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New Control Architecture for the SPS Accelerator at CERN

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Abstract

The Control System for the 450 Gev proton accelerator SPS at CERN was conceived and implemented some 18 years ago. The 16 Bit minicomputers with their proprietary operating system and interconnection with a dedicated network do not permit the use of modern workstations, international communication standards and industrial software packages. The upgrading of the system has therefore become necessary.

After a short review of the history and the current state of the SPS control system, the paper describes how CERN's new control architecture, which will be common to all accelerators, will be realized at the SPS. The migration path ensuring a smooth transition to the final system is outlined. Once the SPS upgrade is complete and following some enhancements to the LEP control system, the operator in the SPS/LEP control center will be working in a single uniform control environment.

I. HISTORIC REVIEW

The SPS control system was designed in 1972 and brought into operation in June 1976. By that time no standard communication network protocol existed and pioneering work had to be done to interconnect initially some twenty minicomputers located in 6 equidistant equipment buildings and one central control room around the 7 Km circumference of the SPS accelerator ring. The minicomputers used were NORD10 from Norsk Data with 16 KByte core memory and 128 KByte drum mass storage. The equipment interface consisted of CAMAC crates connected to the computer's I/O bus with CAMAC modules linked directly to some of the beam instrumentation while all other equipment was controlled via a CERN designed multiplex (MPX) system composed of a serial field bus, MPX crates and user dedicated MPX modules.

On the software side, the manufacturer's operating system has been modified to suit the particular real-time control requirements of our distributed multiprocessor environment. While most of the software drivers were written in computer assembly code, an interpreter, called NODAL, has been developed to provide easy interaction between the operator and the equipment connected to CAMAC, remote access facilities and network functions. Every computer had a resident NODAL interpreter allowing to use it in interactive mode and in stand alone operation for test and commissioning purposes. No one computer would be the over-all master of the control system and the message transfer system was designed so that any computer could pass a message to any other without a preset master-slave relationship, implying that the system was completely symmetrical and transparent [1].

II. PRESENT SITUATION

Since the start-up of the SPS in 1976, the control system has been extended to cope with the changing requirements of the accelerator which was initially designed as a pulsed proton accelerator for fixed target experiments, then modified to act as a proton/antiproton storage ring for collider physics, and now also as an injector to LEP, accelerating electrons and positrons interleaved with proton acceleration. Such evolution has required a great flexibility of the control system with the ability to modify programs as necessary in a simple way and to add computers, network links and equipment interfaces where and when required, sometimes even during the exploitation of the accelerator complex.

Today the SPS control system is composed of 52 operational process and central computers (NORD100) interconnected by a multi-star network with 6 Message Handling Computers (MHC). The interfacing between computers and accelerator equipment is done by CAMAC (72 crates and 450 modules) and by the MPX system (693 crates and 5500 modules). Figure 1.

With the need to operate the SPS in a supercycle mode when using it as a LEP injector, major additions had to be made to the control system since about 1986. A more flexible and versatile exploitation of many accelerator components like beam monitors and pulsed power converters was required. At the equipment level, this requirement has led to the use of 8 Bit and 16 Bit microprocessor based systems, embedded in G64bus and VMEbus crates. These Equipment Control Assemblies (ECAs) are connected to the appropriate NORD100 process computer via 1553 field bus segments and a VMEbus crate housing the bus controllers and linked to the computer's I/O bus.

In the accelerator control room, Apollo workstations where installed to cope with the more complex supercycle operation. These communicate with each other and with an

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Apollo file server via an IBM Token-Ring network. A gateway from the Token-Ring to the old proprietary star network of the SPS permits the Apollos to communicate with the NORD100 computers.

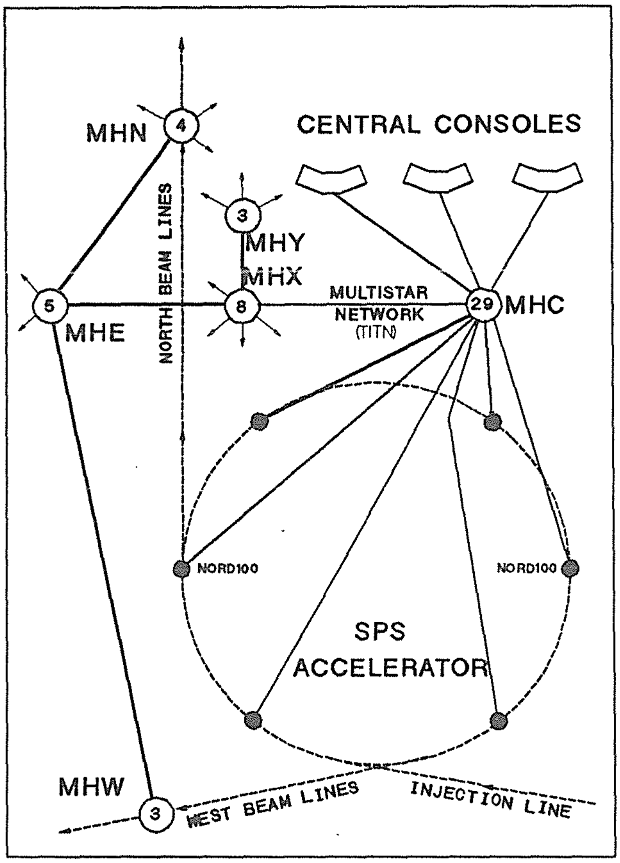

Figure 1. Present SPS Control Network.

The SPS was also used as a test bed for the LEP control system [2]. To this end a full network infrastructure including a backbone Token-Ring around the accelerator and a Time Division Multiplex (TDM) system for long distance transmission were installed at the SPS well before this was possible in the LEP tunnel. All SPS auxiliary buildings were equipped with LEP type Process Control Assemblies (PCAs). Each of these consists of a PC linked to a VMEbus crate via a 1553 connection, the VMEbus crate containing the bus controllers for the 1553 field buses which extend to the equipment. This infrastructure has permitted to validate the technical choices for LEP, but will now also serve in the framework of the new SPS controls.

III. CERN's NEW CONTROL ARCHITECTURE

The new control system architecture on which the PS and the SPS/LEP control groups have agreed after extensive studies and consultation with the control system users, is laid down in a comprehensive report [3] and presented in some detail in another paper at this conference [4]. Here only a short summary will be given to make this paper self-contained.

A. Architecture

The new architecture is based on three computing layers:

the *Control Room Layer* which provides the operator with a user friendly interface using modern UNIX workstations with OSF Motif and X-Windows graphic software packages. This layer comprises also a number of central servers for data and file storage, model computing, alarm collection, network management and for an on-line relational database.

the *Front End Computing Layer* with its so-called Device Stub Controllers (DSCs) based on Personal Computers (PCs) and VMEbus systems, running a POSIX compliant real-time operating system. Secure disk space is provided locally or centrally by dedicated file servers. Local access and graphics are standard features of PCs and are provided on VMEbus crates by terminals and displays connected to dedicated modules. Alternatively, a local terminal server or an X-Terminal, connected to the Ethernet segment, will provide access to all computers (local or remote) on the control network.

the *Equipment Control Layer* with Equipment Control Assemblies (ECAs) connected to front end computers via field buses and to the equipment by mean of general purpose or dedicated electronic modules. Branch or serial CAMAC and 1553 field bus will allow to integrate existing CAMAC and MPX crates at this level. Figure 2.

B. Network and Communication

The data communication between CERN's different Main Control Rooms will be done via a Fiber Distributed Data Interface (FDDI) network. The FDDI is a Local Area Network (LAN) protocol defined by the ANSI X3T9 Standards Committee. The network has a ring topology, uses token passing access, a fiber optic transmission media, provides a 100 Mbit/s data rate, can span distances up to 2000 meters and supports up to 500 network nodes. This FDDI network will allow to share common PS-SPS servers and an ORACLE data base computer.

The communication within and between the Control Room and the Front End Computing Layers is based on modern LANs: Ethernet and Token-Ring conforming to IEEE 802.X International Standards and using the TCP/IP protocol. Program communication will rely on a CERN designed Remote Procedure Call (RPC) until a standard is defined and industrial products become available. Where long distances are involved (>500 meters) a Token-Ring backbone is implemented with transmission over TDM equipment conforming to the CCITT G700 Standard.

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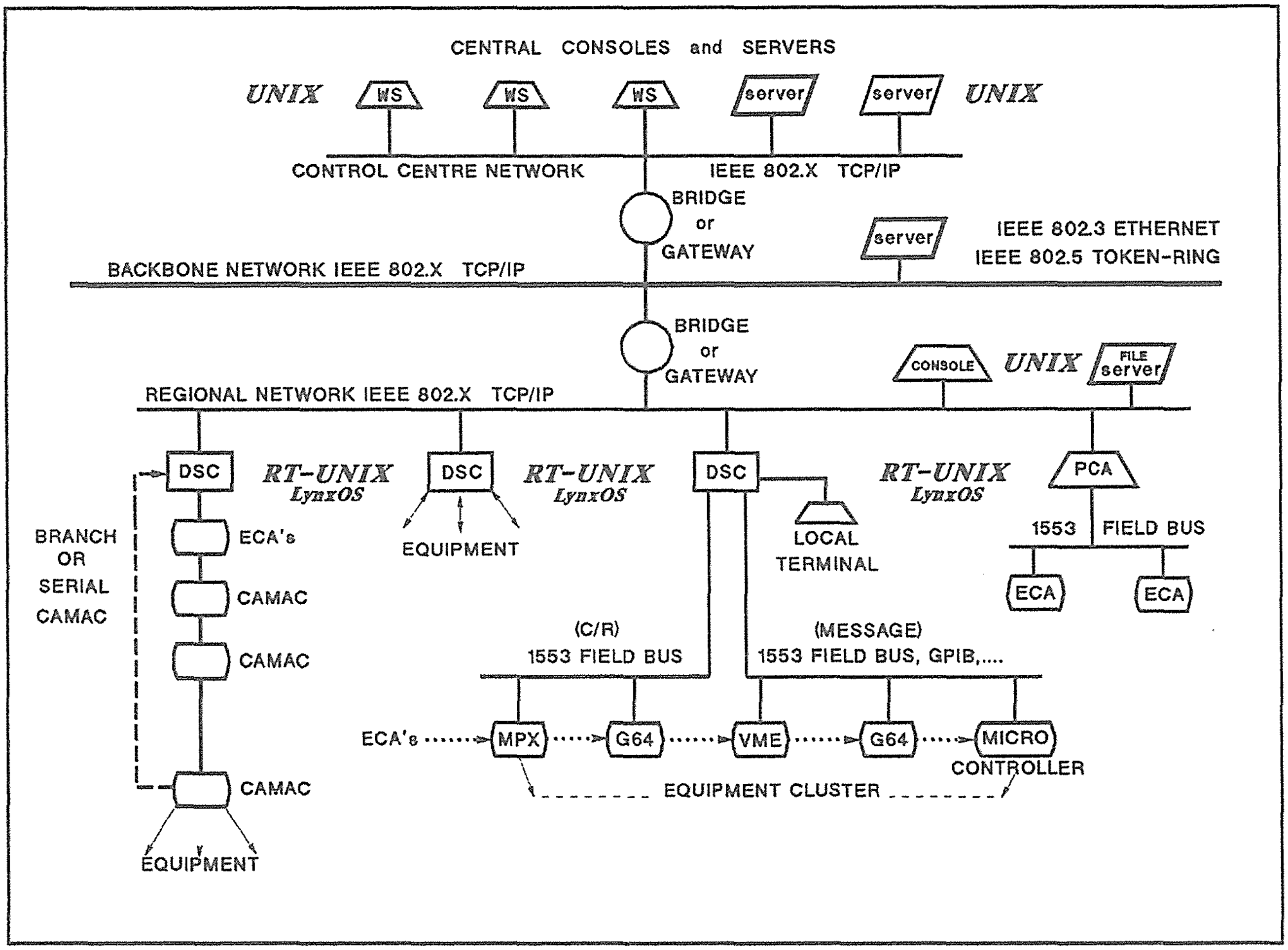

Figure 2. New Control Architecture.

C. Operating Systems

It has been decided to use a UNIX environment for the control of CERN's accelerators to the largest possible extent.

UNIX is the only operating system supported by virtually all computer manufacturers, from the PC clones up to the large CRAY or IBM mainframes. UNIX provides *scalability* which allows to move programs and data from smaller machines to larger ones. UNIX avoids getting trapped in a proprietary environment: overcharges, poor services, failure to provide an upgrade path, company which goes bankrupt, etc.. In this case the *portability* of UNIX permits to move programs and data to another brand of hardware. For the programmers it is easier to port an application between any two versions of UNIX than any two closed operating systems. In addition, combining UNIX with a public networking standard (TCP/IP), it provides *interoperability*; the ability of networked computers to share files and applications.

For the front end process computers, it has been decided to use a commercial real-time operating system, which runs on both industry standard 386/486 PC/AT compatibles and VMEbus CPU modules, based on the Motorola 68030 microprocessor, and which complies with the IEEE 1003-(1990) POSIX standard (POSIX.1 for the application program interface, POSIX.2 draft for shell and utilities and POSIX.4 draft for the real-time extensions).

The acronym POSIX stands for Portable Operating System Interface. POSIX is written by IEEE working groups as a US standard and acquires international status via its acceptance by ISO/IEC (International Standard Organization International Electrotechnical Commission) as International Standard 9945, [5].

POSIX is a software interface standard which guarantees portability of application source code but is not an operating system implementation standard. Real-time POSIX addresses the full range of real-time systems, from full scale UNIX down to small embedded kernels with the highest demands on true real-time performance.

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It is well known that basic UNIX is not designed to be a real-time system. Its goal is to give a fair share of system resources to every user, not to have, for instance, a high priority process taking the CPU and keeping it as long as necessary. On the contrary, real-time POSIX ensures an operating system the ability to provide a required level of service in a bounded response time.

Following a CERN tendering procedure LynxOS has been selected.

IV. IMPLEMENTATION OF THE NEW ARCHITECTURE AT THE SPS

A. General consideration

CERN's new control system architecture described above defines the general framework and the guide lines to be respected when replacing the old SPS system. It leaves, however, the freedom to take account of other facts proper to the SL division: the existence of and experience with the LEP control system as well as the infrastructure created during the preparation of the SPS as a LEP injector. Both facts, in particular the experience with the LEP system and the desire to create a uniform controls environment for the two accelerators, have had and are still having a strong influence on the detailed choices made for the SPS.

B. The Control Room Layer

SPS and LEP are both operated from the same control room. Apollo workstations running under Domain OS 10.3 are currently used to provide the operator interface to LEP and also to control the supercycle operation of the SPS. More powerful machines of the same workstation family offer central services, such as data and file storage or model computing. Recently, Hewlett-Packard workstations, model 9000/400 and 9000/425, still running under Domain OS, have been added to the system.

We are now in the process of introducing a few DEC 5000/200 workstations, running ULTRIX 4.2, into the SL control system. Their main function is to provide centralized secure disk space for applications and data, to provide disk service for diskless front end processors and to be the bootstrap servers for front end processors, workstations and X-terminals. The DEC stations were mainly chosen in the framework of the collaboration with the PS division, permitting to set up common services like a common ORACLE database.

In the near future, HP 9000/730 and 9000/750 workstations will make their appearance at SL. Running HP UX 8.05, they will add to the diversity of UNIX flavors used at the level of the SL control room layer. This diversity is considered to be temporarily acceptable and should largely disappear with the future introduction of the OSF 1 operating system for both DEC and Hewlett-Packard workstation families.

While the general data presentation and user interaction in the SPS/LEP control room are presently still based on the Apollo proprietary user interface management system Domain/Dialogue, all future developments will make use of the X-windows protocol and OSF Motif (toolkit, User Interface Language, resource manager, style guide).

C. The SPS control network

As mentioned before, a backbone Token-Ring was installed around the SPS a few years ago already, completed by local Token-Rings in the main control room and in the SPS auxiliary buildings. To this installation, local Ethernet segments will now be added in order to guarantee a better connectivity of equipment from different vendors to the network.

D. Front End Computers

All NORD100 computers will be replaced progressively by front end computers based on PCs or on VMEbus crates depending on the type of equipment they control, on the necessity to have local mass storage, graphics facilities and local interactivity for testing purposes. It is essentially the responsibility of the Equipment Group in charge to decide which technical solution is best.

Typically, equipment like beam instrumentation which needs fast response and high throughput, will be directly connected to modules located in VMEbus front end computers. These in turn will be connected to the local Ethernet segment and share either a local or a central file server. Such an arrangement has recently proved to be very successful at LEP where some 40 VMEbus crates with direct connection to the network are used for closed orbit correction [7].

For systems with large numbers of identical Equipment Control Crates (ECAs), PC based front end processors will be used to regroup the ECAs via a 1553 field bus and enable local supervision, alarm reduction and alarm identification before transmission to the main control room. The Process Control Assemblies (PCAs) described in chapter II will be the most frequent configuration used in this context.

Local consoles, PCAs and VMEbus based front end computers installed in the equipment buildings will operate under LynxOS and will be able to run the same programs as the central workstations and servers located in the main control room, all will communicate over the control network using the TCP/IP protocol.

E. Equipment Field Buses

In LEP, ECAs usually contain microprocessor units and are addressed in message mode via the 1553 field bus.

This mode of operation will also be used in the SPS whenever old obsolete electronics will be replaced by new modern boards housed in intelligent control crates [6].

However, many of the existing MPX crates are still working reliably and will be preserved. In this case the old MPX multidrop bus, connecting them via a CAMAC crate to the NORD100 computers, will be replaced by a 1553 field bus, generally controlled by a PCA. As no microprocessor is

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used in the MPX system, the 1553 field bus will be working in command/response mode and a special 1553/MPX interface card has been developed for this purpose.

It is at the field bus level that the General Machine Timing (GMT) is distributed to the equipment. For economical reasons and cabling simplicity, both control and timing signals are transmitted over two twisted pairs of wires in the same multidrop cable [8].

Other field buses can be used at the SPS to link ECAs to the front end processors. Industrial systems are often delivered with a proprietary field bus: Bitbus, Fip, Filbus, J-bus, Profibus, Proway, etc.. To be integrated into the SPS control system these industrial systems must be delivered with a VMEbus or a PC/AT bus controller and an adequate software driver, compatible with the LynxOS real-time kernel, must be available. In addition, the manufacturer's equipment control protocol must be known and be converted to the CERN standard to allow homogeneous access to all equipment of the accelerator from the operator's workstation.

The experimental areas of the SPS present a special case where the existing field bus, a serial CAMAC loop, will be replaced by Ethernet. A PC connected to the local Ethernet segment will be installed in each of the stations which regroup the equipment control hardware. This hardware will continue to be controlled by CAMAC modules and their CAMAC crate will be linked to the PC by the parallel Vme Inter-Crate bus (VICbus).

V. THE MIGRATION PATH

A major step of the migration towards the new control architecture is planned to take place during the 1991-92 winter shutdown of the SPS.

The existing gateway between the old multistar network and the new Ethernet/Token-Ring infrastructure only allows communication in command/response mode from the Apollo workstations to the NORD100 computers. It will be replaced by a new bidirectional gateway which will enable the NORD100s to address to services on the new network. The library computer used for data and file storage and other NORD100 based servers, all operating with obsolete disk units, will then be removed and their tasks taken over by modern workstation based servers.

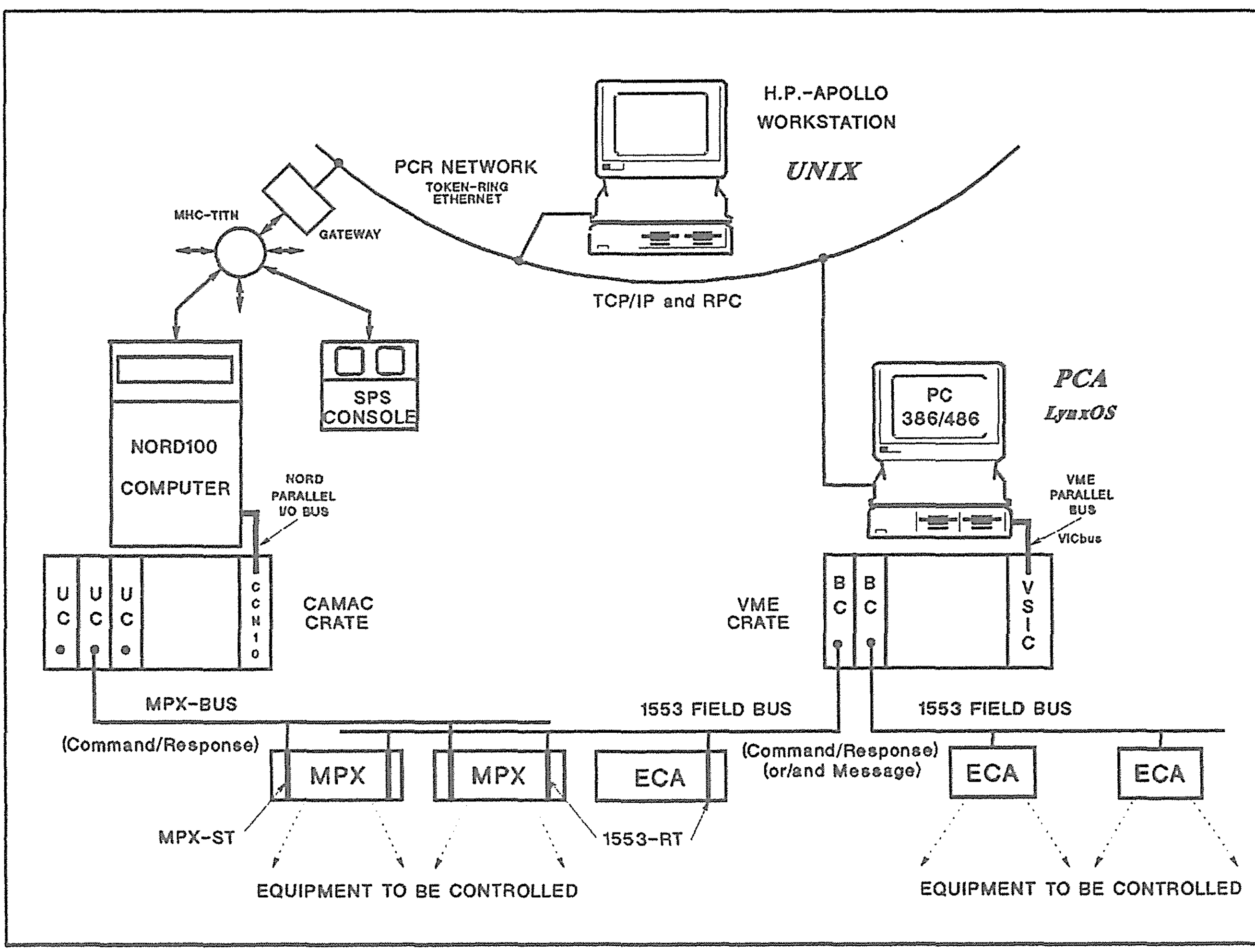

Figure3. Migration from NORD100 to PCAs

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The new gateway will be installed during the month of October and put into operation during the last two months of the year. This new gateway will first operate in parallel with the old one to allow for software debugging during accelerator operation while keeping the possibility to switch back at any time in case of problems.

At the same time a new version of the CERN RPC (Remote Procedure Call) will be introduced as well as an improved version of the NODAL interpreter, written in C language, providing additional functionalities.

During this winter shutdown existing VMEbus based front end computers and PCAs will be connected to local Ethernet segments which in turn will be bridged to the Token-Ring backbone and all PCAs will be upgraded by using the VICbus connection to the VMEbus crates, instead of the 1553 link.

It is also foreseen to install LynxOS 2.0 in the PCAs, in replacement of the present SCO XENIX.

This upgrade combined with the general use of NFS (Network File System) and the hardware improvements described above is expected to provide a better overall performance and response time compared to that of the present LEP control system.

In the main control room DEC file servers have already been installed to provide secure file space for programs, applications, data storage and remote boot facility for the PCAs and the VMEbus based front end computers.

Existing Hewlett-Packard workstations will be used with X-windows and Motif to write new application programs for the systems linked to the new infrastructure. Thus the complete chain, from the operator workstation down to the ECAs including the network and the new front end computers can be tested and debugged.

To facilitate the migration of application programs from the old NORD100 consoles to the Hewlett-Packard workstations, for equipment remaining to be controlled by MPX crates, an alternative access will be possible for test and debugging purposes during the transition phase. Figure 3.

VI. CONCLUSIONS

Modernizing the control system of a running accelerator is a difficult task. Since its first operation in 1976 the SPS has undergone a number of smooth upgrades to cope with the changing demands of the accelerator exploitation. Generally more installation of the same kind of equipment or replacement of mini computers by more powerful ones of the same family, was fairly straightforward.

This time, a drastic change is required. Computers, networks, local intelligence, application and system programming have changed totally over the last 15 years. Hardware and software standards are available but the job has not become easier for the control specialists. New skills are required and system integration is the buzz word.

To preserve the integrity of the accelerator operation, the migration work must be done in well defined steps. The test bed chosen for the validation of the new architecture and the methodology adopted must be representative and include all aspects of the project. The overall planning is essentially determined by the duration of the annual accelerator shutdown and available manpower, particularly in the field of application software.

VII. ACKNOWLEDGEMENTS

Many members of the PS and SPS/LEP control groups have contributed to the definition of CERN's new control system architecture and to the application of the ideas within the SPS environment. The authors wish to thank them all. Particular thanks are due to J. Altaber and F. Perriollat who where co-authors of the first proposal to harmonize the controls of all accelerators at CERN.

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