INTER-LABORATORY SYNCHRONIZATION FOR THE CNGS PROJECT

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Abstract

CERN will start sending a neutrino beam to Gran Sasso National Laboratory in Italy in July 2006. This beam will cover a distance of around 730 km through the crust of the earth from an extraction line in CERN's SPS to dedicated detectors in Gran Sasso. This paper describes the technological choices made to fulfill the specification of inter-laboratory synchronization in the region of 100 ns, as well as some preliminary results. The common time standard is UTC as disseminated by the GPS system, and the techniques are similar to those used by national metrology laboratories for the manufacturing of UTC itself. In addition, real-time messages sent through the Internet allow the detectors in Gran Sasso to go into calibration mode when no beam is being sent. Data concerning the delay and determinism of this international network link is also presented.

INTRODUCTION

The CNGS (CERN Neutrinos to Gran Sasso) project aims at delivering a high intensity neutrino beam though the Earth's crust from CERN (Geneva, Switzerland) to the Gran Sasso National Laboratory (LNGS) located 120 km east of Rome in Italy. This beam will contain exclusively neutrinos of the muon type, and the detectors in LNGS will try to find tau-neutrinos resulting from the oscillation of muon-neutrinos as they travel though the 730 km straight line separating CERN and LNGS.

In order to correlate the events observed in LNGS with the beam pulses sent from CERN's SPS, both of them will be time-tagged using Universal Coordinated Time (UTC) as a reference, therefore allowing discrimination of events caused by CERN neutrinos with respect to spurious events. The local time bases in LNGS and CERN are provided by GPS Disciplined Oscillators (GPSDO), delivering Pulse-Per-Second (PPS) outputs and 10 MHz clocks to break each second in 10 million ticks. Both GPSDO devices contain Rubidium oscillators to ensure good short-term stability and rely on the numerous Cesium clocks driving the GPS constellation of satellites for their long-term stability. As a result, the quality of the 10 MHz output is excellent, with typical Allan variances [1] of 10^{-11} for an averaging time of 1 second and 10^{-12} for 100 seconds. The limiting factor to achieve good inter-lab synchronization is therefore the variance between the output times of the PPS pulses in LNGS and at CERN. This report presents the results measurement campaigns performed to quantify the systematic offset between the two PPS pulses, used to calibrate the system, and also to study the variance of these measurements to ascertain whether the specified performance (100 ns RMS) is achievable with the basic GPSDO setup, knowing that more involved techniques, such as common view and two-way satellite time transfer [2] could be implemented to improve performance if necessary.

Once each laboratory has a facility with a well controlled and characterized GPSDO, it is necessary to take that time reference from there to the place of interest, i.e. the SPS extraction point at CERN and the Opera detector in LNGS. In both cases, the fibre delay incurred has to be measured and taken into account when generating the time tags. The methods used are also presented in this report, along with results from actual measurements.

Another request from the CNGS project concerns the possibility of running calibration procedures in the Opera detector during periods of no beam from CERN. In order to synchronize these calibration runs, taking into account that the SPS is a multi-cycling machine with a multitude of operating modes decided online by operators, a fail-safe scheme using UDP packets though the Internet was put in place. We describe the scheme and comment on some preliminary results which confirm that this cheap, non-deterministic solution is indeed good enough for our purposes.

GPSDO CALIBRATION

A GPSDO is a special kind of GPS receiver designed to provide very accurate and stable timing signals. In order to do so, it works to find a very precise position fix during the first hours after power-up. This implies of course that the device should not move at all during normal operation. After many position averages (around 100000 in our case), the device goes into "timing" mode, i.e. it fixes its position and only solves the time equation. This means that a GPSDO can keep track of time with only one GPS satellite in sight (and not three as would be needed to find its position as well) but the more satellites the GPSDO sees the more accurate the timing will be.

The biggest source of errors in the generation of a stable PPS output in a GPSDO is the variable propagation time of GPS signals through their one-way trip from the satellites to the GPSDO, especially through the ionosphere and troposphere [2]. For our two relatively close locations, we assume there will be a "common mode" effect whereby the deviations from UTC of our two GPSDOs will go in the same sense and will have roughly the same values. For more local variations, typically of a faster nature, the Rubidium oscillator on each GPSDO will act as a low-pass filter, with a time constant of around 3 hours, smoothing out the short-term variations.

To validate our assumption and gain some extra confidence, we decided to calibrate CERN's GPSDO both against the official source of UTC time in Switzerland (the Swiss Federal Office of Metrology, METAS, in Bern)