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The ANTARES Local Control Modules and their functional test bench characterisation

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The ANTARES Local Control Modules (LCMs) are electronic units achieving all the required functionalities inside a deep-sea submersed detector. LCMs sample, integrate, time stamp and digitise the analogue signals coming from different sources to which they are connected, pack and send to shore and to other LCMs the read out data together with a slow control flow and a synchronising stream of commands. This document reports on the LCM functionalities and on the construction of a dedicated test bench.

1. The ANTARES Local Control Modules

The ANTARES Collaboration is producing the first of 12 lines which will constitute a large undersea neutrino telescope located 20 km south of Porquerolles Island (France) at a depth of 2500 m [1]. The detector will be a three-dimensional array of photomultipliers distributed along 12 lines, each contained in a pressure resistant glass sphere called Optical Module (OM [2]). Three OMs including the PMTs looking downward at 45 degrees from the vertical constitute a storey: the front-end electronics is contained in a titanium cylinder acting as the Local Control Module (LCM) of each storey. LCMs are grouped in *sectors* of 5 units: one out of them contains the Ethernet switch which concentrates the data traffic coming from the other 4 and from itself. This particular LCM, called Master LCM (MLCM), transmits the Gigabit Ethernet data traffic to the String Control Module (SCM) located at the line base, using a Dense Waveform Division Multiplexer (DWDM) protocol. The main functionalities of the LCM are reviewed in this work: a functional view of the module is presented together with some of its design specifications. The production test bench, designed to detect manufacturing defects of the LCM assembly, is then described.

The main purpose of a LCM is the digitisation of the data coming from the OMs triplet, yelding a raw data stream containing information on time, charge and pulse shape of the detected events. Besides this main function, the LCM provides a set of features reported on Tab.1, where a decomposition of the LCM into its high level functional subsystems is also presented.

Two software processes, the *harnesses*, implement the LCM's DAQ/SC finite state machine. Each of them is dedicated to one particular data channel: OMs data acquisition (DAQ) and slow control (SC) commands and parameters read-out. Both channels share the same physical medium constituted by a monomode optical fibre transporting 100 BASE Ethernet data between each LCM and its sector's MLCM[1]. The third data communication channel is the clock (CLK) data link: its physical channel is separated from the DAQ/SC[2]. Unlike the DAQ/SC link case, two optical fibres are used to transport the clock channel in and out each LCM and MLCM. In more detail, the subsystem features presented in Tab.1 are:

Power supply. The Local Power Box (LPB) provides the required DC voltages to the various loads present in a storey: LCM's boards, OMs and additional Beacons, hydrophones or marine instruments. It is fed by a

[1] A pair of monomode optical fibres transport the Gigabit Ethernet data link from the MLCM to the SCM and vice versa.
[2] The actuation of the commands transported by the clock data link has not to deal with the finite state machine implemented by the two harnesses.

Table 1. Overview of LCM subsystems and their features.

LCM Subsystem	*External features provided*
Power Supply	electrical power to the external OMs and satellites together with a means to monitor and control their switching state and the high voltage ramping of the PMTs
Front end + DAQ/SC	digitisation of the various signal features and packing into homogeneous data frames
	transmission of the physical (OMs data acquisition) and parametrical data flow to the optical fibre communication link using an Ethernet protocol
	processing of the slow control (SC) command and data flow monitoring internal electrical parameters as well as environmental physical conditions (internal-external temperatures and internal humidity)
	handling of the information generated by the internal acoustic positioning system and by the compass-tiltmeter system
	monitoring of the LED and Laser Beacons used for the calibration (see [4] for the use of beacons on ANTARES time calibration)
CLK	sub-nanosecond timing synchronisation with the reference clock (generated on shore) and reception-distribution of synchronised (on shore and with other LCMs) commands
Mechanical structure	removal of the internal generated heat by conduction, avoiding hot air pockets inside the cylinder and reducing at the same time EMI propagation

380 Vdc system, common to all 5 LCMs in the same sector, capable of supplying a maximum time limited power of 200 W. The LPB monitors and controls, via the SC, its own generated DC voltages and the switching of 4 of its outputs to the OMs or other satellites connected to the LCM. The total output power of one LPB is about 60 W with an overall efficiency greater than 70%.

Front-end. The LCM discriminates the OM signals in two categories: 1) single photo-electron (SPE) and 2) complex waveform shapes. Depending upon this discrimination, only the time and the integrated charge are measured and digitised (first case), or (second case) the signal is sampled and digitised. Both features are provided, for each connected OM, by a dedicated board (ARS_MB) containing two ARS chips [3]. When present, the external light Beacon monitor PMT, or a different satellite requiring digitisation of its output, is connected to another ARS: the maximum number of ARS chips digitising analogue signals is then of 7. The configuration of each of the ARS chips may be changed via 74 internal digital registers setting all its internal thresholds and references, acquisition modes, and also controlling the chip behaviour. These *bitstream* configurations are held in a central database after having been selected during the characterisation of the ARS chips. The optimised bitstream maximising the performances of each ARS is used to calibrate the overall time, charge or amplitude transfer functions. These transfer functions, often approximated by a linear fit, are then compared with the responses (offset and slopes) obtained during ARS_MB and LCM level tests, and the settings are readjusted. The calibration task will be completed by dark room testing of the complete sector and by *in situ* measurements.

Clock (CLK). It provides a time reference and synchronous commands capabilities to the front end electronics. One digital 20 MHz clock signal is extracted from the CLOCK IN fibre incoming dataflow: the same dataflow also carries the synchronous control signals using commercially available data transceivers (HOTLink system developed by Cypress Semiconductors). The time stability offered by this subsystem is better than 0.5 ns with a synchronisation precision with the GPS time stamp better than 100 ns.

Data acquisition and slow control (DAQ/SC). The scheduling of the two harnesses, the readout of the raw ARSs physical data flow, its organisation in 13.107 ms long frames and their sending to the Ethernet link together with the slow control data flow are in charge of this subsystem. More precisely, the read-out and the control of the front-end electronics are achieved by a Xilinx FPGA while the control of the I/O busses and ports at board level, of the Ethernet link and of the LCM's DAQ memory are in charge of a Motorola MPC860 PowerPC.

Mechanical structure. The aluminum crate has been designed to offer a complete cooling solution for all the electronic boards populating the LCM: the hotspots of the high dissipating devices are glued with heat-conducting paste to cooling bases bolted to the crate; the crate itself holds two large hemicylindrical cooling plates spreading the heat, through an air gap, to the external titanium cylinder at seawater temperature. Eight shielding plates, thermically glued to the crate, divide it in 9 compartments for electronic boards: they increase the rigidity of the structure and also help reducing EMI radiations. Great care has been put in offering a dedicated routing path for all the optical fibres traversing the interior of the crate, being prone to signal attenuation or ruptures in case of improper bending.

2. LCM Test Bench Overview

Because the detector will be inaccessible during operation, the reliability of all the components constitutes a crucial issue concerning its construction. A total number of 240 LCMs and 60 MLCMs must be assembled at three different production facilities and then sent to two different line integration facilities where the 12 strings are built to be ready for deployment. All the electronics boards and the mechanical parts are produced by different companies and sent to the LCMs assembling sites after individual testing. The bench testing of a large serial production of a complex electro-mechanical item like the LCM is, involves the use of various bench equipment to trigger the module and measuring its responses. It needs to be highly automated: the large number of test settings and their configuration parameters together with the need to shorten the total testing time (given that the schedule of the line deployment is already planned) put an upper limit to the number of tests which an human operator may perform. Furthermore, its ease of operation is a factor to be considered on its own: involving the test of several subsystems and their known or supposed failure modes, the test bench must provide its users with the largest possible flexibility in changing test strategies or applying different sets of parameters.

The LCM Test Bench is based upon a set of LabVIEW[3] virtual instruments which control both the bench and the two harnesses processes running on the LCM Under Test. It offers a scripting language allowing the expert user to fine tune the test flow, implementing two classes of tests: 1) *functional*, aimining at verifying all the external features reviewed above, and 2) *physical*, as part of the module calibration task. After its assembly, the LCM is connected to the bench and the operator chooses the test flow to be performed between a predefined list: different LCM configurations may in fact require different testing strategies. No cooling is provided during the test flow and the overall procedure (power on period for the LUT) has been contained within half an hour in time. The basic test flow verifies: 1) good general assembly (internal routing of optical fibres, internal/external electrical connections) 2) data channels (DAQ/SC and CLK) and 3) front end features (time, charge and shape information). Besides that, the bench has been designed for being capable of running many production tests and supporting the three LCM production facilities. A strong effort has been put to offer the flexibility of a modular architecture as well as a minimal requirement on the overall instrumentation used.

[3] LabVIEW is a commercial graphical development environment developed by National Instruments.

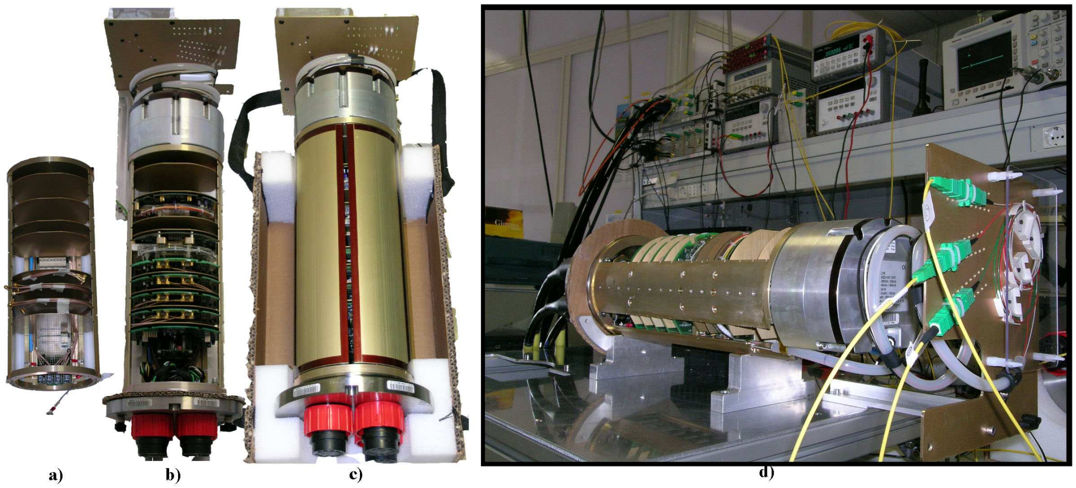

Figure 1. Photographs showing various phases of the LCM manufacturing process: **a)** the 9 compartment aluminum crate; **b)** the LCM populated with all electronic boards, LPB, titanium endcap holding the connectors to the OMs (bottom side) and optical fibre protection tube (top); **c)** the LCM closed with its hemi-cylindrical cooling plates; **d)** an opened LCM connected to the Test Bench. On the foreground (right) the three optical fibres exiting the LCM. On the background (left) the three submarine cables used to link the LCM with its satellites.

3. Conclusions

The main external features of ANTARES Local Control Modules have been presented together with its high level functional description and with the basic characteristics of the system which has been built to bench testing its mass production. The LCM design has been proved robust and functional during its prototyping phase: its production is starting at the time of writing and the first batch of 25 modules will be completed by the end of July 2005.

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