Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

# GPS PRECISION TIMING AT CERN

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*Abstract*

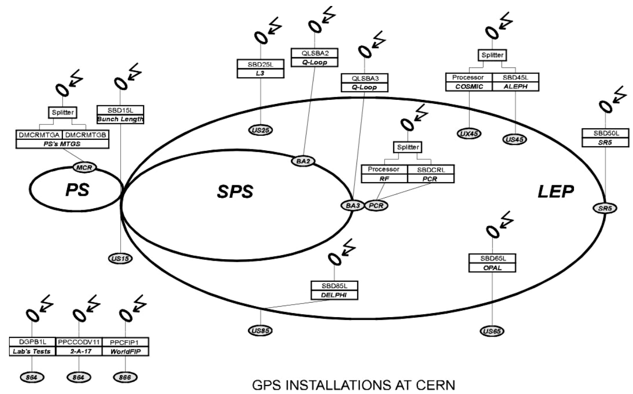
For the past decade, the Global Positioning System (GPS) has been used to provide precise time, frequency and position co-ordinates world-wide. Recently, equipment has become available specialising in providing extremely accurate timing information, referenced to Universal Time Co-ordinates (UTC). This feature has been used at CERN to provide time of day information for systems that have been installed in the Proton Synchrotron (PS), Super Proton Synchrotron (SPS) and the Large Electron Positron (LEP) machines. The different systems are described as well as the planned developments, particularly with respect to optical transmission and the Inter-Range Instrumentation Group IRIG-B standard, for future use in the Large Hadron Collider (LHC).


## 1 INTRODUCTION

The Global Positioning System (GPS) is claimed to be the most accurate system for worldwide distribution of precise time, frequency and position ever deployed. Each of the 24 operational satellites, plus spares, carry an ensemble of on-board atomic clocks which are controlled and maintained by the US military from their control base in Colorado Springs. Monitor stations in Hawaii, Kwajalein, Ascension Is. and Diego Garcia ensure a worldwide absolute time reference, with respect to UTC, from 3 to 100 ns. depending upon technique and the good will of the US military.

The “Interface Control Document” (Letter of Intent) was signed in 1982 by six leading US firms and the “NAVSTAR USER’S OVERVIEW” was published in 1986, [1]. The system was officially declared operational in 1995. While the NAVSTAR GPS system was financed by the US most equipment sold is now for recreational use which explains the significant price reductions over the recent years. Also, the system was originally conceived for its extreme precision in position, it is only recently that affordable equipment has become available to provide the accurate time facility.

This note summarises the majority of installed operational GPS systems at CERN. To avoid duplication, identical hardware has been used for all the installations. The equipment choice was influenced more by widespread usage of the VME standard at CERN than price performance factors.




GPS INSTALLATIONS AT CERN

## 2 SYSTEMS

### 2.1 Beam Dump Trigger

The initial LEP Beam Dump Triggering system was installed during the 1993 shutdown. The system enables physicists to dump the beam whenever they consider that their detectors are being damaged by beam induced radiation. This is achieved by a hardwired connection from each of the four experiments, plus the control room, to the beam dump equipment located at LEP point 5. Each connection consists of a constant current loop with an electronic switch located within each experiment. Whenever the switch is activated, either manually or by the user’s circuitry, the current loop is opened which causes the beam dump kicker to be fired, thus dumping the beam.

However, during the 1993/1994 runs a few physicists complained that the beam was not being dumped until several milliseconds after they had activated their switch, thus causing expensive damage to their detectors. In order to clarify this situation it was decided to install a GPS monitoring system.

A GPS receiver is installed wherever there is a switch and also at the beam dump. When a switch is activated the time of day, to the nearest microsecond, (with a resolution of 300 nanoseconds), is “frozen” by the receiver. At LEP point 5, a signal that is derived from the actual high voltage pulse, that fires the beam dump kicker, is used to “freeze” the time in the GPS receiver located there. After the beam has been dumped the control system reads and also “unfreezes” the GPS receivers concerned and displays the values via the alarm system. Since the system became operational there has not been a single complaint about the beam being dumped late.

## *2.2 Time of day source for Master Timing Generators (MTG's)*

The MTG's are used to generate millisecond based machine timing for the PS, SPS and LEP machines. The original PC based systems used a "Computime" instrument made by Patek Philippe of Geneva. This unit receives 77.5kHz radio signals from Mainflingen, Germany, and then passes them on to the MTG by means of an RS-232 port. This resulted in a time accuracy of +-10 milliseconds.

When it was decided to upgrade the control system by replacing the PC based 386/486 systems running XENIX with VME platforms using LynxOS operating systems, it was logical to replace the Patek Philippe with VME GPS. The time of day information is now transferred via the VME backplane with an accuracy of less than two microseconds.

## *2.3 Cosmics*

Besides monitoring the results of e+e- collisions in LEP, the four experiments are also excellent devices for detecting cosmic particles. For many years physicists have been exploiting this feature, either interleaved with daily LEP operations or else during the start-up periods. Then they have access to the detectors without the background noise of LEP.

This CosmoLep project requires the synchronisation of the individual observations from the four experiments. This will be achieved by tagging data with the GPS time. Each experiment will have a "time of day" generator synchronised to the GPS receivers located in each pit. The project may be extended to include other European and possibly worldwide, laboratories.

## *2.4 Bunch length Interlocks*

High intensity short bunches excite higher order modes in LEP. This causes overheating, exceeding the capabilities of the cryogenic system, resulting in equipment damage. It is proposed to install an instrument that will continuously monitor the bunch length and intensity of the beam on a turn-by-turn basis. If the set threshold is exceeded then the beam will be dumped, via the triggering system and tagged by GPS.

## *2.5 ATM Tests*

ATM (Asynchronous Transfer Mode) networking technology is being evaluated for its use in transporting data in the future Large Hadron Collider (LHC). In order to gain experience with ATM, it is being used in a feedback loop for control of betatron tunes in the SPS. The two principle elements of the Q-loop are a transverse damper, used to excite the beam, situated in building BA2 and the focussing and de-focussing quadrupole magnets powered from building BA3. Correction data is calculated from beam response observed in BA2 and sent over an ATM link to the power converter in BA3.

The data is transmitted using a standard 53 byte ATM cell. Immediately before transmitting the cell the time of day is read from the GPS receiver, located in BA2, and included in the cell. When the cell is received in BA3 a local GPS receiver is read. The difference between the two times, minus the time it takes to read out a GPS receiver, is used to calculate the latency of the system.

## *2.6 RF Interlocks*

The RF interlock system monitors up to 24 different parameters, i.e. temperature, water flow, vacuum etc. These parameters are then multiplexed down to a single entity that controls a switch. Each switch is included in series with a RF current loop circuit, which follows the LEP circumference, and any switch that is opened breaks the current loop. This action activates the "freeze" register in the GPS receiver located at LEP point 4 (ALEPH) and dumps the beam. The control system then interrogates the GPS module and informs the alarm system who was responsible for the dump.

For the high intensity 1999 run a duplicate system has been installed in LEP point 6 (OPAL).

## *2.7 WorldFIP*

WorldFIP [2] is a fieldbus network protocol designed to provide links between low level sensors and actuators and the bus controllers, VME, PC etc. One of its principle characteristics is that it is deterministic. This feature will be utilised to control the 1700 magnet power converters that will be required for LHC [3].

Although the WorldFIP macro-cycles are deterministic, they are referenced to an internal oscillator contained in each bus controller. Whilst this is acceptable for most industrial applications the inherent "drift" of each oscillator exceeds the LHC requirements.

To overcome this problem, it is intended to externally synchronise the WorldFIP macro-cycles to the GPS system. A test system is currently being assembled to evaluate if this proposal is feasible. The aim being to synchronise the entire 1700 LHC magnet power converters to the GPS.

## *2.8 Lab Tests*

The lab systems are used for both hardware and software developments. These tests resulted in the choice of the active antenna and the type of cable to be used, in addition to the in-line amplifier and the splitters. The lab has direct optical links, both single-mode and multimode, to the control room where one can branch into the main CERNwide optical transmission infrastructure. The accurate map reference co-ordinates of the lab plus all the GPS installations were provided by CERN's survey group

[4]. This was done to verify the correct operation of the GPS equipment.

## 3 EQUIPMENT

### 3.1 Receiver

The choice of the GPS receiver was dictated by the operation of the LEP Beam Dump Triggering system. There were two essential requirements, the unit must be compatible with the existing SL control system and it had to have an externally triggered hardware "freeze" register. The chosen module, TrueTime Model GPS-VME, fully conforms to these requirements.

The specifications of the module can be found at *www.trutime.com*

### 3.2 Active Antenna

The antenna used is NovAtel Model 521. It is environmentally sealed for protection against rain, ice and lightning strikes. For extra durability it is housed in a waterproof "Teflon" structure which protects the TNC connector as well as the antenna.

Full specifications are available at *www.novatel.ca*

### 3.3 Cable

Low-loss coaxial cable type CERN CK50.

### 3.4 Ancillaries

4 way splitter, SCHWAIGER type VTF 7844; 5-2250 MHz. 2 way splitter, Radio Materiel type VTF 7842; 5-2300MHz. In-line amplifier, Axing type SVS 2-00; 12-26dB, 450-2400MHz.

## 4 DEVELOPMENTS

### 4.1 Optical

For operation of the LHC magnet power converters, there is a requirement to transmit time of day timing information, referenced to the GPS standard, to each of the LHC alcoves. At the moment GPS referenced timing is only available in the experimental pits. The distance from the pits to the alcoves is approximately 1000m.

Tests have been carried out using single-mode optical fibres in conjunction with FOXCOM optical transmitter receivers, series 7000 [5]. It has been demonstrated that the GPS antenna L1 frequency at 1.575GHz, can be transmitted over a distance of 1762m. This is more than adequate to transmit the antenna signals to each alcove. However, this solution is expensive, the transmitter receiver units cost over 5000 dollars a pair. A cheaper alternative may be possible with the use of IRIG-B.

Also being evaluated is the transmission of the current MTG type timing over multimode fibres, using FOXCOM type 105 transmitter/receiver units. These modules are far less expensive than singlemode equipment and transmission tests of up to 10Km have been successful.

### 4.2 IRIG-B

The task of standardising instrumentation timing systems was assigned to the Tele-Communications Working Group (TCWG) of the Inter-Range Instrumentation Group (IRIG) in 1956. The standard defines the characteristics of six serial time codes presently used by U.S Government agencies and private industry [6].

The GPS receivers used at CERN generate a 1kHz amplitude modulated IRIG-B coded signal synchronised to the GPS time. This will be connected to the module VME-SG2, also made by TrueTime. This is a time of day generator, either free running or synchronised by an IRIG-B input signal. The manufacturers claim an accuracy of 1 microsecond, this will be evaluated with respect to the GPS receiver time whilst using an interconnecting cable of 1km. This will be done in conjunction with the WorldFIP jitter tests. This scenario may result in a simple inexpensive method of providing GPS synchronised timing in the alcoves for the LHC era.

## 5 CONCLUSIONS

At CERN, all the GPS systems are used to provide sub-microsecond time of day information. Since the original 1993 project, the LEP Beam Dump Triggering System, GPS has been integrated into many different systems. This trend will certainly continue.

For LHC operation greater use of GPS is foreseen. The quench protection system alone will generate over 4000 possible inputs to the beam dump trigger system. In order to perform meaningful post mortem analysis, all systems will have to be time stamped. Due to the uniform distribution of the major systems throughout the LHC complex, it will be essential to use GPS as the source of the time reference.

## 6 ACKNOWLEDGEMENTS

To Robin Lauckner for his support, i.e. funding, of the project plus his assistance in testing the equipment.

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