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The KM3NeT/ARCA Calibration Unit

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The KM3NeT/ARCA calibration unit is a dedicated calibration system designed to improve the accuracy of the acoustic positioning system of the detector optical modules and monitor the water column physical properties. The calibration unit is composed of a calibration base and an instrumentation unit, connected with an electrical inter-link cable. The deployment of one calibration unit for each of the two building-blocks, in which the ARCA detector is subdivided, is foreseen, with the first one to be deployed in 2024. The calibration base is made of an anchoring structure, connected for power supply and communication to a junction-box, where an acoustic beacon and a hydrophone used for the positioning system are mounted and which hosts a pressure vessel containing the required electronics. The instrumentation unit consists of an anchoring base and a 750m-long inductive line, kept vertical by a top buoy and equipped with oceanographic sensors. The base is linked to the calibration base for power and readout and hosts an absolute pressure gauge used as depth reference and a vessel containing the electronics for managing sensor communication. The line hosts two sound velocimeters and two conductivity-temperature-depth probes equipped with dissolved oxygen sensors, to measure sound velocity and allow for the determination of acoustic wave speed, and two Doppler current sensors to provide information on sea current speed and direction, further improving the accuracy of the positioning system.

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1. Introduction

The KM3NeT underwater neutrino telescope consists of two detectors, ORCA and ARCA [1], implemented as large-volume 3D arrays of Digital Optical Modules (DOMs) [2] hosting photomultipliers tubes (PMTs) and placed at a depth of ~2450 m off-shore Toulon, France (ORCA) and of ~3500 m off-shore Sicily, Italy (ARCA). Both detectors are made of vertically aligned Detection Units (DUs), each hosting 18 DOMs. In their final configuration, ARCA will have 230 DUs and ORCA 115 DUs. Each DOM contains 31 3-inch PMTs, calibration and positioning instrumentation including a light emitter and readout electronic boards named Central Logic Boards (CLBs). Each DU is equipped with a top buoy to provide vertical support and is anchored to the sea-floor with a heavy anchor frame which also incorporates the DU Base Module (DU-BM) and calibration devices such as hydrophones, lasers, acoustic beacons. The DU-BM hosts the electronics for powering the DU and a CLB for instrument control and data readout. In ARCA, DUs are connected to submarine Junction-Boxes (JBs), which act as electrical and optical fiber distribution systems, distributing data and power from the main electro-optical cables to the DUs and vice-versa. JBs are also endowed with hydrophones, lasers and acoustic beacons. While both ARCA and ORCA feature the same detection elements, they have distinct layouts designed to suit their respective scientific objectives; in particular, ARCA is designed to study cosmic neutrinos from the TeV to PeV scale and their possible astrophysical sources. The PMT array detects Cherenkov light emitted when relativistic charged particles traverse the detector volume. The recorded data is then utilised to determine the direction and energy of the incoming neutrino, which is responsible for generating these particles. In order to reconstruct neutrino direction with a precision better than 1°, DOMs need to be synchronised with nanosecond accuracy [3], and their exact location determined with an accuracy < 20 cm [4]. Having an impact on sound propagation, sea water properties must be continuously monitored because they affect the positioning calibrations.

To meet these goals, KM3NeT is going to deploy several dedicated Calibration Units (CUs). Measurements of the environmental parameters will be also exploited for Earth and marine sciences studies, providing the capability for continuous online monitoring of the marine ecosystem for extended durations. Due to the different specific requirements of ARCA and ORCA detectors and their sizes, the design of the CUs differs between the two sites. This proceeding provides a comprehensive description of the features, the objectives and the current status of the first ARCA CU that will be depolyed shortly; for the ORCA CU, refer to [5].

2. Positioning calibrations

Under the effect of deep sea currents, DOMs tend to float around the vertical position which must hence be continuously monitored as well as their orientation, provided by internal compass data. This is done by means of a relative acoustic positioning system (APS) which relies on an auto-calibrating Long-Baseline (LBL) system of emitters and receivers displaced in the detector volume, located on the detector elements and on additional autonomous tripods. The accuracy in the determination of the DOMs position with respect to the LBL reference system, required to reach the desired detector angular resolution, is ~10 cm [7] CUs are going to improve the APS in several ways: adding permanent acoustic beacons and hydrophones in the sea-floor network, providing measurements of sea currents along water column and allowing the characterization of sound velocity in the medium with precise measurements to be used in combination with data from the APS.

3. KM3NeT/ARCA Calibration Unit

The Calibration Unit is divided into two main components, connected by a 700m-long electrical ROV-operable inter-link cable: the Calibration Base (CB) and the Instrumentation Unit (IU). The CB will be connected to a JB via a 300m-long standard DU electro-optical inter-link for power and communication with the shore station. Detailed descriptions of the CB and the IU are in Sec. 3.1 and Sec. 3.2. Their locations at the ARCA site are shown in Fig. **??** along with the foreseen dates of deployment.

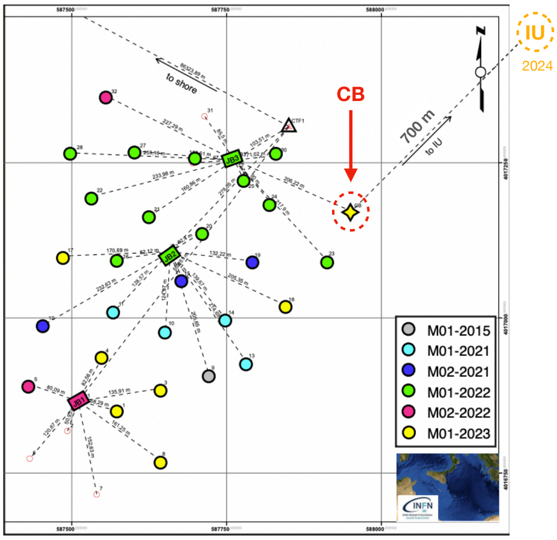
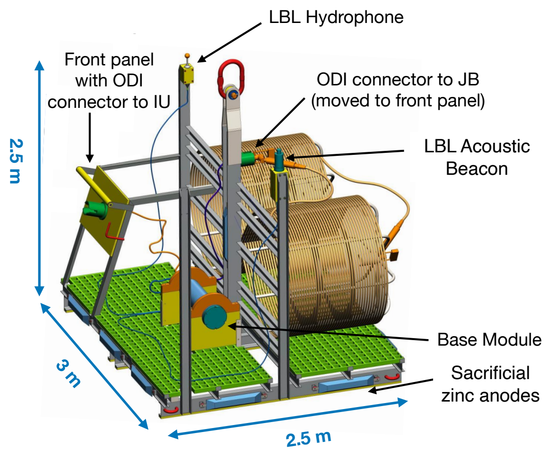


Figure 1: The current ARCA sea-floor map; coloured circles (boxes) indicate installed and next-to-be-deployed (Sep. 2023) DUs (JBs), while the straight lines indicate the inter-link cables connecting the DUs to the JBs. The colour scheme follows the sequence of marine campaigns indicated by a progressive number and the year. Highlighted are the positions of the CB and of the IU. The IU position is chosen to be in safe distance from the DU array and, according to the dominant current measured at site, to minimise the risk of line drifting into the field during deployment and recovery operations.

3.1 KM3NeT/ARCA Calibration Base

The main role of the CB is to contribute to the detector APS by adding a LBL hydrophone and an acoustic beacon to the network. These instruments are mounted on the CB frame and are connected to a BM which contains the electronics for managing the power and communication both with the shore station and with the IU. The main components of the CB are described in the following subsections and are shown in Fig 2a.



(a)

(b)

Figure 2: (a): mechanical structure of the Calibration Base: components and instrumentation are highlighted. (b): the Calibration Base during integration.

3.1.1 Anchoring frame

The CB is a compact structure made of primary and secondary iron crossbars welded together in a configuration which is expected to be effective against corrosion phenomena. It has a central load-bearing beam and two lateral beams to support the hydrophone and the acoustic beacon, and it features a high density polyethylene (PEHD 500) front panel where the ODI ROV-operable plugs [9] for the inter-links towards the JB and the IU are integrated. PEHD 500 is also used for the supports that fix the BM, the hydrophone and the acoustic beacon to the structure. All the bolts and screws used to fix the components with plastic supports are made of titanium. In order to guarantee protection against corrosion for long-term deployment, all the metal surface is coated with anti-corrosion painting (standard NORSOK M-501 [8]) and a cathodic protection system with eleven ~12 kg sacrificial zinc anodes located on the bottom sides and on the central beam is applied. The base includes fiberglass grids easing the assembly and preventing the anti-corrosion painting from scratching during integration. Initially, the structure was built with a support for hosting the inter-link towards the JB and the corresponding ODI connector was foreseen to be integrated on a panel adjacent to the central beam; since this inter-link has been separately deployed in advance, the connector has been moved to the front panel to facilitate ROV operations.

3.1.2 Instruments

The selected hydrophone is the DG1330, a digital omni-directional hydrophone specifically designed and produced by Colmar S.r.l. [10] for KM3NeT to be operated at 3500m depth. It consists of a spherical piezo-ceramic element, read-out by an analogue board splitting the signal in two lines with different gains (+46 dB and +26 dB). The low gain channel has been implemented in order to prevent signal saturation due to the acoustic emission from the beacon in close proximity (~3 m), while the high gain channel is used for analyzing data received from distant beacons, spanning up to a few kilometers, as well as for studying faint acoustic signals, such as those related to bioacoustics, environmental noise, and acoustic neutrino detection [11]. It includes an analogue signal high-pass filtering stage at 700 Hz to reject the low frequency ambient sea noise and improve the signal to noise ratio in the detection of beacon pulses range (20-40 kHz). The sampling frequency is 195.3 kHz, and the acceptance frequency range is 5-90 kHz. The two streams are sampled with a stereo 24 bit commercial ADC (CS-4270) and converted into AES/EBU protocol using a digital interface transmitter. The acoustic beacon is the Mediterraneo Senales Maritimas [12] MAB 100, endowed with a FFR SX30 acoustic transducer. The electronic boards are contained in a shielded titanium case resisting up to 4000m of depth. The beacon is programmed to autonomously emit every 30s its unique modulation signature carried by a sweep signal ranging from 40kHz to 36kHz, but it can also emit with external triggers. Both instruments are connected to the CB-BM via a common GISMA [13] MCIL6M connector, and linked through it to the CLB via the FMC board (see Sec. 3.1.3). Connection for power and communication is done via RS-485 with a RJ45 connector for the hydrophone, while the acoustic beacon power is taken directly from the BPS board (see Sec. 3.1.3) and communication uses RS-232 lines connected to the FMC. The clock from the CLB, synchronised to the master clock in the shore station, is exploited to timestamp data retrieved by the hydrophone and can be used to emit synchronised triggers to the acoustic beacon.

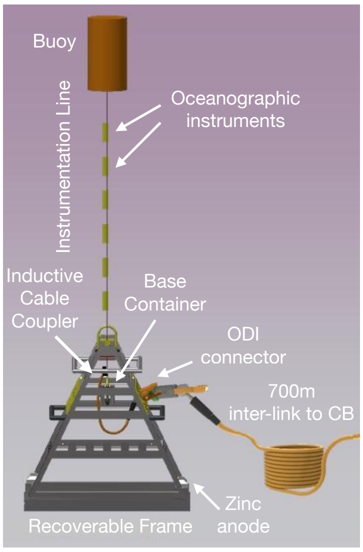
3.1.3 Base Module

The mechanical container of the ARCA CB-BM is made of titanium and it is identical to the standard ARCA DU-BM, except for the interface flange where the connectors for the CB instruments and for the two jumper cables towards the plugs for the IU and the JB inter-links are located. The internal frame is also identical, excluding the electrical and optical elements used to connect the DU-BM to DOMs. The BM hosts the following electronics boards:

- The Base Power Supply (BPS) board receives 375VDC power from the JB and converts it into low voltage to power other electronic boards installed in the BM, the CB instruments and the IU.
- The Central Logic Board is the core of KM3NeT front-end electronics, installed inside each DOM and BM. Regardless of the detector element where they are integrated, all CLBs are identical except for the installed firmware. The CLB in the CB-BM receives commands and the common clock from the shore station and, through the FMC board, it interfaces the BPS, the CB instruments and the IU. Communication between CLB and shore station is established using an SFP laser integrated into the CLB.
- The FPGA Mezzanine Card (FMC) is a piggy pack board mounted on the CLB. It enables CLB communication with BPS, CB instruments and IU.

3.2 KM3NeT/ARCA Instrumentation Unit

The role of the IU is to acquire data regarding sea water properties. It is composed of the Instrumentation Line (IL) and the recoverable frame, shown in Fig. 3a. The IL is an inductive line, kept vertical by a top buoy, which both provides support for the oceanographic sensors and acts as transmission medium of the inductive transducers used to communicate with them, avoiding additional conductors. The frame consists in a metallic anchoring structure which hosts the Base Container (IU-BC) where the electronic boards are located, a front panel with the ROV bulkhead



(a)

(b)

Figure 3: (a): ARCA IU main components. (b): the IU recoverable frame after integration.

plug for connecting the IU-BC to the CB, an absolute pressure gauge and the inductive coupler for the IL. Communication between the CB and IU instrumentation occurs through inductive modems. Two types of modem are present: a Seabird [14] Inductive Modem Module (IMM) hosted inside the IU-BC to allow the communication between the CLB in the CB-BM and inductive sensors, and Seabird SBE-44 Underwater Inductive Modems to interface non-inductive serial sensors to the line. The SBE-44 provides also battery power to connected sensors through a wired power link. A Seabird Inductive Cable Coupler, located on the frame, couples the IMM to the inductive cable.

3.2.1 Recoverable frame

The recoverable frame structure is made of stainless steel coated with anti-corrosive painting (standard NORSOK M-501) and cathodic protection is granted by two ~12 kg welded sacrificial zinc anodes. The front panel and the support floor for the IU-BC and the other devices are built in PEHD 500. The frame has been designed in order to be recovered every two years, together with the IL, for batteries change and instrument re-calibration. To preserve the inter-link cable to the CB during recovery operations, a long-term cable parking terminal frame will be used.

3.3 Base container

The IU Base Container is a titanium pressure vessel containing an electronic board that receives the power and communication lines from the CB. The IMM is mounted on this board, from which it receives 12V power and which also includes a serial converter from RS-422 to RS-232 standards. The board is connected to the CB through a DMS connector on one of the vessel flange via a jumper cable to the ROV connector on the front panel. On the other flange, another DMS connector is used for the cable coupler connection to the board. The floor and the supports which fix the container and the instruments are made of PEHD 500, while titanium screws are used.

3.3.1 Instrumentation Line

The inductive cable is a 750m-long, 3x19-strands galvanised jacketed wire rope with swaged socket terminations to allow grounding with seawater. The IU is equipped with the following instruments:

- Two native inductive conductivity-temperature-depth probes with pressure and optical dissolved oxygen sensors. They measure conductivity, temperature and depth and allow indirect calculations of sound velocity in water as a function of temperature, pressure and salinity through Chen and Millero [16] or Del Grosso's [17] formulas. They will be used to improve the fits of the APS. Measurements of oxygen and salt concentration (the latter inferred from conductivity) in water, as well as its temperature, will be used for oceanographic studies;
- Two non-inductive sound velocity sensors. They perform a direct measurement of the sound velocity in water, thus contributing to improve APS fits.
- Two non-inductive Doppler current sensors. They perform measurements of the sea current along the 3 directions and will be used to improve the mechanical DU line fit model [15].
- One non-inductive pressure gauge, used as absolute depth reference to improve the accuracy of the APS; its measurements will also allow geo-oceanographic studies on the variation of sea depth and can be used to monitor earthquakes and tsunamis.

Collected data will be made available to European oceanographic observatories and organizations such as ESONET-EMSO [18]. The instruments will be distributed along the water column as

Height from seabed (m)	Instrument	Measurement
650	Valeport [20] mini-SVS	Sound velocity
600	Seabird SBE-37 IMP-ODO MicroCAT CTD	Conductivity, temperature, pressure
550	AAndera [19] ZPulse Doppler Current Sensor 4520R	Current velocity
200	Valeport mini-SVS	Sound velocity
150	Seabird SBE-37 IMP-ODO MicroCAT CTD	Conductivity, temperature, pressure
100	AAndera ZPulse Doppler Current Sensor 4520R	Current velocity
0	Paroscientific [21] Digiquartz Depth Sensor 8CB4000-I	Pressure

Table 1: Oceanographic sensors mounted on the Inductive Line, and respective indicative height from the seabed.

shown in Tab. 1, where models are also indicated.

4. Outlooks and conclusions

The first ARCA CB is fully tested and ready to be deployed, while the IU is under finalisation: the recoverable frame is integrated, and instruments have to be configured and mounted on the inductive cable; a final communication test with the integrated IU will be done before preparation for deployment, foreseen in 2024. Firmware for CLB and software for communication with CB and IU instrumentation have been tested. The software update to the detector control system required for interfacing to the IU instruments and to store its data in the KM3NeT database is under development.

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