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Reliability Studies for KM3NeT electronics: The FIDES method

Diego Real[†]
IFIC- Instituto de Física Corpuscular, CSIC-Universitat de València,
Parque Científico, c/ Catedrático José Beltran, 2, E-46980, Paterna, Valencia, Spain
E-mail: `real@ific.uv.es`

Giulia Illuminati[*]
IFIC- Instituto de Física Corpuscular, CSIC-Universitat de València,
Parque Científico, c/ Catedrático José Beltran, 2, E-46980, Paterna, Valencia, Spain
E-mail: `giulia.Illuminati@ific.uv.es`

David Calvo
IFIC- Instituto de Física Corpuscular, CSIC-Universitat de València,
Parque Científico, c/ Catedrático José Beltran, 2, E-46980, Paterna, Valencia, Spain
E-mail: `dacaldia@ific.uv.es`

Stèphane Colonges
APC- AstroParticles et Cosmologie
Université Paris VII Denis Diderot - UMR 7164, Paris, France
E-mail: `colonges@in2p3.fr`

on behalf of the KM3NeT collaboration

High reliability of electronics is crucial for those systems operating in hard conditions, in particular when in-situ maintenance is not possible, as it is the case for space or deep-sea projects. The KM3NeT infrastructure, whose first Detection Units are currently being deployed on the Mediterranean Sea at depths of 2500-3500 meters, has chosen the FIDES method as reliability technique to estimate the failure in time of the different electronics boards. In the present article, the application of the FIDES method to the electronics of the Digital Optical Modules of the KM3NeT neutrino telescope is described in detail.

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[†] Corresponding author
[*] Speaker

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1.Introduction

The KM3NeT collaboration is developing, constructing and operating a neutrino telescope [1], in the Mediterranean Sea, at a depth larger than 2500 meters. The main purpose of KM3NeT is the detection of high-energy cosmic neutrinos. To achieve this goal, a 3-D matrix of light detectors is being deployed on the seabed, which will detect the Cherenkov light emitted by faster-than-light muons generated by neutrino interactions produced in the surroundings of the detector. The arrival time of the Cherenkov photons is acquired by the photomultiplier tubes (PMTs) and the associated electronics and it used to infer the neutrino arrival direction. Thus, the performance of the detector depends on the quality of the track reconstruction. The PMTs, 31 in total, and the associated electronics are housed in high-pressure vessels made of glass, the so-called Digital Optical Modules (DOMs). The DOM is the main component of KM3NeT. The electronics inside the DOM, which includes the PMT Base, the Octopus, the Central Logic Board (CLB) and the Power Board (PB), performs the digitalization of the PMT analogue signal, the synchronization with the rest of DOMs and the communications with the on-shore station. All these functionalities need to be provided during all the DOM operation life without applying any kind of maintenance as in-situ access is not possible due to the difficulties to access to the abyssal environment. Because of this, the reliability required for the KM3NeT neutrino detector is very high. The FIDES method helps to achieve and quantify the reliability desired by KM3NeT.

1.1 FIDES Methodology

FIDES is the reliability methodology chosen by KM3NeT for enhancing the quality of the DOM electronics boards. The FIDES guide [2] has been produced by the FIDES group, which is composed by several European companies from the defence and aerospace sector, as they are AIRBUS, Eurocopter, Nexter Electronics, MBDA or the Thales group, which develop high reliability products. The FIDES methodology is an engineering facility composed of two different sections, one provides a handbook for predicting reliability of the electronics boards under study, and the second one, a guide for audit and control in order to calculate the impact of processes on the final reliability. It can be applied to any domain using electronics. The main objectives of the FIDES guide is to perform a realistic estimation of the electronics board reliability under study and to provide a tool that will help in the production and the control of the reliability. Moreover, it helps to find weak points on the boards that can be addressed before the board mass production is launched. The characteristics that present the FIDES methodology are:

1.- It provides reliability models for the electronics components, resulting in a global reliability model for boards of sub-assemblies of components.
2.- It takes into account the physical and technological factors that have importance in the reliability of the boards.
3.- It takes into account the life profile.
4.- It takes into account overstress (electrical, mechanical and thermal)
5.- It takes into account all phases processes from production definition to operation, including production and design.

The FIDES method helps in taking actions throughout the life cycle of products increasing and improving their reliability, being one of the main characteristics for the identification of the technological, physical and process factors that contribute to the reliability of the boards.

Figure 1: Schematic picture depicting the three main areas of FIDES.

The FIDES method is different from previous statistics methods in the sense that it analyses field data and gets feedback from operation data and previous models to support its validity. The models, especially those related to the process factors, has been calibrated using the experience of the group members. FIDES is free of charge and a tool developed under java distributed on fides.reliability.org. Compared to other handbooks, the FIDES handbook has been recently updated. FIDES will become soon an international standard. This method is at present widely supported in the world.

2. FIDES applied to KM3NeT DOM Electronics

Four are the DOM electronics boards that have passed the FIDES method in KM3NeT: The PMT base, the Octopus, the CLB and PB [3].

- The PMT base provides the HV to the PMTs and digitizes the analogue signal of them, generating a Low Voltage Differential Signal (LDVS). This signal is active when the analogue signal overpass an adjustable threshold.
- The Octopus board transfers the LDVS signals between the PMT base and the CLB.
- The CLB measures the duration of the LDVS signals by means of the TDC modules. Moreover, the CLB is responsible of the synchronization and communication inside the DOM.
- The PB provides all the needed power for the CLB and the rest of the instrumentation. On the next section, the reliability studies obtained for the four electronics boards housed in the DOM are presented.

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The FIDES analysis has been applied to all the four boards in order to quantify their Failure In Time (FIT) and to find weak points that have been addressed before the production of the boards.

2.1 The process factor in KM3NeT. Recommendations for the expected reliability level

Prior performing the FIT evaluation, the process factor is evaluated. The process factor is an accelerating factor (multiplication of the FIT from 1 to 8) considering the impact of process on the system reliability. High reliability level is needed for KM3NeT, as the system will be installed in deep sea. The process factor obtained is 1.91 and it is the same for all the four boards. In order to reach this high reliability level, we have summarised (Table 1) the recommendation for each phase:

Specifications:	Reliability allocated resources in the management plan Environment perfectly known System requirement and design review planned with reliability aspect System maintenance policy defined in a document
Design	Skills table should be established Complete rules updated (know how capitalization) Database capitalizing feedback
Production	Improve the equipment final test (test coverage) Burn-in / ESS procedure and test coverage Corrective maintenance for problems appeared during production Monitor operator skills should be established Production procedure and tools validated in a document Sub-assembly protection means Quality soldering indicators Statistical process control ESD protection and ESD counters are available Configuration management to be implemented (design changes, component changes, firmware/software version…)
Integration	Ensure handling and packaging procedures Non conformities management, preventive and corrective actions Traceability (date code…) and configuration management Products and processes documentation Test equipment, final inspection, acceptance criteria clearly described in the QA plan or written procedures, etc. Assembly procedure clearly defined Human skills clearly identified Control the workplace environment and the production and test equipment Process change management ➔all changes recorded ESD protection and counter available
Field operation& maintenance	Ensure spares handling and storage procedure are written Preventive and corrective actions implementation ensured Ensure product and non conformities traceability (failure backtracking database) Ensure inspection and test (failure detectability and analysis during operation) Commissioning ➔tests, final inspection ➔written procedure (or in QA plan) Documents available (test procedure, user manuals, etc.) Identify human resources and skills necessary Workplace environment and tools for maintenance ESD protection and counter

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Support	Inspection dossier: acceptance criteria, inspections and tests list, associated documents Allocate infrastructure to protect equipment against degradation risk. Enough space available Define performance indicators about reliability engineering and reliability improvement process is described Reliability training and provide resource for reliability tasks Measuring devices are verified Measure the reliability of the system in operation Plan reliability activities Use FRACAS: Failure Reporting, Analysis and Corrective Action System

Table 1: Main recommendations to achieve high reliability levels in KM3NeT.

3. FIDES results

Using the FIDES excel tool, the "Failure In Time" (FIT) and the "Mean Time To Failure" (MTTF) have been calculated for each board. One of the first actions to be performed is the definition of the environmental conditions. That is mainly the definition of the operational temperature when the DOM is on and when it is off. The data are presented in Table 2.

Phase	Mean temperature	Max temperature	Min temperature	Delta T°	Remark
Hot case ON	17	17	17	0	The temperature is stable in the deep sea
Safe mode (OFF)	13	13	13	0	Stable temperature in deep sea

Table 2: Environmental conditions in KM3NeT.

The FIT is the quantity of failure per 10^9 hours. The total FIT is the sum of each individual component FIT. No uncertainty margin has been added. MTTF is the Mean Time To Failure (when not reparable, like electronic component). MTBF is the Mean Time Between Failures (when reparable). Over a period, the probability of failure could be calculated using the formula:

$F(t) = 1 - R(t)$

With R(t) the probability of a system to be still alive over a time period *t*.

$F(t) = 1 - e^{-\lambda t}$

With λ is the board FIT value and *t* is the time period duration in hours.

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Product	FIT	MTTF (hours)
PMT Base	1218	820468
Octopus Large	157	6371772
Octopus Small	156	6396132
Power Board	1424	702502
CLB	417	2398985

Table 3: FIT and MTTF of the DOM electronics boards of KM3NeT.

In Table 3, the FIT and MTTF data obtained for the 4 types of board contained in the DOM are shown. The highest FIT value (and worst MTTF value) is obtained in the Power Board. To carry on a deeper investigation on the board, the FMECA (Failure Mode analysis) would be needed. With this method, it can be analysed if there are some non critical sections that could be excluded from the total FIT (as in fact it is the case of the nanobeacon power supply- The nanobeacon is one of the instruments housed on the DOM-, where a failure will have no effect on the performance of the detector). However, FMECA analysis is outside the scope of the present article. As summary, we can conclude that the results obtained fulfil, overall, the reliability level requested by KM3NeT.

4. Conclusions

In this article, the FIDES method and the result of its application to the KM3NeT DOM electronics has been presented. The main recommendations for acquiring the desired reliability level for an infrastructure where maintenance during the operation life will not be possible, have been taken into account. Moreover, the FIDES result for each DOM board have been also shown.

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