KM3NeT Acquisition Electronics: status, upgrades and current developments

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Abstract. The KM3NeT Collaboration is building a neutrino observatory in the Mediterranean Sea, by installing thousands of optical modules distributed over a seawater volume of more than one cubic kilometer. These modules host acquisition electronics responsible for reading out 31 photomultiplier tubes. This contribution offers an overview of the KM3NeT acquisition electronics, emphasizing recent upgrades, ongoing developments, and reliability enhancements. The presentation addresses reliability improvements through theoretical FIDES analyses and practical HALT evaluations. Using the White Rabbit protocol, the clocks in the optical modules in the large-scale infrastructure are synchronized with a precision of 1 nanosecond.

1 Introduction

The KM3NeT Collaboration is developing two advanced neutrino telescopes at the bottom of the Mediterranean Sea [1], designed to detect neutrino interactions using Digital Optical Modules (DOMs) [2, 3]. Each DOM houses 31 photomultiplier tubes (PMTs) with acquisition electronics [4–6], which are arranged in vertical strings called Detection Units (DUs), with 18 DOMs per DU. To date nearly 60 DUs have been deployed, incorporating over 30,000 active PMTs that are collecting data. When completed the telescopes will feature over ten thousand acquisition nodes, forming one of the world's largest synchronized networks. In this contribution, recent upgrades to enhance the data acquisition and performance of the telescopes are presented. These include improvements of the central logic board, signal collection boards, a switching core board and the backplane.

2 KM3NeT hardware

The DOM is the main element in the KM3NeT telescope operation. The 31 PMTs and all the necessary electronics to control the operation of the DOMs are located inside. The principal electronic board is called the Central Logic Board (CLB), which manages and controls all the functionalities of the DOM. Connected to the CLB is the Power Board (PB), whose function is to generate the different voltages required by the DOM. Each PMT is connected to a base for the generation of the power supply voltage for the PMT and for the digitisation of the electrical signal. The bases are responsible for generating the power supply voltage for the

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PMT and digitizing its electrical signal to be sent to the CLB. The signals from the PMTs are forwarded to the CLB for processing using two boards known as the Signal Collector Boards (SCBs). Finally, each DOM incorporates a device called Nanobeacon for time calibration, which uses a pulsed LED [7].

2.1 Central Logic Board

The CLB [8–11], includes the firmware [12, 13] and embedded software [14] that manages the DOM's functionalities. The CLB has been designed to include a total of 12 layers, comprising 6 signal layers, 2 power planes, and 4 ground planes. These layers are arranged symmetrically around the 2 power planes. The positioning of the ground planes alongside the signal layers enhances the signal integrity. Special attention was given to routing the differential pairs to maintain a time difference of less than 100 ps between different PMT signals and less than 20 ps between clock signals. A reliability analysis was conducted using the FIDES method [15], which indicated an estimated failure risk of less than 10% over 15 years. Various signal integrity simulations were performed for the different signals present on the board, demonstrating a high level of discrimination. Several modifications have been made regarding the original board. One of the most important points has been the provision of a secondary clock circuit. Since KM3NeT is an isolated system that cannot be repaired or modified when in operation if the clock system fails, a backup clock system has been included to prevent the DOM from being completely lost. During the construction time of KM3NeT of several years, components can become obsolete. Several components in the CLB have already become obsolete, the most important being the Molex connector that connects the CLB with the SCBs. A redesign of the electronic board was necessary, replacing the Molex connectors with other SAMTEC connectors specifically designed for KM3NeT.

2.2 Power Board

Each DOM has a voltage converter that transforms the 375 − 400 V DC signal from the KM3NeT high-voltage system into 12 V DC. The PB [16] receives these 12 V and generates the necessary voltages for the DOM: 1 V, 1.8 V, 2.5 V, two 3.3 V (for the CLB and PMT power supply), 5 V, and an adjustable voltage between 5 − 30 V for calibration systems. If the voltages are correct, a "Power Good" signal is activated. Two ADCs measure all voltage and current values. The PB ensures a sequential start-up of the voltages, protecting the FPGA from excessive currents during start-up. In a new version the selection of voltage convertors is optimized based on the current requirements of each power rail, thus improving board efficiency.

2.3 Signal Collector Board

The LVDS signals from the PMT bases are sent to the CLB by two SCBs. The SCB Large handles signals from the 19 PMTs in the lower hemisphere, and the SCB Small manages the signals from the 12 upper hemisphere PMTs. The SCBs also send configuration and monitoring commands from the CLB to the PMTs. Key SCB components include a Molex 754332104 connector, a Xilinx Coolrunner CPLD chip, current sensors, current limiters, a multiplexer for I^2C lines, and a communication link for an acoustic piezoelectric sensor to the CLB. Also, the SCBs have been affected by the obsolescence of components, which has led to a redesign of the electronic board. Similarly to the CLB, the main obsolescence problem in the SCBs was the Molex connector that connects them to the CLB. A change to SAMTEC connectors with a specific configuration for KM3NeT has been necessary for these boards too.

2.4 White Rabbit Hardware

The KM3NeT experiment is an infrastructure composed of thousands of DOMs, which are responsible for detecting and processing the Cherenkov radiation induced by the charged particles produced in the neutrino interactions, to reconstruct the trajectory and energy of these neutrinos. For this the clocks of all DOMs, which are separated by even hundredths of meters, must be synchronized with a precision of 1 nanosecond. To achieve this, the White Rabbit (WR) protocol has been used [17]. WR is a hierarchical network topology designed on top of the Ethernet physical layer, based on bidirectional time Transmitter-time Receiver links, where the time Receiver nodes are the DOMs and the time Transmitters are the White Rabbit Switches (WRSs). This device allows for the combination of both synchronization and data packets on the same physical connection medium. It consists of two electronic boards: the Switching Core Board and the backplane. The main hardware of the WRS is the Switching Core Board, which is designed in the microTCA standard, which is a compact standard with a redundant power supply, and remote control, and designed to support high data rates. Due to the compact size of the microTCA standard, the optical connectors of the 18 switch ports are incorporated on another card that is attached using two QSS-048-01-LD-DP connectors. A reliability study based on the FIDES method was conducted, which revealed that decoupling capacitors were the components that contributed the most to increasing the device failure rate, known as FIT (Failures in Time). Therefore, the board was upgraded with new capacitors which improved the ratio between their maximum voltage and the voltage at which they operate in the WRS. The new capacitors will reduce the failure rate by 66% with respect the original version of the board, complying with KM3NeT reliability requirements. Testing of the produced switching core boards has also been enhanced. The main goal is to improve the reliability. The other electronic board that forms the WRS is called the backplane. It incorporates 18 Small Form-factor Pluggable (SFP) optical fiber transceivers. For KM3NeT a new design was necessary because of space constraints, power consumption, and reliability requirements, a new design was required. The board was designed with a different geometry and with different optical transceivers from the Glenair company, which provides improved reliability and power consumption.

3 Conclusions

The main electronic boards of the KM3NeT experiment and their basic operation within the experiment have been presented. The main upgrades of these boards have been described, as well as the main redesign criteria such as higher efficiency, improved reliability, and component obsolescence requirements. Indeed, the modifications and enhancements implemented have significantly improved the overall reliability and performance of the KM3NeT telescopes. These advancements have been adapted to component obsolescence ensuring the performance and minimising failure rates.

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