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Time Calibration of the NEutrino Mediterranean Observatory (NEMO)

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Abstract: Large volume Cherenkov detectors under water or ice are in construction or under study for detection of astrophysical neutrinos. In all such cases, the neutrinos are inferred from the detection of the Cherenkov light emitted by the charged leptons created in neutrino interactions inside or around the apparatus. The event reconstruction is thus based on charge and time measurements performed by a system of widely-spaced photomultipliers. Time calibration is a very delicate operation for such apparata, as it may directly affect the reconstruction efficiency and pointing capabilities. In this paper, we illustrate a novel approach under study for the time calibration for the km^3-scale apparatus NEMO (NEutrino Mediterranean Observatory), focusing on its implementation for the NEMO Phase 1 prototyping campaign.

Introduction

Very large volume underwater or underice Cherenkov detectors represent nowadays the most common approach to neutrino astrophysics. The capabilities of these experiments are strictly dependent on how well time measurements are performed by the single sensors. In fact, the reconstruction of the physical events, extracted from the large environmental background typical of the marine abysses, is based on the possibility to properly align in time the measurements performed by a large number of widely spaced sensors.

In all cases in which the signals are digitized and time-stamped offshore, two different tasks are required in order to be able to perform correct time measurements: synchronization of the electronics, i.e. the delivery of common clock signals to the whole apparatus, and time calibration of the sensors, i.e. the measurement of how the local time measurements performed by the individual sensors compare to the time measured onshore. For such time calibration an embedded system is required in order to track the possible drifts of the time offsets during the operations of the apparatus underwater.

In this paper we illustrate the time calibration approach under study for the NEMO (NEutrino Mediterranean Observatory) Project, focusing in particular on the implementation and performance of a system tailored to the needs of the NEMO Phase 1 prototyping campaign. The same approach can be anyway scaled to serve any underwater neutrino telescope.

The NEMO Project

The NEMO Collaboration has been established in 1998 with the aim to carry out the necessary R&D towards an underwater neutrino detector with a sensitive volume of the order of the km^3.

The NEMO Collaboration has identified a suitable site for installation of such apparatus at a depth of 3500 m, about 80 km off the coast of Capo Passero, at the southernmost tip of Sicily, Italy.

The proposed layout of the telescope consists of 81 semi-rigid vertical structures, called *towers*, placed on a square grid with a pitch of 140 m in either direction. Each tower will be equipped with 72 large-area photomultipliers, for a total of 5832 sensors in the whole apparatus. More details on the apparatus design and on the activities of the collaboration are reported in a dedicated presentation at this conference [1] and elsewhere [2, and references therein].

The NEMO Phase 1 Demonstrator

As an intermediate step toward the design of a full-scale km^3 apparatus, the NEMO Collaboration has performed the Phase 1 program, aimed at the implementation and operation of a reduced-size prototype of the apparatus at an underwater test site, located at 2000 m depth about 20 km off the coast of Catania, in Sicily, Italy.

This site is connected to a control station located in the port of Catania by means of a long-distance electro-optical cable, one branch of which serves a second underwater test site devoted to geoseismic observations.

The Phase 1 prototype consists of an underwater junction box and a reduced-size tower of the apparatus. The installation of these objects was performed in late 2006. Stable data taking has been performed since then.

The schematic layout of the Phase 1 tower is shown in Figure 1. As the figure shows, the tower is composed of 4 floors, spaced by 40 m. The bottom floor is at 100 m above the sea bed. Each floor consists of a bar of 15 m length, equipped with four optical modules, each containing a photomultiplier tube (PMT) and its associated electronics. The optical modules are located at the two edges of each bar, in such a way that two of them are oriented downward, the other two horizontally.

The data acquisition of the optical modules of each floor is controlled by the Floor Control Module (FCM), who is in charge also of control of the local instrumentation and of all communications with the shore station.

The communications between each FCM and the shore are based on a synchronous communication protocol at a data rate of 800 Mbps. This choice guarantees enough bandwidth to transport to shore all the data collected, without any offshore filtering.

A Dense Wavelength Division Multiplexing (DWDM) technique is used in order to sustain such high data rates on a limited number of optical fibers: standard wavelengths at 50 GHz spacing are used to communicate to and to receive data from each floor. The system is based on simple Add&Drop devices and no active components are needed in the whole path between each FCM and its onshore counterpart.

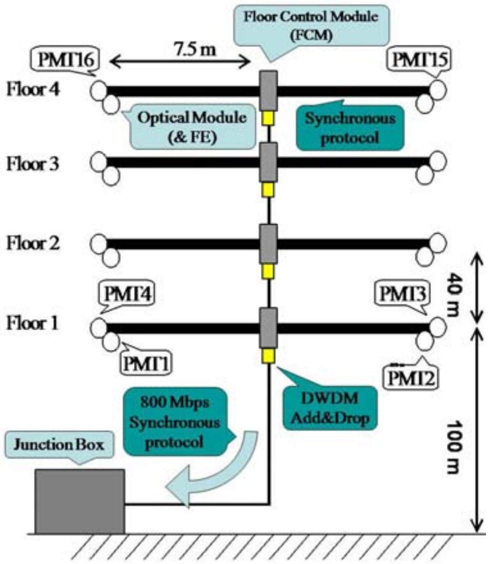

Figure 1: Layout of the prototype tower of NEMO Phase 1.

Symmetric systems are implemented offshore and onshore. This gives the possibility to implement simple elaboration schemes onshore for detection of local signal coincidences. At the same time, it is possible to address individual communications to the different floors of the towers from the shore station.

The front-end electronics (FE) is located inside the optical modules. The main features of the FE can be summarized as follows:

- the signals are compressed before sampling with a quasi-logarithmic law;
- the analogue signals are then sampled and digitized at the frequency of 200 MHz.

The latter operation is performed with two staggered fast-ADCs operated at 100 MHz.

The data are recorded when a threshold value, remotely set from onshore, is reached. When this condition occurs, the readout of a 16-bit counter, which is incremented at 100 MHz, is also recorded to provide information on the pulse detection time. In this way, it is possible to determine the time of the individual samples with a resolution of 5 ns, while sub-nanosecond resolution is achieved by reconstructing the full waveform of the signals starting from the values sampled at 200 MHz. Periodic commands for resetting these counters are broadcasted from shore to the whole apparatus.

The Time Calibration System

As explained in the previous section, the time measurements are performed by the optical modules by referring to a counter which is incremented at a fixed frequency and is periodically reset upon execution of a reset-command sent from the shore.
The task of the time calibration system is therefore to measure the offsets with which these time counters are reset, i.e. the time delays for the reset commands to reach the individual sensors. This operation is performed by sending calibration signals at known times to each optical modules and by comparing the known values of time with the measurements performed. In this way, the time response of the photomultipliers is also taken into account correctly.
The system comprises fast optical pulsers and a network of dedicated optical fibers which connect each optical pulser to a group of optical modules, as illustrated in Figure 2.

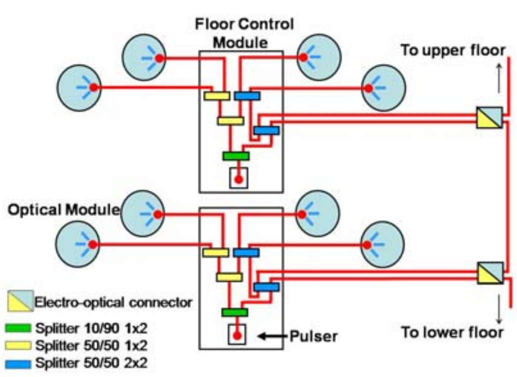

Figure 2: Layout of the time calibration system of NEMO Phase 1. A network of optical fibers (in red) distributes calibration signals from fast optical pulsers to groups of optical modules of consecutive floors.

The whole system is controlled onshore by the same station which performs the clock synthesis and distribution to the whole apparatus. This station is based on a single PC, connected to a GPS receiver from which it receives the GPS time information and synchronization signals. Single communications channels are maintained from this station with the different onshore boards which are interfaced to the offshore FCMs. A 4 MHz reference clock is distributed in this way in addition to time reference information.
This control station periodically performs time calibration operations, by executing user-defined procedures. An electronic logbook is maintained for each calibration session, so that an exact record of each operation is kept and the activation times of each offshore pulser are written; in such a way it will be straightforward to identify the calibration-induced signals in the data streams from each photomultiplier.
The key element of the time calibration system is the optical pulser. The schematic of this circuit, which improves the circuit discussed in [3], is shown in Figure 3.

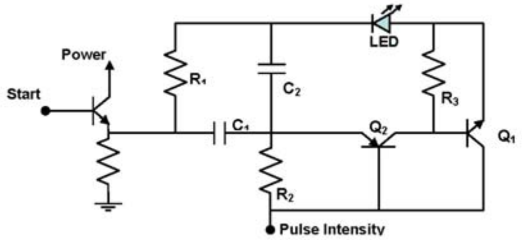

Figure 3: The optical pulser of the time calibration system of NEMO Phase 1.

The pulser features a LED Agilent HLMP CB15, which emits at blue wavelengths, as is needed, and with an aperture angle of 15°. In order to improve the light collection efficiency, the fiber is coupled to the LED by means of a commercial collimator Thorlabs F230FC-A.
Moreover, particular attention was paid to develop reliable and robust interfaces between the fiber and the LED as well as between the fiber and the photomultiplier. For the former purpose, a precision support was designed so as to ensur that the proper alignment between the LED and the collimator is maintained, in spite of the vibrations or mechanical shocks which may occur during transportation and deployment of the tower. For the latter purpose, a support was designed so that the edge of the fiber is fixed on the “neck” of the photomultiplier and oriented toward its photocatode. As Figure 4 shows, the light is then injected from the backside of the photomultiplier, at an angle of about 10° off its axis, chosen so as to maximize the signal amplitude.

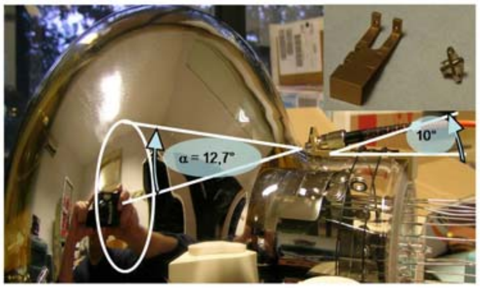

Figure 4: Coupling of the calibration fiber with the photomultiplier inside the optical module. The fiber is fixed, by means of the support shown in the insert, on the "neck" of the photomultiplier. The light cone has an aperture angle of 12.7°.

Extensive tests were performed in order to select the best optical fiber for this application. Thorlabs AFS50/125 was finally chosen, based on a comparison of the measurements that we had performed of light attenuation and dispersion of several singlemode and multimode fibers. The selected fiber is multimode with a core of 50 µm and has a numerical aperture of 0.22.

Convenient splitting ratios were chosen for the fiber network so as to ensure that signals of comparable amplitude are delivered to the different optical modules.

As a purpose of illustration, we show in Figure 5 the distribution of the time values for detection of calibration pulses by one photomultiplier of the NEMO Phase 1 tower. The very good resolution obtained in such analyses confirms the excellent stability of the system.

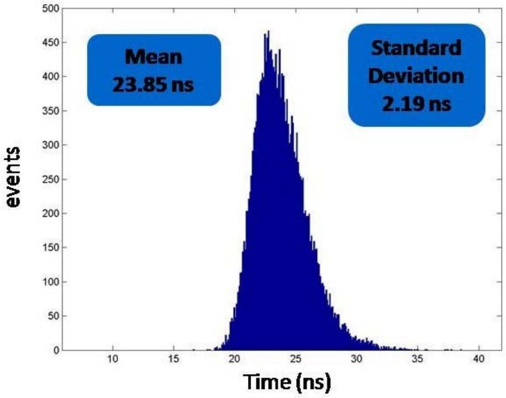

Figure 5: Distribution of the measured time values for the calibration signals detected by one optical module of NEMO Phase 1.

Conclusions and Outlook

The implementation of the time calibration system of NEMO Phase 1 was successfully completed. This system, which exploits a novel approach based on the usage of a dedicated network of optical fibes, has been long operated before and after the installation of the tower on the sea bottom. All tests performed confirm the full functionality of the system and its compliance to all specifications.

No significant change has been noticed in the PMT time offsets measured before and after installation of the tower in the sea.

The activities performed so far include the collection of a large statistics of calibration data taken at different intensity levels of the optical pulsers and the development of an automatic procedure for performing a full analysis of the calibration data sets and for extracting the matrix of time offsets of the optical modules.

The NEMO Collaboration has now launched the NEMO Phase 2 program, which foresees the installation of a full-size tower at the high-depth (3500 m) site proposed for the installation of a km^3 apparatus. The infrastructure for this site is under construction, and the tower is in an advanced state of design.

The time calibration system used in Phase 1 is currently being revisited in order to be adapted to the new configuration of the tower. In particular, an attempt is being made to move the optical calibration pulsers inside the optical modules, so that the system will require conductor rather than optical fiber connections. This upgrade will allow a significant reduction of the system cost.

References

[1] M. Taiuti, The NEMO Status Report, in Proc. of this Conference (ICRC2007).

[2] E. Migneco, Status of NEMO, Proc. of II Workshop on Very Large Volume Neutrino Telescope (VLVnT), Catania, 8-11 November 2005, Nucl. Instr. Meth. in Phys. Res. A 567, 444-451, 2006.

[3] J. S. Kapustinski, Nucl. Instr. Meth. in Nucl. Res. A 241, 612-615, 1985.