Qualification tests and readout electronics reliability analysis for the deep sea underwater telescope NEMO

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On behalf of the NEMO Collaboration

Abstract

The construction of a Km^3 scale underwater telescope for high energy neutrinos is a fundamental task for the development of the high energy neutrino astronomy. The NEMO collaboration is involved in an intense activity to develop apply and test technical solutions for a deep underwater laboratory devoted to study high energy neutrino component of cosmic rays. In this framework the front-end and readout electronics is one of the most important and delicate elements. This electronics must work properly for a long period of time (10 years) in an extremely hostile environment without any repair. For this reason high reliability is requested. In this work we present the test procedure and the reliability results of the NEMO readout electronics.

1. Introduction

Very large volume underwater or underice detectors represents, nowadays, the most common approach to neutrino astophysics. A first generation of small scale detectors has been realized and have set the limits on neutrino fluxes. Following these successuful experiences the realization of the IceCube km^3 detector has started at the South Pole. On the other hand, many issues, as the full sky coverage, strongly support the construction of a Km^3 scale detector in the Mediterranian Sea. For this reason the activity of the NEMO collaboration has been mainly focused on the search and characterization of an optimal site for the detector installation and on the developement of key technologies for the Km^3 underwater telescope. After many campaigns a deep sea site with optimal features in terms of depth and water optical properties has been identified at a depth of 3500 m about 80 km off-shore of Capo Passero (Sicily, Italy).The validation of the proposed technologies via an advanced R&D activity, the prototyping of the proposed technical solutions and their relative validation in deep-sea environment will be carried out with the two pilot projects NEMO Phase-1 and Phase-2 (1).

2. The NEMO Architecture

All the existing underwater neutrino telescopes are based on Cerenkov light detection by photomultiplier tubes as sensors. Due to assembly and deployment needs, all these telescopes are organized as arrays of vertical detection elements called lines, strings or towers. In the "a la NEMO" perspective, sensors are grouped in floors. The first floor is placed at 150 m above the sea ground. All the next are positionated 40 m far from each other.

The NEMO tower is composed of 16 floors. From a mechanical point of view a floor is a bar about 12 m long. Two benthospheres are located at each of its ends (i.e. four benthospheres per floor). Each benthosphere contains the Optical Module (OM) with a photomultiplier and a digitizing readout electronics board. For each floor data collected from readout electronics are concentrated in a unique device called

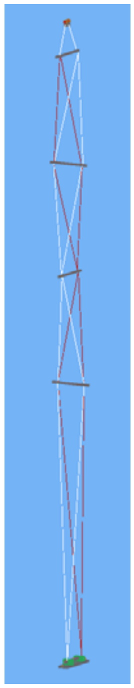


Fig. 1. The NEMO mini-tower

Floor Control Module (FCM) board (2) and sent to the shore laboratory via a 100 km electro-optical cable to a twin FCM board plugged on a PC. In this laboratory the data transmission, data acquisition and storage facilities are installed. The onshore FCM board is perfectly identical to the offshore one, while performing slightly different tasks.The use of the same board for the two sides of the communication cable gives the possibility to save R&D resources. The two boards have been differentiated by only using a different firmware.

3. NEMO Phase 1

During winter 2006 a mini-tower, equipped with 4 floors (schematically shown in fig 1), was employed for the pilot experiment called NEMO Phase1 in the NEMO test-site, about 20 km off Catania's port at a depth of 2000 m. Floor power and fibres are extracted from the electro-optical backbone by proper devices placed inside the breakout vessel (br). The floor electronics is powered by the Floor Power Module (FPM). All floor devices communicate with the on-shore laboratory through the Floor Control Module board (FCM): the main components are the Optical Modules, the oceanographic instruments used to measure water current (ADCP), water transparency (C*), sea water properties (CTD);

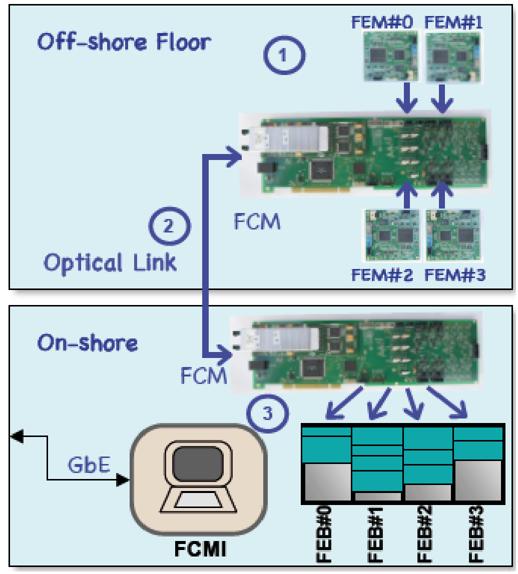


Fig. 2. Scheme of on-shore/off-shore point to point link.

acoustic positioning is implemented using a pair of hydrophones (H) placed at each floor end. The tower electro-optical cable can be connected to the main cable, which arrives from on-shore, by a submarine operable connector (HC). Even though the number of floors is reduced, the functionalities of the full tower are preserved, as far as possible, to have the deepest insight into the final system. In fact, the design of the mini-tower permitted us to test scalability issues in order to allow a progressive enlargement of the experiment just adding more and more towers. Fig. 2 shows the basic scheme of the floor data acquisition and communication system. Each floor is independent of the others and is connected by an optical bidirectional point-to-point link (indicated as (2)) to shore (1).

The PMT measurements and the monitoring data, produced by front-end boards, are collected by the FCM, packed together and transmitted through the optical link; control data are received from on-shore following the opposite direction. The on-shore host machine, called Floor Control Module Interface (FCMI), can be accessed through a Gigabit Ethernet (GbE) connection.

4. Qualification tests and reliability analysis

The offshore NEMO electronics is designed to work autonomously for a long period of time in an extremely hostile environment without any human repair. For this reason the NEMO electronics must have a very high reliability. Generally speaking the expectation is that complex systems, such as NEMO electronics, are not only free from defects and systematic failures when they are put into operation but also perform the required function failure free for a stated time interval and have a fail-safe behaviour in the case of critical failures. However the question of whether a given item will operate without failures during a stated period of time cannot be simply answered by yes or no. Experience shows that only a probability for this occurrence can be given. This probability is a measure of the item's reliability. To measure this probability it is very important to develop a qualification procedure to test the reliability of the system. In order to estimate the reliability of an experimental device it is important to evaluate some fundamental parameters such as required function, operating condition and the mission profile. The mission duration is also considered as a parameter t. The reliability function is then defined by R(t). R(t) is the probability that no failure at item level will occur in the interval (0, t], with the assumption R(0) = 1. The Mean Time To Failure (MTTF) of electronics components lies typically between 10^7 and 10^{10} hours. With such figures only accelerated tests are practicable. An accelerated test is a test which the applied stress is chosen to exceed that encountered in filed operation, but still below the technological limits. This is in order to shorten the time failure of the item considered by avoiding an alteration of the involved failure mechanism. In accelerated tests, failure mechanisms are assumed to be activated selectively by increased stress. The quantitative relationship between degree of activation and extent of the stress, i.e. the acceleration factor A_f, is empirically determined. Generally it is assumed that the stress will not have any influence on the type of the failure free operating time distribution function of the item under test, but it only modifies the parameters. From now on this hypothesis is assumed to be valid. Many electronic component failure mechanisms are activated raising the temperature. Calculating the acceleration factor A_f, the Arrhenius model(3) can often be applied over a reasonably large temperature range. The Arrhenius model is based on the Arrhenius rate law which states that the rate of a simple (first-order) chemical reaction depends exponentially on the temperature. By transferring this model to the mean time to failure we have:

$$MTTF = A \cdot exp\frac{E_a}{KT} \qquad (1)$$

where A is a parameter, E_a is the activation energy expressed in eV, K is the Boltzmann constant and T is the operating temperature. For a modern electronic device we can assume Ea = 0.75 eV so we can consider that MTTF depends basically on the temperature. Using the Arrhenius model it is possible to define the acceleration factor A_f as:

$$A_f = exp[\frac{E_a}{K}(\frac{1}{T_w} - \frac{1}{T_s})] \qquad (2)$$

Where T_w is the work temperature and T_s is the test temperature.

5. Test results

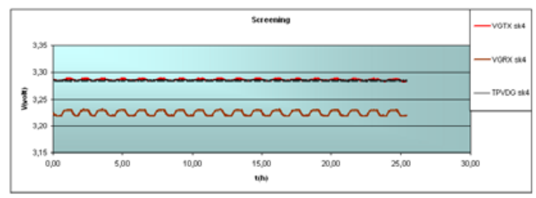


Fig. 3. Power supply voltages measured during the screening test.

Many qualification tests focused on FCMB, namely the crucial device of the NEMO DAQ system. In particular the reliability tests have been performed on the board power supply system due to its fundamental role in the board operation. The tests have been carried out in two different phases. The first one, the screening test, was dedicated to detect any constructional faults. During this test the operational temperature was periodically changed from 0° C up to 70° C and the output parameters of the devices have been measured.

Data did not shown any significant dependence on the temperature (fig 3). Furthermore the device

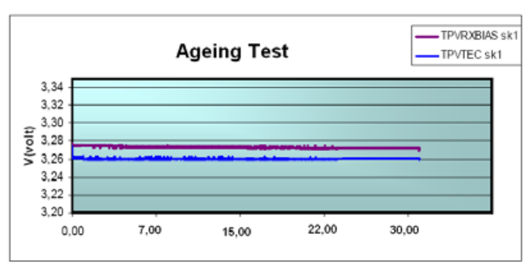
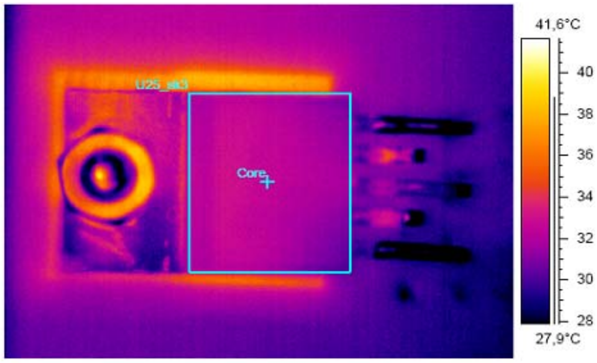


Fig. 4. Power supply voltages measured during the ageing test.



Analysis

Label	Value [°C]	Min	Max	Max - Min	Avg
Image		24,8	39,9	15,1	
Core	32,5				
U25_sk3		29,6	35,0	5,3	32,2

Fig. 5. IR image acquired after the ageing test.

under test (DUT) was inspected with an IR camera screening for any hot spots which are immediately related to functional defects. Also this inspection has shown no relevant problems. Accelerated life tests have been carried out in order to estimate the Mean Time To Failure of the FCM boards by using the operational temperature has a stress factor according to the Arrhenius model. The environmental temperature was fixed to 100° C, providing an acceleration factor AF = 1081 for the standard working temperature of about 14° C. The overall life time corresponds to about 30 years. DUT output parameters were monitored during the test and no system failure has been found.

Data analysis provide a MTTF greater than 0.9 x10^6 hours (fig 4). Also after the accelerated life test the DUT was inspected with the IR camera (fig 5) and no defect has been found.

References

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