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DEVELOPMENT OF THE SPS/LEP CONTROL SYSTEM

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## Abstract

The major design constraint of the control system for LEP is the compatibility with the existing SPS control system. The first reason for this compatibility is to allow a long-term convergence of the SPS control system towards the LEP one. The second reason is to operate both LEP and SPS machines from a unique main control room.

The paper will describe the distributed architecture of LEP and the existing SPS control systems. The design of the equipment interface for both machines will then be explained. Finally, the infrastructure of the common main control room for LEP and SPS will be described.

## <u>Introduction</u>

CERN is constructing a Large Electron-Positron (LEP) accelerator and collider ring on the Swiss/French border near Geneva. The new machine has a circumference of 28 kms and is located in an underground tunnel at 60 to 120 m depth below the surface of the ground. Equipment will be installed into the tunnel and be controlled from underground alcoves as well as from surface buildings located at eight equidistant areas around the machine. LEP is expected to start operation early 1989.

The existing Super Proton Synchrotron (SPS) accelerator, also installed in an underground tunnel (approximately 7 kms in circumference), will be used as an injector for LEP. The SPS equipment, much of which dates from 1973, is now being upgraded to meet the new requirements of the accelerator.

The SPS/LEP control system will use a fully distributed system, made up almost entirely of multiprocessor control assemblies implemented in VMEbus following the IEC 821 standard, complemented by equipment conforming to the G64 standard.

The LEP collider will be operated from the same control room as the existing SPS accelerator in operation since 1976. The philosophy of the LEP/SPS control system follows a functionally and geographically distributed architecture for the real-time control of a very large amount of equipment [1]. Instead of conventional mini-computers the LEP control system will use multimaster-multiprocessor control assemblies communicating via token-passing ring networks conforming to the IEEE 802.5 standard protocol [2].

The main purpose of this paper is to describe the development of the real-time multiprocessor control network being implemented at CERN using the IEEE 802.5 standard token-passing ring protocol. To cover the circumference of the LEP ring and the long distances (up to 3.5 kms) between geographically distributed control areas an unconventional transmission method has been implemented and successfully tested. The method based on Time Division Mutliplex (TDM) techniques, as defined in the CCITT G.700 series of Recommendations [3], will be presented.

## Distributed Control Architecture

The control system for large machines such as the SPS and LEP has to be more than just a collection of controls transferred from various apparatus to a central place. It is necessary to find means of analyzing the vast amount of data required and presenting it to the control crew in a suitable form for easy assimilation and to carry out settings and measurements. As the distance between the control room and the control buildings is very large, it is essential to concentrate and process some of the data at the place where they are being produced. This implies that computing power has to be integrated into distributed control system. For each major a identifiable geographical/functional sub-system a computing element is assigned, close to the devices to be controlled. These computing elements are inter-connected by a network, together forming the control system for the accelerator.

The existing SPS control system makes use of conventional mini-computers (Nord computer from Norsk Data) for its computing elements. Each Nord computer contains a minimal real-time multi-tasking operating system. The network, designed at CERN, uses point-topoint connection in a multi-star topology. Over eighty such connections are operational.

Today's availability of powerful microprocessors and the existence of international standards are fully exploited in the SPS/LEP control system design. The computing elements will be built as multi-microprocessor assemblies [4] (Motorola M68000 families) implemented in VMEbus according to the IEC 821 standard. To select its VME based multiprocessor control assemblies, together with a distributed realtime operating system industrially supported, CERN has consulted all major European computer manufacturers. After analysis of the offers, the choice has been made in favour of the DLX multiprocessor system and its ELECTRE real-time executive available from the French CIMSA-SINTRA Company. The ELECTRE real-time executive follows the SCEPTRE norm (Standardisation du Coeur des Exécutifs des Produits Temps Réels Européens) published by the BNI (Bureau de la Normalisation Informatique).

The software and hardware for these assemblies will be provided by the company CIMSA-SINTRA. The network will be based on a multiple access protocol, as specified by the IEEE 802.5 standard, better known as the token-ring [5]. The main reason for this choice is that this standard has no limitation on the physical size of the network. In addition, it provides a deterministic response time as well as a good behaviour under heavy load which are two major advantages for real-time operations.

All accelerator equipment and sub-systems are connected to multiprocessor assemblies by a multi-drop bus conforming to the MIL-1553-B standard protocol [6].

## Token Ring

Presently the token ring works at 4Mbit/s and

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CSMA/CD ETHERNET at 10 Mbit/s. The token ring speed improvement will follow the semiconductor technology and 16 Mbit CMOS and NMOS chip sets have been announced by several manufacturers. In the long term token rings working at 80 Mbit/s or more can be expected. Thus the installation today for LEP of a high quality transmission medium for token ring will permit CERN to profit later from these technological progresses.

The connection of a large number of multiprocessors in the LEP control network is facilitated by an insertion/extraction mechanism provided for in the token ring topology. The star/ring configuration allows local clusters of computers to be easily integrated or isolated in case of local failure. The token access ring wiring medium can be installed within a building using a radial (star) wiring scheme. Star wiring implies that the transmission cable is installed from concentration points within a building to the various user work areas; such as local control rooms in the eight LEP sites.

Another design criteria is that any network fault or disruption should be quickly detected and isolated to restore normal operation. The wiring concentration points provide centralized access to some of the primary network components to enhance the maintenance and reliability aspects of the overall system. In addition, the flow of data and control signals around a closed ring provides an inherent capability for monitoring normal token operation from a given location in the ring and enables ring faults to be quickly detected.

The token ring uses uni-directional transmission on a single high quality shielded and twisted pair cable over distances of 800 m. In case of by-pass of one token ring station the distance may be twice as long to reach the next active station. As a consequence, the maximum distance between two stations cannot exceed 400 m. It has been necessary to conceive a method for crossing the 4 km between two adjacent LEP control sites. This has been achieved by using standard G700 TDM equipment.

## The TDM System

As links become longer and as the cost of electronic equipment falls, it becomes economical to multiplex different information streams on to one physical link. Also, the trend is increasing to transmit information digitally. Time Division Multiplexing (TDM) is particularly appropriate to digital multiplexing.

In order to harmonise interfaces to TDM equipment, and to allow interworking of equipment from different manufacturers, the CCITT have produced the G.700 series of Recommendations. TDM networks designed according to these recommendations have been introduced by many PTTs around the world, and equipment is available from a large number of manufacturers. Therefore, it has been decided to base the TDM system for the SPS and LEP on these recommendations.

The TDM system will be available at locations around the SPS and LEP sites for transmission of information. The information streams will be of different types and for many different users. Audio signals for the LEP telephone system will be carried by the network, as well as slow-scan television. Examples of data traffic are point-to-point links, the accelerator timing messages, and a token-passing data network.

In the case of the SPS and LEP TDM system, the physical links are of two types: optical fibre

cable and coaxial cable. Optical fibre cable will be used wherever possible on account of its very high bandwidth. However, the high levels of radiation in the accelerator ring tunnels precludes its use in those locations and coaxial cable will be used there instead. Initially, both optical fibre and coaxial cables will carry data at 34 Mbit/sec.

The links provided specifically for the SPS and LEP timing system [7] will normally be configured in a double ring topology, one ring for each accelerator. The links on each segment of the rings are inherently full duplex; this feature will be exploited to provide two independently routed signals, following clockwise and anti-clockwise routes around each ring. These alternate signals will be used in the interface equipment for added reliability in case of link failure. It is not however excluded that, for reconfiguration or other reasons, different routes will be used from time to time.

An identical solution has been adopted for the token-ring links. The main difference being the data rates of the links, 2.048 Mbit/s for the timing and 8.448 Mbit/s for the token-ring.

CCITT Recommendations G.703 defines electrical interfaces to TDM systems at specific data rates in the range 2-565 Mbit/sec. In the CERN situation the information to be transmitted will normally have a different line protocol to that of the TDM system; interface conversion units will therefore be required.

For the accelerator timing system the interface has been developed by Vertec Ltd., a Salford University based UK company, in conjunction with CERN. The unit connects the 512 kbit/s Manchester coded timing frames to the 2.048 Mbit/s TDM data channel. Vertec are currently investigating the feasability of connecting a standard 4Mbits/s token ring to a standard 8.448 Mbit/s TDM channel. Hopefully, this will obviate the present necessity of replacing the 4 MHz quartz crystal of the token ring interface for a 4.224 MHz quartz.

#### The Main Control Room

The existing SPS control room comprises five identical general purpose consoles. A console is based on a number of interactive devices driven by CAMAC crates connected to a dedicated Nord computer which belongs to the star network of the SPS control system. Such a design has been very successful in the past but it is very tightly coupled with the Nord computer and CAMAC. It is not adequate for the LEP control system and the upgrade of the SPS control system, consequently it has been decided to design a new main control room for the LEP and SPS.

The essential goal of the new MCR architecture has been the use of commercial products in an open manner, i.e. products from different manufacturers can be used with ease. It soon became clear that one way to achieve this was to base the architecture on a standard Local Area Network (LAN). In such a distributed architecture a number of consoles and a number of servers are connected on a LAN. The choice for the LAN was rather straight-forward, the IEEE 802.5 standard has been selected as it will be used as well for the machine networks of LEP and SPS.

The principal elements of the control room are the consoles. They are implemented on commercial personal computers. Each console contains a powerful microprocessor, a large memory (more than 1Mbytes), a medium scale mass storage and a man-machine interface based on a colour screen and a mouse.

To provide a large number of entry points, the IBM PC/AT has been selected; the essential reason for this choice is its low price and its architecture which uses a non-proprietary bus thus allowing the integration of multi-vendor compatible products. Such cheap consoles will be used for program development and running single task control procedures. For more elaborate operation more powerful workstations will be used. They will essentially offer multi-tasking and multiple windows facilities, thus allowing several of the control procedures to run concurrently each of them with its own window, the operator being able to interact with any of them at any time. To fulfill this enhanced requirement four Apollo 3000's have been received from the manufacturer and two more will be installed in the control room prior to the June 1987 SPS start-up.

In addition to the consoles a number of servers are foreseen on the main control room LAN:

- a large global mass storage server together with a back-up facility will offer the necessary features for the consoles to share-files;
- hard copy devices such as printer/plotter, possibly in colour, will be available;
- a powerful 32-bit Nord 570 computer will offer modelling capabilities as a server;
- the central Master Timing Generator (MTG) which must be accessible from all consoles. The MTG for the SPS e<sup>+</sup> e<sup>-</sup> timing system has been operational since August 1986 and two others, one to replace the existing SPS "old MTG" and the other for the LEP timing system, are currently being installed.

This list is far from being exhaustive but the openness of the architecture guarantees that it will be easy to introduce new ideas as the need arises.

# Software

To obtain full openness of the architecture described above it is necessary to implement "open software" to run on the top of it. This can be achieved by selecting commercial portable packages, widely used or possibly following international standards.

For the operating system the UNIX\* system V was quickly identified as the best candidate. In fact, UNIX system V is available on a large variety of computers and it offers all the essential features: portability, large choice of commercial packages, hierachical file system, powerful command interpreter, multi-tasking and inter-task communication, etc.

As a consequence of this decision the choice of networking software immediately focuses on the DARPA suite of protocols better known as TCP/IP. Indeed implementations of this network protocol are available on most UNIX systems and it includes readily available functionalities such as file transfer, mail, remote terminal, etc. Although this protocol has not been endorsed by any international standardisation body, it is available on a very large number of computers and operating systems from large main frames (CRAY, IBM) down to microcomputers (Intel 8'286, Motorola 68000).

For the implementation of the man-machine interface, and as we have restricted ourselves to a colour screen and a mouse, the ISO GKS standard was found to be the best choice.

Under the UNIX operating system there is a large choice of programming languages available. Amongst them we have selected three:

- C-language as a natural consequence of UNIX;
- Fortran 77 as the mathematical language.
- NODAL as the interpreter [8]. A portable version of the NODAL interpreter has been implemented in the Modula-2 language at CERN and has been compiled on a number of computers [9].

## Conclusion

This paper has presented the current state of the SPS/LEP control system. A minimal version was used for the September 1986 oxygen-16 physics run. The deadlines imposed by the June 1987  $e^+ e^-$  start-up are being fulfilled as are the longer term LEP requirements. This has only been possible due to the design and implementation efforts from all members of the SPS/LEP Controls Group.

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<sup>\*</sup> AT&T registered trademark.