File Management with CVS

CVS [9.5] is a version control system for keeping track of all modifications to project source code files. CVS is widely used in both open source and proprietary software development projects, and is generally considered to be the best freely available, full-featured version control tool. Two features make CVS particularly suited to collaborative development across any network, including the Internet:

- Multiple developers can edit their own working copies of files simultaneously. CVS then deals with combining all the changes and notifying developers when there are conflicts.
- Developers have remote access to source code file repositories. Project members can obtain and modify project files from virtually anywhere.

CVS is a client-server system. The CVS repository is maintained on a server; clients run on users' machines and connect to the server via the network (or Internet). Clients are available for nearly all platforms, including Unix, Windows, Macintosh, and any Java-based platform. CVS allows project members to:

- Check out source files and directories
- View differences between versions of files
- View change log history and comments
- Commit changes made in their local copies of the source files to the main source code repository
- Update their local project files when they want to remain in sync with changes committed by other project members

CVS has proven very beneficial to many other accelerator projects in the world, and there is a very large CVS knowledge base within the EPICS community.

9.4.5.2 Application Development

Most application requirements can be met through the standard tools discussed in this section. Where more intelligence is required at the application level, there are EPICS interfaces to all the popular programming languages. The preferred solution will be to use C/C++, Java, or scripting languages to minimize the number of supported languages.

C/C++. C, and C++ are high-level programming languages that have become the de facto standard for portable open systems solutions on Unix/Linux platforms, with C++ usage increasing due to the popularity of Object-Oriented design and programming. Both languages have been widely used both for the EPICS baseline product and for driver software and other applications built on top of the baseline. For the NSLS-II Control System, the emphasis will be on re-use of existing software. Improvements are expected to meet NSLS-II requirements.

Tcl/Tk, Python/Jython. Tcl and Python are widely-used open-source scripting languages. They have simple and programmable syntax and can be either used as a standalone application or embedded in application programs. Tk and Python are Graphical User Interface toolkits that can be used for rapid development of powerful GUIs. Tcl/Tk and Python are highly portable, running on essentially all flavors of Unix (Linux Solaris, IRIX, AIX, *BSD*, etc.), Windows, Macintosh, and more. Tcl/Tk and Python are well supported and extensively used on many EPICS-based projects, particularly for GUI development.

Java. Java is an object-oriented interpretative programming language with a built-in Application Programming Interface that can handle graphics and user interfaces. Java can be used to create standalone applications. However, a more important use is in the development of applets, programs that can be embedded in a Web page. The growth of the Internet, together with Java's hardware independence, has made the language essential for web-based developments.

Currently, Java performance issues mean its usage will only be considered for applications where response time is unimportant. Generally, though, Java solutions providers are seeking to improve performance with developments such as just-in-time compilers and Java processors. If these developments yield effective performance improvements during the development phase of the NSLS-II project, then Java's importance to the project will increase.

9.4.5.3 Server Development

Development of EPICS at the server level is required potentially in three places, namely record and device support, database, and state notation language.

9.4.5.4 Record and Device Support

While there is extensive record and device support available for EPICS, addition of unsupported hardware will necessitate the development of Device and possibly Record Support layers. The EPICS toolkit provides well-defined interfaces to each of these layers and examples to aid development. Device development is carried out in C within the standard EPICS development environment.

Building and developing EPICS requires either the VxWorks [9.6] or RTEMS development environment. VxWorks is currently only available for Windows or Solaris. However, given that the development environment is based on the GNU tool chain, it should be possible to run the RTEMS tools on Linux. The preference will be to standardize on one operating system for development, preferably Linux.

Database Configuration Tools

There are several Database Configuration Tools available. These DCTs allow designers to create EPICS databases by implementing them visually with a “block diagram and link wire” approach, similar to that used in electronic schematic design packages.

NSLS-II will use VisualDCT [9.7] as its database configuration tool. VisualDCT is an EPICS database configuration tool written in Java. It can therefore run under any operating system that supports a Java Runtime Environment. It was developed to provide features missing in existing configuration tools and to make databases easier to understand and implement.

The database development cycle will involve importing the EPICS runtime database into the central relational database to have a single repository of all control system information. VisualDCT has a powerful database parser, which allows existing DB and DBD files to be imported with ease. The parser detects syntax errors in databases, as well as defective visual composition data or its absence. Faults in DB files are safely handled and do not raise any critical errors. VisualDCT automatically lays out all objects that have no visual composition data and saves all visual data as comments to maintain backward compatibility. The output from VisualDCT is also a DB file, with all comments and record order preserved.

Visual DCT has been written within the EPICS community specifically to support EPICS, and is available free to EPICS database developers. However, some development of VisualDCT required to add some missing functionality will need to be undertaken.

State Notation Language / Sequencer Tools

The sequencer is a tool within EPICS that allows the implementation and control of one or more state machines on the IOC. The state machines are created using EPICS SNL. SNL has a C-like syntax, with constructs for building state machines. Once the SNL source code has been written, a SNC pre-processes it into “C” code and then compiles it to create an object file which the sequencer runs in the IOC.

9.4.5.5 Client Tools and Middleware Data Servers

Client tools are available at level 2 of the control system architecture. Clients at this level can directly access all channels in the control system through the Channel Access protocol. These data are time stamped by the Event System for reconstruction of accurate time sequences or correlation of events. At this level, client tools can use data from the IOCs directly, use control system data along with accelerator equipment information for model-based physics applications, or provide computed or correlated data to other clients.

9.4.5.6 Console Applications

The EPICS software package offers comprehensive operator display applications, which include:

- Extensible Display Manager
- Channel Archiver and Archive Viewing Tools
- Strip Chart Tool (StripTool)
- Array Display Tool (ADT)
- Parameter Display Page (DP)
- Alarm Handler
- Knob Manager (KM)
- Operator Electronic Log (CMLOG)

These applications will be used to supply operator display facilities, which will include the following functions.

Operator Menu Bar

This will provide rapid single-click access to all key operator facilities.

Plant Synoptics

These full-screen plant schematic diagrams will provide operators with an at-a-glance indication of plant conditions. Each process value displayed on a synoptic will constitute a “hotspot”; clicking on a hotspot will produce a pull-down menu providing access to further information and control actions relevant to that process value. Typically, a text description of the signal, the units of measurement, alarm limits, maximum and minimum, trend, alarm history, wiring information, operator comment and web access to online help might be provided. By this means, plant synoptics will act as the launch platforms which allow operators to access a wide variety of data in a seamless manner.

Ease of navigation will be considered during the detailed design stage for plant synoptics. An overall Synoptic Menu will be provided, which lists all synoptics grouped by functional area, presenting a clear hierarchy. In addition, where appropriate, plant synoptics will contain links to other associated synoptics. The design aim will be that operators should be able to navigate around the hierarchy without the constant need to return to the Synoptic Menu. Plant synoptics will be designed to have a simple, uncluttered appearance so as not to present more information to the operator than can reasonably be taken in.

Control Panels

Usually sized smaller than full-screen, control panels will be available with a wide variety of control widgets (radio buttons, slider bars, data entry fields with data validity checking, etc.) to allow users to apply control actions to the plant.

Control panels can be configured such that a single slider bar is used to control simultaneously a number of control outputs. Mathematical functions are available to define how these combined control outputs operate in relation to one other.

User-Configurable Tabular Displays

Operators will be able to configure their own sets of tabular displays showing closely-related accelerator parameters. Facilities will be provided to save these user-configured displays with a user-chosen name, and to recall the display from a list presented in a pull-down menu.

System Status Indicators

These schematics will show the status of IOCs, operator monitors, printers, etc. They will also display the health of key applications—so that, for example, operators are made aware quickly if alarm processing stops due to an alarm server program crash.

Operator Comments Facility

This will allow operators to enter lines of text comment for any plant input—to record, for example, when an input is not reading correctly due to a known fault. The presence of an operator comment for a process variable will be clearly indicated on any synoptic which displays that process variable. Individual comments will be easily readable via a suitable control panel, and it will also be possible to collate lists of comments (e.g., all operator comments entered during a shift).

Signal Information Panel

Only a subset of the process variables will be displayed on plant synoptics. However, operators require rapid access to information about any process variable and the Signal Information Panel satisfies this requirement. The panel will provide a Search section and a Display section. The Search section will enable the user to carry out a name search on the relational database, using a name mask to search for either an EPICS database record name or an EPICS record descriptor. Clicking on one of the returned search results will enable the user to request further information (e.g., trend, alarm history, operator comment, etc.).

Message Logging

The CMLOG package available with EPICS will be used to provide a distributed message logging system. This package can be used by any application or system that needs to log messages to centralized log files and display distributed messages to users. The CMLOG package supports C++, C, and CDEV application interfaces for logging messages and has C++ application interfaces for searching/retrieving messages from a dedicated logging server. Applications may send a selection rule to the server to select a subset of log messages for viewing; these rules can be in a form similar to C logic syntax or in a form similar to SQL.

A sample Message Log Browser (an X-Windows Motif application) is included with the CMLOG package. An additional browser will be developed using the supplied application interfaces once detailed requirements are established during the detailed design phase of the project.

9.4.5.7 Alarm Handling

The EPICS Alarm Handler package will be used to provide the following facilities:

An alarm list allows the users to view and manipulate current plant alarms. The alarm list will incorporate the following facilities:

- Indication of alarm acknowledgement state.
- Alarm message which includes EPICS record name, descriptive text, alarm value and date/time of alarm generation.
- Removal of acknowledged alarms from the Alarm List when they are no longer in the alarm state.
- Access to a menu-based set of facilities from each alarm in the Alarm list. The menu would give access to further information about the alarmed signal, including:
    - Trend
    - Alarm history
    - Access to a synoptic which includes the alarmed signal.

- Web access (e.g., a link to a text page with more details about the alarm condition and possible corrective action)
- Operator-selectable alarm inhibition to prevent use of the Alarm List from being disrupted by non-genuine alarms (e.g. "flickering" alarms being generated by a faulty switch). The names and descriptions of inhibited signals will be viewable on a separate list, from where it will be possible to de-inhibit each signal.
- Association of each alarm with a plant area, along with the ability to display only alarms for a particular plant area.
- Color indication of alarm severity.

All alarm messages will be logged to a text file for interrogation and archiving purposes. An alarm log viewer will be available, with various filtering options such as date/time, alarm severity, input name, etc. Provision will be made for audible alarm tones, driven from software using wav files. A separate alarm tone will be available for each alarm severity. An alarm banner window will be available to display a configurable number of recent alarms in a dedicated window at the top or bottom of the screen. Alarms can be acknowledged via the banner without having to call up the main Alarm List.

9.4.5.8 Archiving

The EPICS software toolkit offers comprehensive short, medium, and long-term data collection, archiving and retrieval through the EPICS Channel Archiver package. This package will be used to provide the following facilities. For long-term archiving, the archiver provides support for:

- Data retrievable in tabular and trend form
- A data quality indicator associated with each item of data
- Data compression to minimize the size of archive files
- Dumping of data to removable storage media, for long-term storage
- Loading of archive data from removable storage media for data analysis
- Timely warning to operators when archive data collection is compromised by a "disk full" condition on the archive server
- Variable data collection intervals for archiving
- A mechanism for easily configuring large numbers of process variables for archiving (e.g., by use of name masks)
- Facilities for collecting data in user-definable data sets, where data sets can include files as well as process variable data

The Historical Data Collection provides for short- to medium-term data collection offering the following features:

- Data retrievable in tabular form and trend form
- Data quality indicator associated with all data
- Variable data collection intervals
- Mathematical functions (e.g., averaging, MIN-MAX, etc.) applicable to historical data

A wide variety of data retrieval and data management tools are available with the standard Channel Archiver package, including:

- Retrieval via scripting tools, provided by the Channel Archiver Scripting Interface. Tcl, Python or Perl can be used to develop automation of archive handling.
- Retrieval via native tools, with Xarr/Striptool for UNIX-based systems and WinBrowser for Win32 systems. WinBrowser also provides data export in spreadsheet format or in a format suitable for the Matlab data analysis and modeling package.
- Retrieval via a web server plug-in, offered by the CGIExport client, which allows users to browse the archive via any web browser. File download in spreadsheet or Matlab format is supported by this plug-in.

- Command-line tools provided by the ArchiveExport/ArchiveManager component, providing commands to manage archives and to export data to a spreadsheet, to Matlab or to the GnuPlot plotting utility program.
- The Archive Engine component of the Channel Archiver package includes a built-in Web server. By using this feature, current operational parameters can be viewed and interactive configuration can be carried out via any Web browser.

9.4.5.9 Plotting

The StripTool program will be used for displaying trends of current and archived data. The key features of the StripTool program are:

- A StripTool chart displaying recent live data can be scrolled back to view archive data.
- Data acquisition via both Channel Access and CDEV, thereby allowing trending of both EPICS and non-EPICS data on the same axes.
- Ability to drag signals from synoptic diagram (drawn using MEDM) into a graph window.
- Flexible configuration options, including logarithmic and linear transformations, sampling rate, graph refresh rate, plot colors, grid lines, graph legend coloring, and plot line width. The trend can also be easily reconfigured to make one or more plot curves invisible without removing the plot configuration information for that curve.
- Trends can be printed and trend data saved to file.
- Trends are customizable via X resources, giving access to a wider set of configuration options than those offered by the standard StripTool configuration facilities.

9.4.5.10 Automatic Sequencing

For increased operational efficiency, and in support of a demanding accelerator availability requirement, the control system will include the capability of automatic sequencing, including decision making. These sequences could include automatic run-up procedures, automatic fault-recovery sequences, and automatic data-taking routines. The system will provide simple tools for defining sequences as experience is gained and will be capable of monitoring the status of automatic sequences, annunciating problems encountered in sequences, and intervening or overriding sequences if necessary.

9.4.5.11 Data Server

Computed data and aggregate data are to be done with consideration to overall performance metrics. Where it is reasonable, these data are to be created once in a server and provided to other clients in the control system. Examples of this are first turn data, ring current, and emittance measurements.

9.5 NSLS-II Control System Applications

In addition to the capabilities described above, existing toolkits will enable the following site-specific applications and interfaces to be developed for NSLS-II.

9.5.1 Physics Applications Rapid Prototyping

Rapid prototyping of physics applications is supported through a number of programming language interfaces to the Channel Access protocol. These include: analysis packages such as Matlab, Labview andMathmatica; scripting languages such as Jython, Pearl, Tcl/TK, and SWIG; and programming language interfaces such as: Java, C, and C++. Applications that are prototyped in this environment can be migrated into the standard EPICS front end controllers and the XAL environment for operations. (Figure 9.5.1).

9.5.2 Model-Based Physics Applications

Model-Based Physics applications must be available for all phases of commissioning. The system should be capable of operating in online and predictive modes. A RDB must contain the model parameters needed for the model based control. A physics modeling system will be needed to provide an interface between the control system and standard codes such as Tracy2, Elegant, or RING. These codes can mathematically model the behavior of various accelerator systems. They can be used to aid understanding of the machine, as well as being a vital tool for optimizing and operating a complex accelerator.

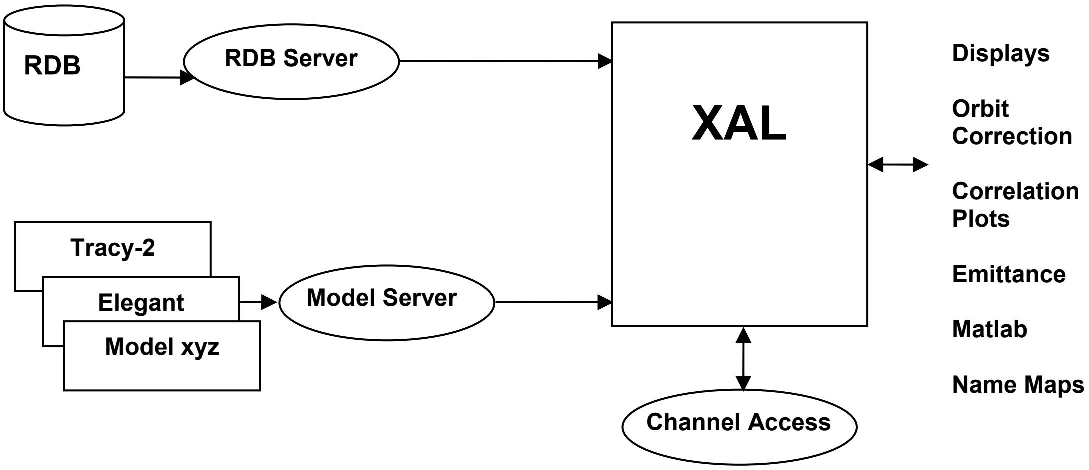

Figure 9.5.1 High-level application architecture.

XAL – the Model-Based Control Framework

NSLS-II will use a toolkit framework and applications developed in the framework, such as XAL, which is in use at SNS. NSLS-II will be able to leverage SNS developments for a faster start, but additional development will be necessary to tailor these approaches to NSLS-II.

Relational Database

ORACLE will be used as the main data store for all beamline component information that is needed for model-based control. Tools will be provided to enter this data, produce reports, and create files needed for run-time control.

Online Mode

Real-time magnet and RF data will be passed to the modeling system. Computed values of Twiss parameters, Q values, chromaticity, momentum compaction factor, etc. will be made available to the rest of the control system or to Accelerator Physics applications.

Predictive Mode

In this mode, offline magnet and RF values are supplied to the modeling system rather than real-time data. This will allow predictive and “look-and-see” experiments to be performed using the machine model to predict the behavior of the accelerator.

Middleware Data Servers

Middleware data servers will be provided to separate the data collection from the visualization layers. All client applications that collect data from the control system that result in the production of new data will be served to multiple, distributed clients. The distribution of this data is done over a standard protocol such as Corba. Alarm information, orbit, archive data, and emittance are some examples of data that may be produced by clients and served to other clients.

9.5.3 I/O Controllers / Equipment Interfaces

The I/O controllers and equipment interfaces must support the wide range of applications that are encountered in an accelerator control system. To minimize integration, training, and maintenance costs, this hardware should be limited to a solution that can meet each class of hardware integration needed. The front-end computers will run a Real-Time Operating System. The RTOS candidates are vxWorks and RTEMS. Although vxWorks runs on a wide variety of CPUs and provides much functionality, it does not provide source code without a prohibitive investment. RTEMS is an open-source RTOS that requires more man-power to wield. Several EPICS sites now support RTEMS. Control at this level of the architecture can be done at the rate of 1 kHz with latencies of 33 µsec. Dedicated data and timing buses are required to achieve this level of performance over distributed controllers.

High-Speed Signals

High-speed signals such as RF, image diagnostics, and beam position signals may be processed with an FPGA to produce results that are used by the control system at a slower rate. These devices may operate on data into the MHz range and be used to analyze high-speed signals from LLRF, Beam Position Monitors, and Power Supply Controllers. These may be implanted as single device controllers that are equipped with dedicated processors to run EPICS and provide the interface to the control system, an FPGA to process the signal, a high-speed interface between the FPGA and the control system, and an interface to the timing system. These device controllers may control a single device or a set of devices. A standard architecture that includes a Power PC with a PCI or PCI interface in the Coldfire format is a candidate for this application.

Low Latency Response I/O

I/O that requires the control system to respond in the minimum time (known as high-density I/O) requires an instrumentation bus that provides interrupts on an external trigger and reasonable data transfer times between I/O boards. This can be implemented using either VME or PCI.

High-Reliability IO

Applications such as vacuum interlocks, flow switch interlocks, and cryogenic control require high reliability control of simple processes. A Programmable Logic Controller will be provided for these applications. All data from the PLC shall be available through the control system. The Control Logix PLC in conjunction with the Flex-I/O line could provide this function at a reasonable price. In any case, one PLC family will be chosen as the NSLS-II standard. These PLCs will be integrated into the control system through an IOC.

9.5.4 Global Control System

9.5.4.1 Buses

The control system must provide some global communication that requires higher performance than is available in a commercial network. NSLS-II requires: an Event System for synchronizing data acquisition and control; a high-speed data network for providing beam-steering data to all ring power supplies for orbit correction; and a Machine Protection System that is a fast-response bus provided for mitigation against failures that greatly impact the operation of the facility by either producing excessive radiation or causing equipment damage. We will evaluate the systems available from other laboratories and select one that meets our requirements.

9.5.4.2 Event System

The Event System, also referred to as a timing system, provides all beam and RF synchronization for all control and data acquisition. The event system provides a master pattern of events that reflect the operation mode of the machine. It provides the synchronization needed to control the beam injection into the ring for initial fill and top-off. The event system may also communicate data that are required for operation and data correlation, as well as data communicated to the subsystems that change with the mode of the machine. Examples include time stamp/pulse ID, machine mode, and global machine status.

The timing system is required to provide control of the beam transfer from the electron source to the storage ring and provide diagnostic equipment and beamline equipment with synchronization signals. The most recent light sources [8] have made use of commercial equipment and built on equipment designed by other light sources, often in collaboration with industry; it is envisaged that the same approach will be adopted for NSLS-II.

Fast Timing

The task of a timing system is to synchronize all the relevant components in an accelerator complex. One part of this task is to control the injection by triggering the particle source and firing the transfer line components, such as injection- and extraction-pulsed magnets, at the correct times. Also, beam diagnostic components such as beam position monitors and current transformers must be synchronized to the passage of the beam. This has to happen with fine time resolution, to RF frequency, clock precision, and low jitter, and is termed Fast Timing.

Event System Signals

Other tasks for the timing system are related to synchronizing components where the resolution is more relaxed. Examples include triggering the magnets for an acceleration ramp, triggering operational sequences such as the filling of the storage ring, BPM acquisition, feedback timing, insertion device control, and supplying the distributed control system with time synchronization for control and correlation of data. The time resolution for these tasks is less demanding; these tasks are often termed Events. Event Signals will be produced with a precision set by the storage ring revolution period and with predictable jitter.

Timing System Components

In designing the accelerator timing system, it is important to consider what has been used at other recently constructed sources and the integration into the EPICS control system. The time-stamp system already exists within the EPICS infrastructure and can be used in conjunction with the Event System, which was developed at APS [9] and enhanced by SLS and, more recently, DIAMOND. The APS/SLS Event System can be used to meet all slow timing requirements. The Event System is fully EPICS compatible and the required VME modules are available.

Table 9.5.1 Diamond Version of the SLS Version of the APS Event System Specification.

Events	8-bit code – 255 events
Resolution	8 ns
Event TX trigger	Hardware input, software, Event Ram Clock.
Event RX output	Hardware output, software (EPICS record process)
Transmission medium	Gigabit Ethernet

The requirements for fast timing are more specific to a particular accelerator dimensions and operation. Two options are available for the hardware for fast timing, the KEK TD4V as a VME module delay generator and the Stanford Research DG535 as a self-contained instrument. Each is available with EPICS drivers to provide the controlled delays.

Table 9.5.2 Fast Timing Hardware Options.

	KEK TD4V	Stanford Research DG535
Form	VME 6U	Bench / Rack mounting
Delay	16 Bit / RF clock	0 to 1000 s – 5 ps steps
EPICS Support	Yes	Yes, via GPIB
Channels	1	4
Jitter	4.5 ps at 508 MHz	<60 ps

System Structure

Figure 9.5.2 gives an overview of the Event System and Fast Timing control. The Event Generator receives a start signal from the RF clock gated with a line frequency component. Events are then sent to all IOC Event Receivers for timestamp synchronization and to output relevant event signals or process EPICS records. The fast-timing IOCs will require a fast clock and trigger derived from the RF source, but fast sequences can also be initiated upon receipt of an event.

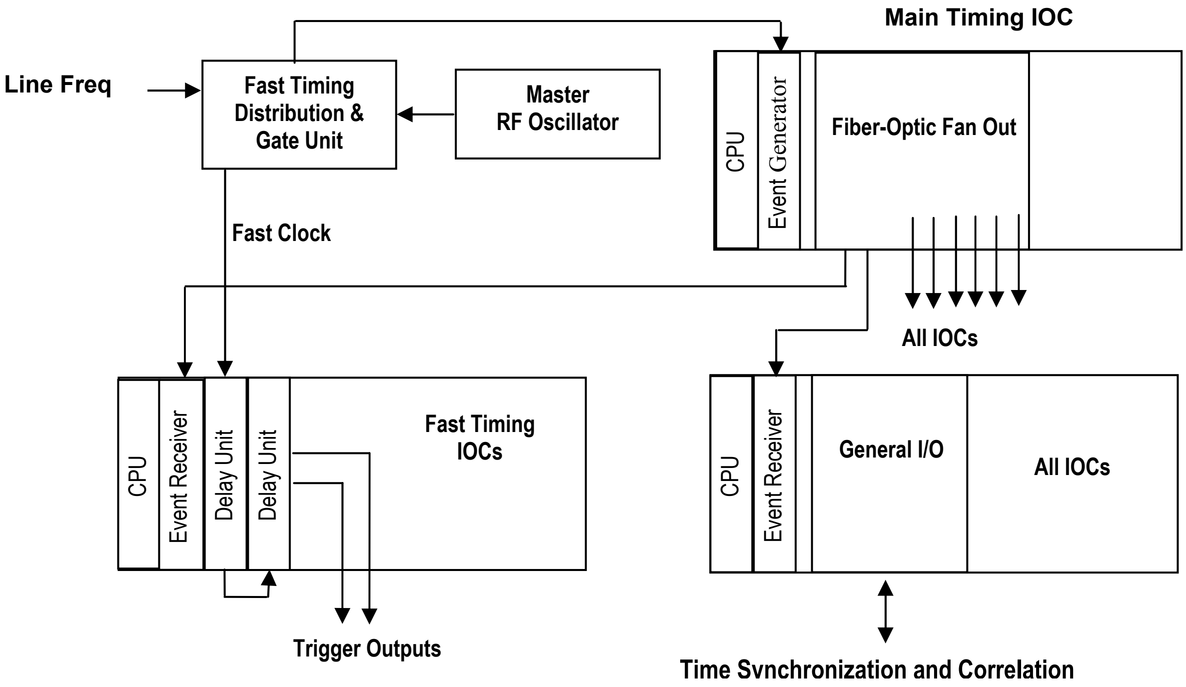

Figure 9.5.2 Block diagram of the Event System and Fast Timing.

Signal Distribution

The Fast Timing and Event signals will be distributed over fiber-optic cable for reasons of noise immunity and distance capabilities. Further investigation is needed into the delay drifts that could be introduced by the fiber installation from temperature differentials and the standardization of length-induced delays in a facility the size of NSLS-II.

Fast Feedback

A beam position stabilizing system is required to maintain orbit stability to within 10% of beam dimension and to provide dynamic correction of low-frequency orbit disturbances. The proposals presented here are very much based on the work on Diamond, APS [9.10], ALS [9.11], and SLS [9.12].

9.5.4.3 Global Feedback

The feedback system will use measurements of the position of the electron beam in the storage ring and the photon beams in the beamline front-ends. This information will be compared against a reference orbit and the error used to calculate desired corrections to be applied to corrector magnets in the storage ring.

The response matrix relates the effect of small changes in corrector magnet fields to the resulting changes in the particle beam orbit as measured at chosen BPMs. By inverting the response matrix the relationship that maps orbit perturbations to changes in corrector magnet fields is obtained. For small orbit errors, this relationship is assumed to be linear and time-invariant. Different objectives, such as correcting the orbit in an rms sense or correcting specific locations, can be achieved by choice of BPM and corrector locations and by applying different weights to correctors or BPMs when computing the inverse response matrix.

Performance

Two global feedback systems, operating in parallel, are proposed to correct orbit errors on NSLS-II, namely a Slow system, correcting DC drift, and a Fast system, correcting beam disturbances to 100 Hz. These systems will use data from both the electron and photon BPMs and operate on either or both of the steering magnet or fast correctors. For both systems, the BPMs need to be sampled synchronously, which will be achieved using Events distributed to the IOCs.

Table 9.5.3 Feedback System Comparisons.

	Correcting Feedback	Update Rate Feedback
Slow	DC drift	0.1 Hz
Fast	0.2 mHz –100 Hz	2 KHz

Slow Correction

The Slow correction will correct the orbit at 10 second intervals, using the desired correctors and BPMs to compensate for slow changes in the orbit. This will maintain the user-steered orbit applied at the beginning of each fill. Communication to the BPM and Steering IOCs will use the EPICS CA communication mechanism. The slow correction will be realized as a dedicated application running on either a console or a computer server.

Fast Correction

Fast correction is not possible through EPICS CA mechanisms because of insufficient bandwidth. It will be realized at the IOC level on separate feedback processor boards dedicated to this function. This involves partitioning the correction calculation across the 30 Steering IOCs to calculate the correction values for the steering elements local to that IOC. Each steering IOC requires access to all the BPM values, to give flexibility in the correction algorithm. This requires a high speed connection to share data between the 30 BPM IOCs and 30 Steering IOCs. Two potential solutions for this are to use either reflective memory or network broadcasts.

EPICS process variables will be used to control the feedback process, by downloading algorithms to the feedback processors and setting coefficients and update rates.

9.5.5 Reflective Memory

Reflective memory is an off-the-shelf solution to distribute information across multiple computer systems without requiring processor time. It enables BPM data to be written to the reflective memory module in each of the BPM IOCs and appear in memory in all the Steering IOCs. In the system shown in Figure 9.5.3, an event received by all BPM IOCs would cause the photon and electron BPM values to be read by the feedback processor and written to the reflective memory board for each of the 30 IOCs. The data would propagate to all the steering IOCs and when all values are received, the feedback calculation would be carried out on the Steering IOC to produce the new steering settings. These values would then be written to the steering elements in conjunction with the slow system values received through EPICS process variables.

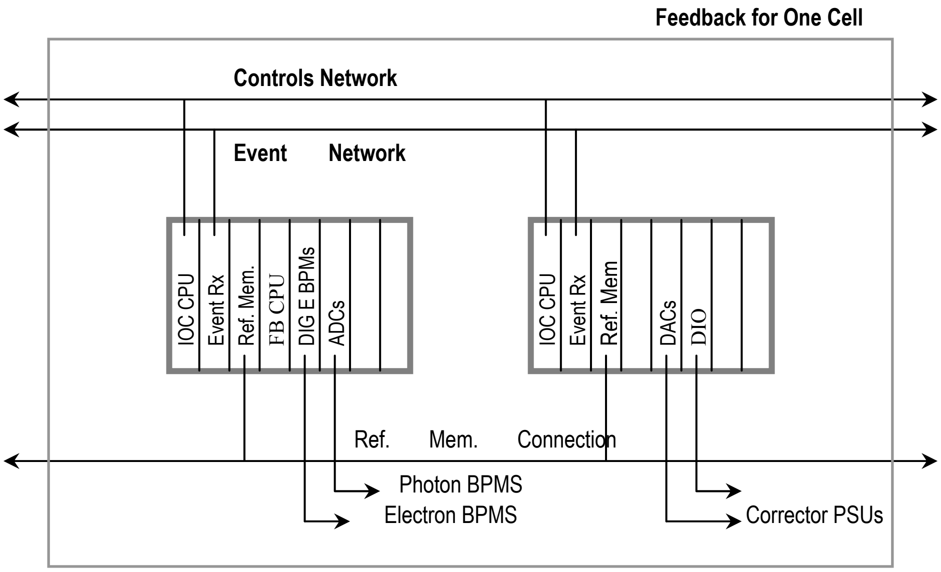

Figure 9.5.3 Reflective memory structure for one cell.

Commercially available reflective memory sizes and update rates provide for moving multi-megabytes per second across tens of boards, and so should easily meet the requirements of this application.

Network Broadcast

In the Network Broadcast system each of 60 feedback processors in the BPM and Steering IOCs is connected to a private network with a central switch in a star configuration. The feedback processor in each of the BPM IOCs reads the BPM values and broadcasts them over the network to be received by each steering IOC. The broadcasts take place simultaneously but do not collide, because the switch buffers each packet as it receives it. The switch then forwards the packets to all the Steering IOCs.

In the system shown in Figure 9.5.4, an event received by all BPM IOCs would cause the photon and electron BPM values to be read by the feedback processor and broadcast over the private network. When each of the 30 broadcasts has been received by all of the Steering IOCs, the calculation would be carried out on each Steering IOC to produce the new steering settings. These values are then written to the steering elements in conjunction with the slow system values received through EPICS process variables.

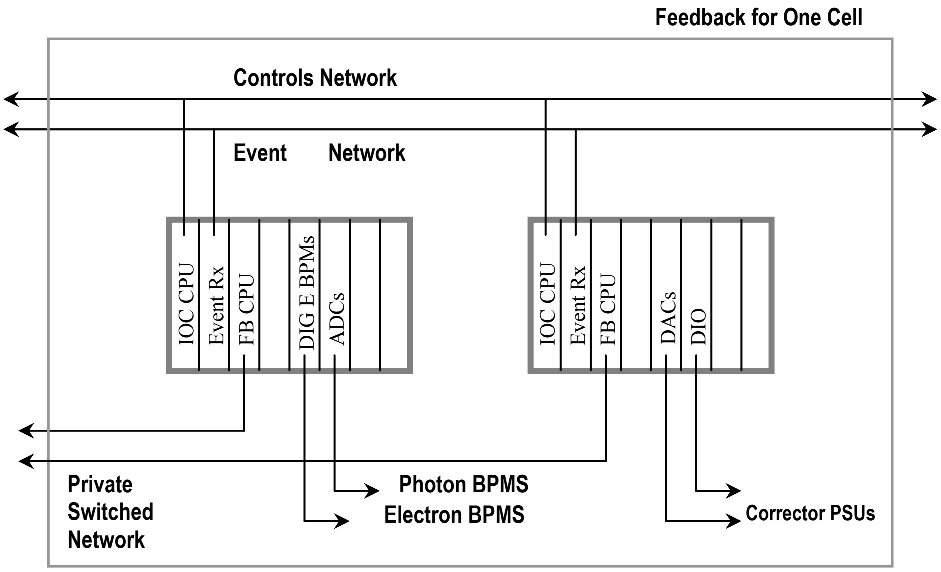

Figure 9.5.4 Network broadcast structure for one cell.

This option is cheaper in terms of hardware because it alleviates the need for the reflective memory boards, but incurs a development overhead to produce software for the broadcasting. The performance achievable using broadcasts also needs to be determined, to establish whether it would meet the requirements of this application.

Feedback Processor

On the Steering IOC, the calculation to produce the new steering values from BPM values and the inverse response matrix needs to be carried out. The time available to carry out this calculation is dependent on the desired update rate, the time to acquire and distribute the data, and the time for the correction to propagate through the steering power supply, magnet and vessel to the beam. While the current generation of PPC processors offers similar performance as DSP processors, in terms of operations per second, they do not have the architectural feature of DSP processors for signal processing intensive calculations. However, the performance available from current PPC makes them suitable to carry out the feedback calculations at a price advantage over DSP processors.

9.5.6 Machine Protection

The control system must monitor beam envelope and other operational parameters that determine if the beam is threatening to damage equipment. Detection and reaction to dangerous conditions must be completed within 3 msec.

9.6 Equipment Protection System

The beamlines at NSLS-II are expected to handle x-ray beams with very high power and power densities. Therefore, care must be taken to design the beamline with components that can handle these power loads. Any component that has to handle these high levels of power has to be monitored. The beamline Equipment Protection System provides a means of monitoring the components which, when jeopardized, can cause component failure. The EPS has the responsibility to act on alarm conditions by mitigating the situation that has caused the alarms.

9.6.1 Functionality

Every beamline EPS will monitor and interlock the devices in the front end and the beamline.

All front ends at NSLS-II are expected to have two safety shutters, one photon shutter, and a few masks (see Section 7.4). In addition, the front end will also have vacuum inline valves to provide vacuum isolation. The front end is also expected to have a fast valve to provide a conductance limitation during a vacuum accident. Most beamlines will also have an x-ray exit window as part of the front end. These x-ray windows will provide a vacuum isolation but will transmit the x-ray beam. Certain beamlines, such as the soft x-ray beamlines, are expected to share the storage ring vacuum with the front end providing the interface. In such cases, the fast valve, along with the rest of the inline vacuum valves, provides the isolation needed in case of accidents.

Due to the large power loads, all components in the front end that intercept the beam will have water cooling. These components are typically the fixed mask, photon shutter, and exit windows. The water flow will be monitored by flow meters and the signals will be fed to the EPS. All vacuum valves will be pneumatically operated. All vacuum valves will be operated by the EPS and have their positions monitored (see Sections 7.3.6.4 and 7.4.3.4).

Most beamlines are expected to have some beam conditioning optics upstream of their monochromator. The beam conditioning optics will see the large power of the beam and as such will be interlocked by the EPS. Beamlines are also expected to have vacuum valves, which will also be controlled by the EPS.

It is expected that the beamline portion of the EPS system will be customized to suit the condition of the specific beamlines.

9.6.2 Design Specification

The design of the EPS is expected to be robust. The system will be based on programmable logic controllers. The hardware used will be the same as used in the beamline Personnel Protection System (Section 9.7) and the Accelerator Personnel Protection System (Section 9.8). PLCs provide excellent customization capability and also extensive diagnostics.

The sole function of the EPS is to provide protection from damage of equipment due to synchrotron radiation. As such, the EPS will consist of only one PLC per beamline. Each beamline will have its own EPS system. The EPS system will consist of three parts – front-end EPS, beamline-specific EPS, and command/control of PPS components such as shutters and station doors. The front-end portion of the EPS is expected to be similar on most beamlines, while the beamline portion of the EPS will be customized to each beamline. Similarly, for the command/control of PPS components, the front-end shutters will be identical in all beamlines; however, additional shutters on the beamline will be beamline specific.

All front-end components that intercept the synchrotron beam will have water cooling of the components. The water flow of the components will be monitored by the EPS via flow meters. The EPS will be in alarm state if the flow drops below a specified setpoint. Depending on the location of the component it monitors, it will command the photon shutter to close and for cases where the flow is upstream of the photon shutter it will request the stored beam to be dumped.

All vacuum valves in the front end will also be controlled by the EPS (see Sections 7.3.6.4 and 7.4.3.4). Setpoints from vacuum controllers will be provided to the EPS, which will be used to determine when it is permissible to allow opening of the valves. The EPS will determine when it is necessary to close a valve, and will do so if it senses a vacuum alarm based on the vacuum setpoint to the system.

For specific beamlines, the EPS will be customized based on the user requirements for that beamline. Besides monitoring the water flow and controlling the vacuum valves, the EPS system may be used on beamlines to monitor other variables such as temperature, position, and so forth.

The EPS system will be used to control the actuation of the shutters. The EPS will monitor the status of the PPS for each shutter and, when a permit is available, it will accept requests to open the shutters. The EPS system will be responsible for sequencing the shutters in cases that involve a combination of photon shutters and safety shutters. All station doors that are automated will also be operated by the EPS.

9.6.3 Interface

The EPS system will have human Interfaces (HMI) located at the main location of the hardware, which is expected to be located directly above the front end on top of the storage ring tunnel. In addition, there will be a minimum of one HMI per beamline at the beamline stations.

The EPS provides the command and control functionality for the beamline PPS. It receives the status information of the PPS and, based on that, can operate the shutters. The PPS, in addition, can request the shutter to close and the EPS system will then command the shutter to close. In the event the shutter does not close within a specified time, as determined by the PPS, the PPS will initiate an emergency shutdown (ESD) situation.

The EPS also interfaces with the Accelerator Equipment Protection System. When the EPS detects a fault condition it signals the Machine Protection System to remove the stored beam. Example fault conditions include front-end water flow issues and vacuum issues. To protect the front-end components, the EPS will request that the MPS drop the beam. In some rare instances, problems in the beamline water cooling of components or beamline vacuum issues could also make the EPS request that the MPS dump the stored beam. The EPS provides only equipment protection and as such it does not interface to the APPS.

The EPS system will have an EPICS interface to the control system. The EPICS interface will provide both the main control room and the beamlines a complete overview of the status of each beamline. The data from the EPICS interface will also be logged and archived by the central computing systems.

The EPICS interface to the EPS will be both read and write. The write functionality will be controlled by the EPICS Channel Access Security. This is essential to isolate the possibility of accidental control of the wrong beamline EPS via the control system.

9.7 Personnel Protection System

NSLS-II will produce intense light from IR, UV, and hard x-rays. Beamlines are designed to use either the bending magnet radiation or the radiation from insertion devices located in the straight sections of the storage ring. Beamlines may have more than one station along the beamline for every port. These stations are expected to work in parallel or sequentially.

The Personnel Protection System is an engineered system that provides a means to ensure that personnel are not exposed to the radiation in the beamline. At NSLS-II, the role of the PPS is specifically to protect personnel from prompt radiation that is present only when there are stored electrons in the storage ring. The PPS is an engineered interlock system and is expected to monitor the various devices installed in the beamline for personnel safety and to provide emergency shutdown in case of breach of the interlock.

The PPS system, along with the required shielding in the beamlines, is expected to provide personnel safety during routine operation of the facility.

9.7.1 Functionality

Beamlines will consist of stations where synchrotron radiation is expected to be admitted. The beamline stations are expected to be made of lead-lined walls and roof, as appropriate for the particular radiation characteristics. These stations will house beamline optical components or beamline experimental equipment. The stations are expected to be large enough for personnel to work with the equipment inside.

The beamlines will have one or more shutters based on the particular layout, which is expected to vary from beamline to beamline. However, the functionality of the shutters, from the Personnel Protection System perspective, is expected to be the same and they will be monitored by the PPS. All x-ray beamlines will have shutters in the front-end area inside the storage ring shield wall (see Section 7.4). The bremsstrahlung radiation emitted by the synchrotron can only be stopped by heavy metal elements such as tungsten or lead. The heavy metal device that stops the bremsstrahlung radiation is referred to as the safety shutter. For the sake of safety, the shutter is expected to be redundant. The synchrotron beam, consisting of very high total power and power density, will be stopped by a device that is water cooled, made of copper or alloys of copper, and referred to as the photon shutter. These three devices, the two safety shutters and the photon shutter, will form a shutter cluster and their positions are monitored by the PPS.

Along the beamline are beamline optical elements that will condition the beam, including, for example, monochromators and mirrors. These devices change the characteristics of the synchrotron radiation. The radiation passing through the monochromator will, in most cases, be displaced in either the vertical plane or the horizontal plane from the incident radiation and only a small fraction of the incident radiation with a band pass (of about 0.1% or less) will be passed, with little or no power. In such cases the shutters, located downstream of the monochromator, will be called monochromatic shutters. They will be made of heavy metal and will be much shorter than the safety shutters. Once again, these monochromatic shutters are expected to be redundant for safety and will be monitored by the PPS.

A major role for the PPS will be to provide a means of ensuring that no personnel are inside beamline stations when the station is opened to synchrotron radiation. Prior to admitting the synchrotron radiation inside these stations, a search of the area has to be performed by a human. It is expected that the station search will be performed by one person only. There will be PPS devices called “search boxes” inside the station which must be visited as part of the search. Search boxes are strategically placed to ensure that during the search all parts of the station are either visible or visited by the search personnel and no person is left behind inside the station. The search is completed when the station door is closed. The PPS will then lock the door.

Once the search process is started the PPS will start a beacon and audio signal inside the station, warning all personnel to exit. This signal is expected to last for some time, on the order about 20 to 30 seconds after the station door is closed. The function of the beacon and audio signal is to warn any personnel overlooked by the search person of impending danger. There will be very distinct emergency shutdown buttons placed inside the station which, when pressed, will instantly remove the presence of the prompt synchrotron radiation hazard. In addition, there will be also emergency egress buttons inside the station to unlock and open the door.

9.7.2 Design Specifications

The PPS will be designed to be robust and provide the emergency shutdown functionality to provide personnel safety from prompt radiation. Like the EPS, the PPS is expected to be based on programmable logic controllers. PLCs have numerous advantages over the relay logic scheme of interlocks. They can be reprogrammed to reflect changes in configurations and also have numerous diagnostics. The use of PLCs in safety system is very common now.

All devices attached to the PPS are expected to be designed to be fail-safe—that is, in case of failure the device will fail in such a manner as to either remove the hazard or remove the permit to generate or maintain the hazard.

Every beamline PPS will be designed under the same guidelines. The PPS will consist of two PLCs, referred to as chains A and B. The two PLCs will provide redundancy and will independently monitor all the devices.

All shutters will have two switches, one for chain A and one for chain B. There will be switches to monitor the closed and open positions. Similarly, all station doors will be monitored with two switches, one each for chains A and B.

At beamlines, there will be circumstances when a device such as a mask or photon beam stop is provided to absorb the power of the beam, while the radiation safety is provided by lead shielding as collimators or radiation stops. In such cases, the integrity of the masks and beam stops cannot be compromised, as they, in turn, protect the lead shielding which provides the personnel safety. In these cases, the mask or beam stop will be monitored by the PPS to ensure that it is not compromised. In most cases, the water flow to these components will be monitored independently by chains A and B of the PPS.

All PPS equipment will be clearly identified, and secured in locked cabinets. Cabling for the PPS equipment to field devices will be on separate closed raceways, which will be used exclusively for the PPS. All power to the PPS will be provided by uninterruptible power supplies, which will be backed up by generators.

9.7.3 Interface

The PPS must interface with numerous systems. The primary functionality of the PPS is to monitor and provide emergency shutdown.

To provide emergency shutdown, the PPS interfaces to the Accelerator Personnel Protection System. The PPS will remove a permit to the APPS to operate the storage ring. In the event of the removal of the permit by the PPS, it is the responsibility of the APPS to remove the hazard by dropping the dipole power supply and the RF to the storage ring systems.

The APPS will monitor the positions of the front-end shutters located inside the storage ring shield wall. The APPS will fan-out the status of the shutters to the PPS. There will be a provision in the APPS to remove the PPS interactions for a specific beamline. This is expected to be in the form of a Kirk Key in an interface box between the PPS and APPS for each beamline. The APPS will monitor the closed positions of the front end shutters when the PPS is not available and will remove the storage ring permit if it experiences any “not closed” activity. When the PPS is available, the APPS will ignore the status of the shutters. This scheme will allow installation, maintenance, and validation of the PPS to take place while the machine is in operation.

All PPS functions will be monitored and data archived using the control system at NSLS-II. It is expected that EPICS will interface to the PPS PLCs to monitor their functionality. The EPICS interface will be read-only; there will be no writing to PLCs from the EPICS interface. Changes to the PLC operating codes will be possible from the field devices or when the PLC software is downloaded to the PLCs during routine validation of the system.

All command and control functionality for the PPS will reside with the EPS for the beamlines and front ends. The EPS will interface to the PPS and will receive signals from the PPS prior to operation of the shutter. In the event the EPS malfunctions, the ESD procedure of the PPS will activate and will remove the permit for the machine to operate. The PPS will only provide the ESD functionality and hence it expected to be simple and easy to maintain and validate.

9.8 Accelerator Personnel Protection System

As it relates to personnel protection, the NSLS-II facility consists of an electron gun and linac enclosed in a shielded area, and a main storage ring/booster enclosed in a heavily shielded tunnel. There are also numerous beamline experimental stations located on the perimeter of the accelerator tunnel. Protection from beamline radiation will be provided by the Personnel Protection System (discussed in the previous section), from linac radiation by the Linac Personnel Protection System (discussed in this section), and from radiation from the main ring/booster by the Accelerator Personnel Protection System (also discussed in this section).

9.8.1 Linac/Gun Personnel Protection System

The Gun/Linac area will contain linac accelerating sections where electrons emitted from the gun will be accelerated to an energy level for injection into the booster. The radiation hazards present during linac operation are two-fold, resulting from: 1) a high level of RF present in the linac sections that can accelerate free electrons and produce ionizing radiation fields, and 2) the acceleration of electrons to the full linac energy. RF power is supplied through klystron amplifiers powered by pulse modulators. Turning off the RF power will stop the production of radiation.

The Linac Personnel Protection System is specifically designed to protect personnel from radiation which is present only during linac operations. The LPPS is an engineered interlock system and is expected to monitor the various devices installed in the linac for personnel safety and provide emergency shutdown in case of breach of the interlock.

9.8.1.1 LPPS Functionality

A major role for the LPPS is to provide a means of ensuring that no personnel are inside the linac when the gun is on or the klystrons are pulsing. Prior to Linac operation, a search of the area has to be performed by a human. It is expected that the linac search will be performed by one person only. There will be LPPS devices called "search boxes" inside the linac, which must be visited as part of the search. The search boxes are strategically placed to ensure that during the search all parts of the linac are either visible or visited by the search personnel and no person is left behind inside the linac area. The search is completed with the closing of the linac door. The person searching will lock the door when the search is completed and use a Kirk Key system to complete the search process.

Once the search process is completed, the LPPS system will start a beacon and audio signal inside the linac, warning all personnel to exit. This signal is expected to last on the order of about 60 to 120 seconds after the linac door is closed. The function of the beacon and audio signal is to alert any personnel who have been overlooked by the search person and trapped inside.

Emergency shutdown buttons which are very distinct will be placed inside the linac; when pressed, a shutdown button will instantly remove the radiation hazard.

9.8.1.2 LPPS Design Specifications

The LPPS will be designed to be robust and provide the emergency shutdown functionality for providing radiation safety to personnel in the linac area. The LPPS is expected to be based on programmable logic controllers. PLCs have numerous advantages over the relay logic scheme of interlocks. A PLC can be reprogrammed to reflect changes in configurations and also has numerous diagnostics. The use of PLCs in safety systems is very common and is an accepted practice at accelerator facilities across the United States.

All devices attached to the LPPS are expected to be designed to be fail-safe—in case of failure the device will fail in such a manner to either remove the hazard or remove the permit to generate/maintain the hazard.

The LPPS system will consist of two PLCs, referred to as chains A and B. The two PLCs will provide redundancy and independently monitor all the devices. To immediately stop the production of radiation, power to the modulator power supplies will be removed redundantly. This will be accomplished through the use of AC contactors, one for chain A and one for chain B.

Two critical devices will prevent radiation from entering the main ring from the linac: 1) the linac-to-main-ring stop, and 2) the bending magnet located upstream. The linac-to-main-ring stop will have two switches to monitor the closed and open positions, one switch each for chains A and B. The bending magnet upstream of the stop will be redundantly monitored for current and voltage by both chains. When the magnet is not powered it will prevent electrons from entering the accelerator tunnel area. All linac doors also will be monitored with two switches, one tied into each chain.

All LPPS equipment will be clearly identified and secured in locked cabinets. Cabling for the LPPS equipment to field devices will be separated in raceways. All power to the LPPS will be provided from an uninterruptible power source, backed by generators.

9.8.1.3 LPPS Interface

All LPPS functions will be monitored and data will be archived using the NSLS-II control system. It is expected that EPICS will interface to the LPPS PLCs to monitor their functionality. The EPICS interface will be only read-only; there will be no writing to the PLCs from the EPICS interface. Changes to the PLC operating codes will only be possible locally.

9.8.2 Storage Ring/Booster Personnel Protection System (APPS)

The storage ring and booster will coexist inside the same tunnel. The Accelerator Personnel Protection System interlock will be required to serve both the storage ring and booster. Radiation hazards during normal operations and conditioning are produced from multiple sources under different operational conditions. Operation of the RF accelerating cavities, both booster and main ring, can produce high radiation fields from secondary emissions that are accelerated by high RF fields. This radiation can be produced without electrons injected or stored in either ring.

The electron beam injected from the linac is another hazard, and, finally, stored beam in either the booster or main storage ring will produce synchrotron and bremsstrahlung radiation. The APPS must protect personnel from all conditions.

9.8.2.1 APPS Functionality

The APPS protects personnel from radiation hazards by 1) ensuring that no one is left inside the ring enclosure before operations that will produce radiation and 2) by providing a means of emergency shutdown of components, enabling personnel to stop the production of radiation in an emergency.

The ring enclosure is physically very large and will be divided into six searchable sections. Each section will be separated by a physical barrier in the form of a gate. Before operations begin, each section will be physically searched by a human. Once the search process is completed, the APPS system will start a beacon and audio signal inside the section being secured, as a warning to any overlooked personnel to exit. This signal is expected to last on the order of 60 to 240 seconds after the section gate is closed.

Emergency shutdown buttons, which have a very distinct appearance, will be placed inside the tunnel. When pressed, a shutdown button will instantly remove the radiation hazard.

The gates, along with Kirk keys, will be part of a system to allow controlled access to parts of the ring under defined conditions while other sections remain secured. With the APPS, beam will be dumped to allow authorized personnel controlled access to the ring sections while ensuring that no electron beam can be injected. Access will be monitored via a remote TV camera hookup to the control room. Each person entering the ring must remove a Kirk key; this inhibits the radiation source. A physical search of the section will be required before operations and radiation production can be resumed.

The first application of this concept defines an area around the RF accelerating cavities. The booster and storage ring cavities will need to be powered with RF for conditioning but without injected electron beam. The APPS will ensure no personnel are in the vicinity of the RF cavities during conditioning, while inhibiting electron beam from being injected into the ring. If the area is breached, the RF power source will be immediately shut off, redundantly.

During injection, while the linac-to-main-ring stop is open, if the storage ring area is breached the APPS interlock must dump stored beam and reach back to the LPPS to shut down the linac modulators.

The APPS may also be required to monitor conditions required for top-off operation of the injector. These conditions have not been determined but could include requiring a minimum stored current before top-off mode is enabled and requiring the dipole current to be at the proper energy level.

The APPS will also monitor the status of the front-end ports and will dump the beam if a port is open and the PPS detects a breach of an experimental station.

All APPS conditions and access modes are displayed and controlled from a dedicated rack in the control room.

9.8.2.2 APPS Design Specifications

The APPS will be designed to be robust and provide the emergency shutdown functionality to ensure personnel safety for the storage ring/booster area. The APPS is expected to be based on programmable logic controllers. PLCs have numerous advantages over the relay logic scheme of interlocks. A PLC can be reprogrammed to reflect changes in configurations and also has numerous diagnostics. The use of PLCs in safety systems is very common and is an accepted practice at accelerator facilities across the United States.

All devices attached to the APPS are expected to be designed to be fail-safe—in case of failure the device will fail in such a manner to either remove the hazard or remove the permit to generate/maintain the hazard.

The APPS system will consist of two PLCs, referred to as chains A and B. The two PLCs will provide redundancy and will independently monitor all the devices. To immediately stop the production of radiation, power to the RF plate power supplies and low level RF will be removed redundantly both for storage ring RF and booster RF. This will be accomplished through the use of AC contactors, one for chain A and an RF switch for chain B. The redundant means for dumping beam will also shut off the main dipole power supply through the AC contactor with both chains A and B.

The storage ring tunnel circumference is large; to avoid ground loops and EMC effects on APPS signals, fiber optic transmission of bus signals (one for each chain) will connect field I/O blocks around the ring to the main PLCs located in the control room. The control room PLCs will also connect to the RF and dipole power supply via a fiber optic I/O bus to avoid interference and corruption of signals.

The system will be designed for testability and will have built-in test features. The concept of diversity will be applied where possible.

The APPS main ring doors, emergency stops, and section gates have two switches, one each for chains A and B. All APPS equipment will be clearly identified and secured in locked cabinets. Cabling for the APPS equipment to field devices will be separated in raceways. All power to the APPS will be provided from an uninterruptible power source, backed by generators.

9.8.2.3 APPS Interface

The PLC program will incorporate a circular buffer of each scan that is triggered by an interlock breach. The buffer will be retrieved via EPICS to troubleshoot problems. All APPS functions will be monitored and data will be archived using the NSLS-II control system. It is expected that EPICS will interface to the APPS PLCs to monitor their functionality. EPICS will read data from a dedicated group of registers that reflect conditions and I/O points in the PLCs. The EPICS interface will be separate from the I/O bus. The EPICS interface will be only read-only; there will be no writing to the PLC from the EPICS interface. Changes to the PLC operating codes will only be possible locally.

9.9 Beamline Controls and Data Acquisition

9.9.1 Introduction

The NSLS-II accelerator control system will be in an isolated network by itself and each beamline is expected to have its own network to connect its computers and its hardware. Connections between these systems will be designed to provide the integrated flow of information between the accelerator and end stations that is needed to meet the requirements for beam monitoring and stability.

All insertion device beamlines require control of the insertion devices [9.13] which are located in the controls network. In addition beam position information, as well as numerous other signals, is needed from the accelerator control system. Similarly, beamline information, along with intensity and beam position from the beamlines, will be needed in the accelerator control system to provide continuous control of the beam.

The infrastructure needed for the exchange of information between the beamlines and the accelerator will be built into the facility. It is anticipated that single-mode fiber will be employed to connect the beamline EPICS hardware and accelerator EPICS hardware. Every beamline will be provided with a dedicated single-mode fiber bundle from the beamline to the accelerator control system racks located on top of the storage ring. In addition, there will dedicated single-mode fibers to the main control room, where some of the timing hardware is expected to be located. These single-mode fibers will be used to provide high-precision timing signals to synchronize the beamline experiments with the arrival of the x-ray beam.

Data exchange between the beamline and the accelerator EPICS systems, which do not require a very fast data rate, will be provided through an EPICS channel access process variable gateway system. This system will reside in the accelerator control system and will have an additional network connection to each of the beamline networks. This way the control, as well as data readbacks, can be accomplished with a high level of security without jeopardizing the integrity of the accelerator or beamline control systems. Such schemes have been used successfully at other facilities, such as APS and BESSY.

The development of the EPICS software for the beamline will be conducted in parallel with the accelerator to ensure that they are consistent and the exchanges of data between the two are seamless.

The beamlines will have their own computers and servers for data acquisition and control. There will be large storage capacity at the beamlines, and a central storage and backup service, with large disk farms, will be available as well. There will be 10 gigabit redundant network structure built into the facility. Each beamline network will be redundantly connected to a central computing facility, which will have a firewall to provide secure access to the outside world.

The offices in the LOBs will also have computing capability. Each LOB will be on a different network and will be serviced by a central computing facility. The LOBs will also be serviced by 10 gigabit network infrastructures. The centralization of data collected from the beamline will allow a user to retrieve data from multiple beamlines for analysis. Data reduction and analysis software will be developed by, and available from, the central computing services.

The variety of information exchange between the various control systems related to the needs of the experimental facilities is schematically indicated in Figure 9.9.1. Patterned after the system at APS [9.14], this system will be based on EPICS process variables, as discussed above.

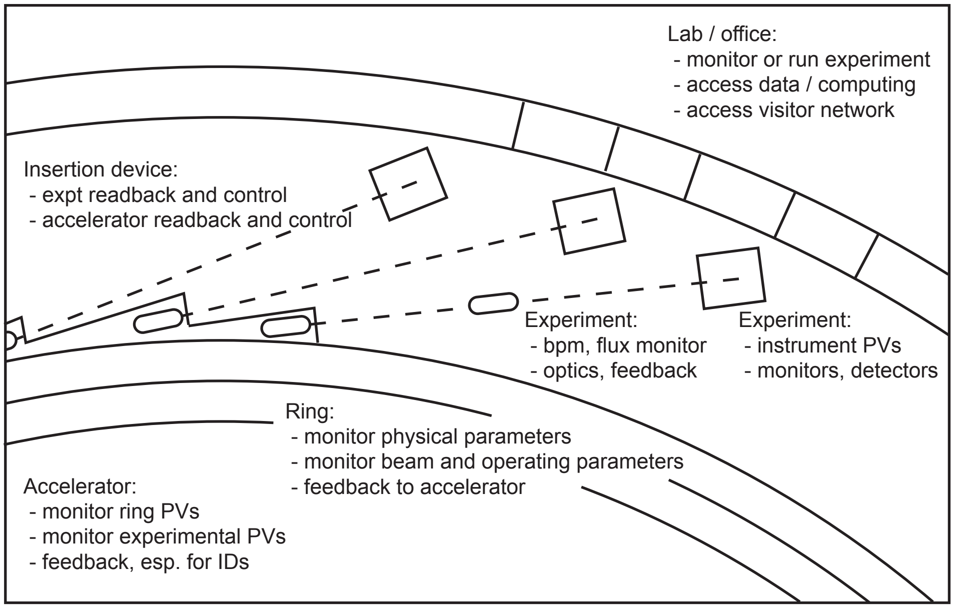

Figure 9.9.1 Activities requiring information distribution in experiment hall.

9.9.2 Design Concepts

From the point of view of the beamline and end station, the requirement is that every beamline have at least one dedicated EPICS IOC controlling its insertion devices and intercepting other information from the facility. For many of the hard and soft x-ray facility beamlines, EPICS will be used as a standard to control optics and beamline motors also. Specialized equipment may have different control systems, which may exist as additional EPICS clients or may in some cases be independent. It will be beneficial for the EPICS IOCs to be of a standardized hardware type. VME is a current favorite, due to its reliability, but the availability of drivers in the future and the improvements in PC-based hardware may cause the latter to be more favorable some years from now. The standardization of beamline server hardware will be assessed during the years preceding beamline commissioning and a standard will be chosen. The same requirements we have today must be satisfied. Hardware must be robust and reliable. A large basis set of scalers, motor indexers, analog and digital I/O, multi-channel analyzers, and so on must be in use. Pre-existing EPICS support for the hardware will be a third criterion.

The network as seen from the beamline is illustrated in Figure 9.9.2. As an example, a Linux PC running Medm GUIs may serve as the operator interface, while a VME CPU serves as the IOC for the beamline control system. Beam transport components with PVs that need to be available to the facility are connected to this network. (The insertion devices, on the other side of the shield wall, are networked separately.) A server acting as router, firewall, and PV gateway connects this sector or beamline network to the experimental network, to other beamlines, and to the other facility networks. The PV gateway controls all permissions necessary to establish who has control permission vs. read-only permission of the PVs.

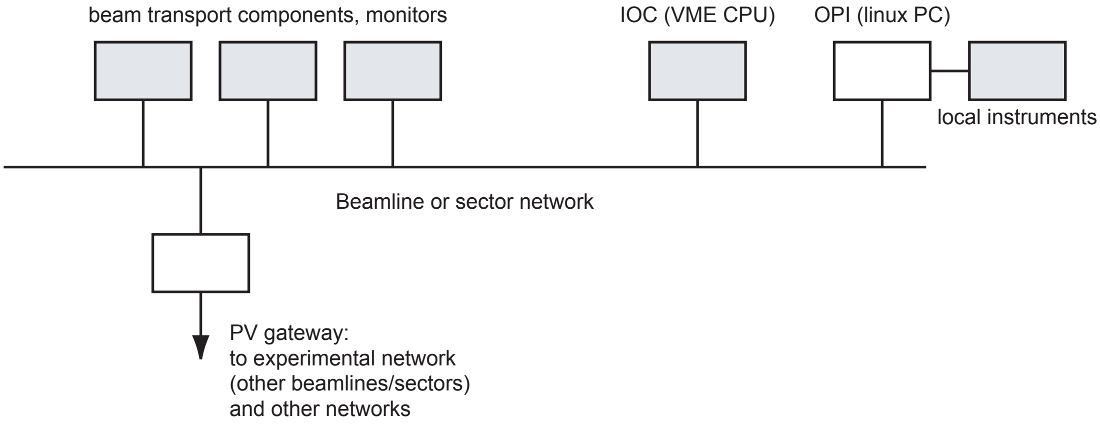

Figure 9.9.2 Sector networks make important process variables (PVs) available to the entire facility through a PV gateway. IOC=input/output controller, OPI=operator interface (as Medm GUI).

We anticipate that the system will be designed so by default read-access is available for everything, everywhere. This way, there will be no need to make assumptions during the initial configuration as to which machines' PVs and monitor values need to be communicated between the accelerator and the experiment hall. Finally, local instrumentation can be assembled on private networks as desired by the users of the individual beamlines. Specialized detectors and other instrumentation controllers may be interfaced to the beamline controls as applicable, particularly as EPICS clients.

9.9.2.1 Considerations for Accelerator–End Station Information Exchange

The accelerator monitoring complex will have far too much information in it to be useful to users as raw PVs. The accelerator group will design simple ways of mapping and colorizing the status of the accelerator with respect to beam excursions, pressure, temperature, and other sensor readouts, and make this digested information available as a monitoring system that the experimenters will be able to use. This will allow the beamline staff and users to gauge where problems may be coming from. It will also provide a unified way for the experimental division to log local beam stability in connection with pertinent information about the ring stability. This information will be provided as part of the general control system information.

The following elements will be expected to provide useful data from the beamlines back to the operations staff:

- position monitors (beams and pipes)
- ambient conditions (pressure, temperature, cooling water flow)
- status of insertion device and recent history (i.e., feedbacks triggered)
- beam figure of merit (quality after optics as defined by the end stations' needs: divergence, angular motions, spatial motions, energy drift).

It will be beneficial to create more generalized "status" readouts for beamlines as well as for the accelerator.

9.9.2.2 Design of the Main EPICS Node at Each Beamline

Resident on the experimental network and associated with each beamline, there will be a CPU running an EPICS IOC and a Linux PC configured with control GUIs and administrative scripts for that beamline. These computers will be quite similar across the NSLS-II complex, since many upstream beam components and interfaces to the gateways and other networks will be common. These computers, and the configuration to interface with facility networks and information buses, will be centrally administered. Giving each beamline a similar, centrally managed system benefits operations by allowing a standard set of tools and debugging know-how to be applied everywhere. One important concern is cybersecurity requirements. Even if the experiment network is within a firewall, the laboratory will require certain security scans. Uniformity of the beamline machines on this network will make it easier for staff to provide patches and fixes consistent with both security and smooth operations.

EPICS tools alone are sometimes insufficient for scientific data acquisition. Synchrotron beamlines have diverse needs, such as dedicated detector drivers, reciprocal space calculation, spectroscopic tools, and visualization tools for imaging. The end station equipment will be so varied that a top-down attempt at standardization would be very harmful. Thus, each beamline is expected to instrument itself in an independent way. Still, NSLS-II users and staff will benefit from having as much common support as is reasonable to interface different experimental systems and connect them to the EPICS platforms. Many different data acquisition platforms can be clients of the EPICS system. For example, LabView and Spec are widely used control and data analysis systems.

9.9.3 Support for Large Data Sets and Data Analysis Software

All synchrotron experiments have evolved toward faster data acquisition and larger data files, as shown in Table 9.9.1. Drivers for this trend include position- and energy-sensitive detectors and area detectors; beam focusing that enables mapping and energy modes; and high brightness leading to faster sample throughput.

Furthermore, the nm-scale beams and fast data acquisition possible with the very high brightness of NSLS-II have the potential to turn many more experiments into imaging experiments. Microbeam imaging and high resolution macromolecular crystallography already accumulate >250 Gb data sets for typical runs. When nanobeams are employed in imaging experiments, characterization of micron-scale areas will result in 500 GB to 5 TB datasets. For example, with five imaging or PX style beamlines accumulating 1 TB/week and 16 other beamlines collecting 250 GB/week, a total of 9 TB/week would be generated. In 20 weeks of such operations, 180 TB of data would be collected. Significant facility infrastructure, including fast networks and central scientific computing support, must be designed to collect and archive these large data streams. Making sense of such large amounts of data will require sophisticated data analysis, mining, and visualization software even for the expert user. In order to continue the trend of recent years of synchrotron science extending into new fields and new user communities, it will be necessary for this to be readily accessible to the non-expert user as well.

Table 9.9.1 Typical data rates and total data collected in representative experiments

Representative Experiments	MB/sec Live	MB/day Run	Total Run
X-ray scattering, single channel detector	0.0002 to 0.002	2.5	15 MB
SAXS or crystallography, area detector	0.3	400 to 1,200	1.2 to 2.4 GB
EXAFS	0.00005	3	10 MB
Quick-EXAFS	0.1	3,000	3 GB
High pressure, energy dispersive	0.03	1,000	2 GB
High pressure, angle dispersive	0.03	1,000	2 GB
PX, bend magnet	1	52,000	260 GB
PX, insertion device	10	260,000	260 GB
IR spectroscopy, micro-spectroscopy	0.0000.5 to 0.0005	12 to 60	12 to 60 MB
Microbeam XRD, single channel detector	0.001	40	160 MB
Microbeam XRD, area detector	0.3	5,000 to 30,000	12 to 130 GB
Scanning transmission x-ray micro-spectroscopy		2 to 30	50 MB
Fast 2D detector	> 30		> 250 GB
10 nm beams for scanning modes	0.3	5 x 10^6 to 5 x10^{10}	500 GB to 5 TB

9.9.3.1 Data Server Facility

To manage the volume and diversity of user data at NSLS-II, a dedicated data server facility will be established. The data server will have 200 TB of redundant storage, expandable as future requirements increase, and rolling over on a week-to-month timeframe as users collect their data. The physical location and architecture of the disk system can be designed in a number of ways, either distributed among beamlines or in a central farm, but a key feature must be that the data is dropped transparently from the experiment and then can be retrieved later under the direction of a dedicated data management staff. Significantly, many users will be active at more than one beamline. Data dropped to the server can be deposited with a time and source (beamline) stamp so that successive drops are never overwritten. Users will have an authentication allowing them to access the data site and retrieve data they may have generated from any of the NSLS-II beamlines. A selection of protocols and tools might be developed to retrieve data: web-based tools, secure shell gateways, dedicated client/server tools, etc. This facility is advantageous for the beamline operations staff, who will not have to manage disk farms and user authentication from offsite. It is advantageous for users, who will have a well-supported, global interface connecting them to their data. And the data will be protected from being lost or overwritten, since a uniform database management scheme will protect it, distribute it, and log all transactions.

9.9.3.2 Data Analysis Concepts

The experimental communities naturally need a variety of data analysis tools, which each community is accustomed to generating on its own. This often leads to isolated analysis efforts that are not well coordinated across the community. Without good analysis and visualization software, only the most expert users can benefit from the beamlines. Because NSLS-II has the capability to specialize in nanobeam imaging, it should be expected that very large numbers of non-expert users will be interested in characterizing their materials in straightforward ways. For this, dedicated and well supported software is essential.

NSLS-II will support software experts who are responsible for developing creative analysis and visualization solutions, as well as performing extensive quality control checks to ensure that the results are reliable and can be trusted. By working closely with beamline staff, this team of professional programmers will greatly enhance the ability of the beamline to generate real-time information to assist users in getting the most benefit from their beamtime. In the context of microbeam diffraction, for example, a coarse scan might consist of a thousand diffraction patterns. Rather than “solving” them, the real-time goal might be to determine a figure of merit from them (such as crystallinity or orientation of grains) and create a false-color image of the scanned sample area. By constructing a database that combines the diffraction data with the instrument calibration and operating parameters, it would become possible to query the data across any value in real space, reciprocal space, or environmental variables—in other words, variables that relate to the sample and not to the detection format. This kind of online analysis needs to be programmed by dedicated professionals who can continually add capabilities for new experiments while remaining compatible with the instrumentation and local resources such as the central data server.

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