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Prototypes of the most critical parts of the deployment/recovery system

In this document we discuss, and where it is possible we describe, the most critical parts of the future Neutrino Telescope Infrastructure (main electro-optical cable, horizontal cables, primary Junction Boxes, Secondary Junction Boxes, …) with a special attention to the deployment, positioning and eventually recovery operation. All these elements of the Infrastructure have been studied in such a way to optimize their functionality but also in order to facilitate and make possible their deployment, connection and eventually the recovery.

The operation of the ANTARES experiment, the experimental activities of the NEMO and NESTOR project have allowed to develop several techniques for the deployment and positioning of the several elements of the future infrastructure. The real tools needed for the final deployment will be developed once the final mechanics of the apparatus will be drawn. Here we describe how the different parts of the Infrastructure will be realized, how the deep-sea cables network, Junction Boxes, Detection Units will be distributed in order to facilitate all the deployment/connection operations, which deep sea tools (ROV and manipulators) will be needed.

In some case (the Junction Boxes of the ANTARES and NEMO experiments, the NEMO Medium Voltage Converter, the ROV acquired by INFN-INGV, the Main Electro-Optical Cables of ANTARES, NEMO, NESTOR infrastructures) allowed us to have a "prototype" of a deep sea infrastructure needed for the deployment/recovery operations: in this case the prototype has allowed to gain direct experimental knowledge.

1. Study of the Telescope Deep Sea Network

1.1 General description

The detector layout presented in this document is the result of a configuration optimisation performed with a Monte Carlo simulation described elsewhere in this document. The geometry parameters that have been optimised are: the spacing between detection units; the spacing between storeys; the bar length of the storey as well as the number and orientation of the PMTs in the storey.

We assume here that the Detection Units (DU, already described in this document) will be, schematically, arranged on the seabed in a hexagonal form with 180m spacing between DUs (Fig. 1). For reasons connected to deployment and connection operations a wider distance between the towers located on the central axes has been also envisaged.

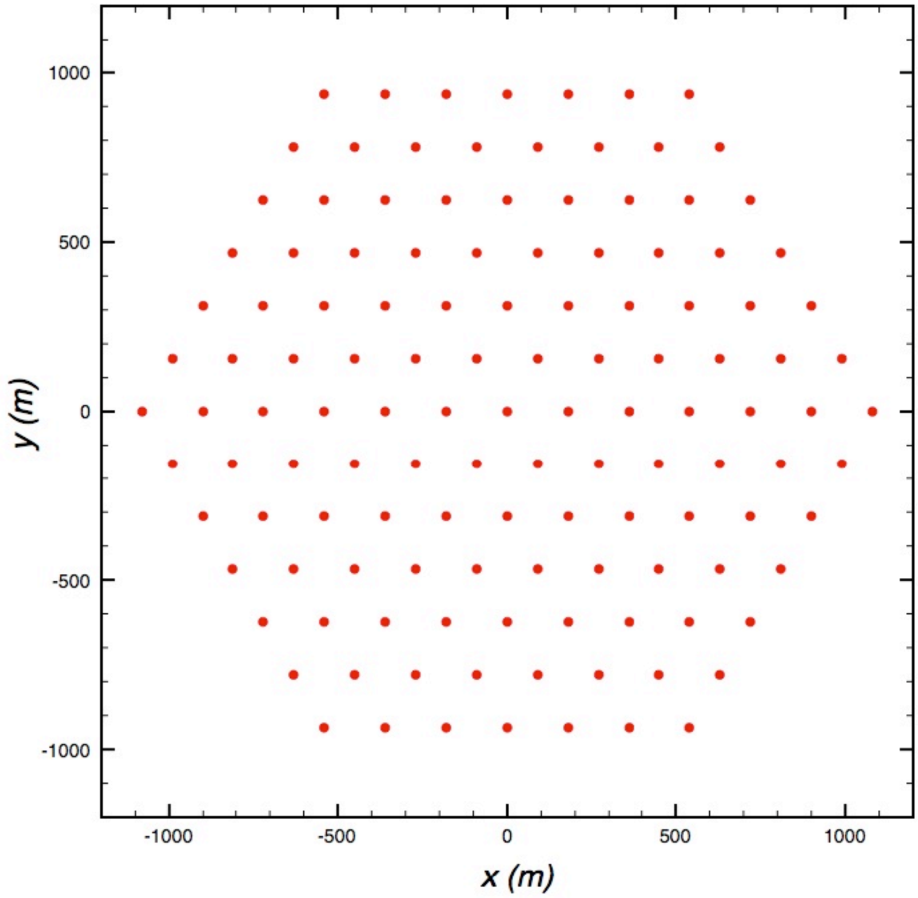

Fig. 1 – Seafloor layout for the 127 DUs detector.

A Main Electro-Optical Cable (MEOC) will provide the connection of the detector to shore for power feeding and data bidirectional transmission. A hierarchy of Primary (PJB) and Secondary (SJB) Junction Boxes will allow the distribution of services to the individual DUs.

In deep sea, the mechanical structures holding the optical modules move under the effect of currents, thus their positions must be continuously monitored using an acoustic positioning system (acoustic beacons and hydrophones).

Two kind of solutions for the data and power distribution layout have been proposed, one is based on a "star" like layout of cables (see **Error! Reference source not found.**), the other distribution is characterized by a "ring" geometry" (see Fig. 14). The two solutions have not been developed at the same level of details so the first one will be extensively described, the second one will be mentioned at the end of the chapter as one of the study going on.

1.1.1 Power and Fiber Optical data connection with a "star" layout

The connection of the on-shore laboratory and the telescope is provided by a system of optical fiber carried by the MEOC and distributed the DUs by a network that involves the PJB and the SJB.

Here we start with the description of the "star" like layout.

Fig. 2 shows the scheme of the power and fibre optic distribution.

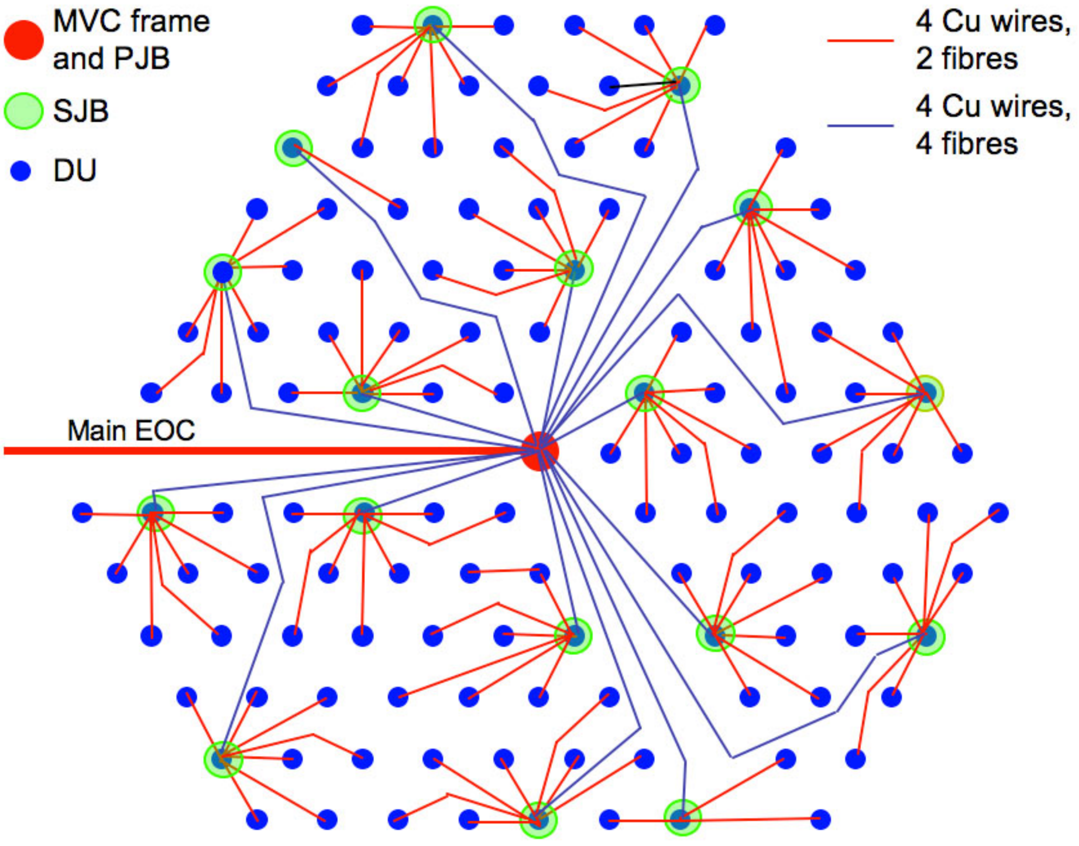

Fig. 2 - Scheme of power and fibre optic distribution.

The scheme has been defined taking into account limitations dictated by the cables and PJB, SJBs and DUs deployment and interconnection operations. Three "corridors", ~300m wide, are realized separating the whole detector into three parts such to allow for the laying of the MEOC and the passage of an ROV for deployment, connection and maintenance operations. The PJB (and the MVCs) is located at the centre of the detector. All the SJBs are located either along the "corridors" or externally to the detector layout. Each SJB is connected to eight DUs (only one is connected to 4 DUs and 1 to only 2 DUs) in agreement with the requirement of the solution chosen for data transmission on optical fibres. The cables (from PJB to SJBs and from SJBs to DUs) are never superimposed; the cable lengths are as short as possible mainly to reduce the power dissipation (the length of cables from PJB to SJBs are less than 1.5 km, from SJB to DUs are less than 400m).

1.1.2 Power Distribution

The power feed and distribution system is based both on the experience gained in ANTARES and NEMO. It takes into account current market availability and deployment issues.

The main design requirements considered are:

- 127 DUs;
- power load of the individual DUs up to 300 W.
- distance to shore of the deep-sea installation up to 100 km;

The total power load, off-shore, for the 127 DUs amounts to about 38 kW.

The power consumption foreseen for the Associated Science equipments will amount to about 10 kW, so the total power that will be required off-shore is of the order of 48 kW.

It will be described later that, including all power losses, the on-shore power needs will amounts to less than 70 kW.

The power feed system is in DC and is based on a 10 kV / 375 V DC, 10 kW Medium Voltage Converter (MVC) like the one developed by Alcatel for the NEMO project, based on a design developed by JPL-NASA for the NEPTUNE project (ref. B. Howe et al. IEEE J. Oceans Eng. 27 (2002) 267 and http://www.neptune.washington.edu)

The MVCs needed to feed the required power load are located in a frame placed close to the Primary Junction Box. The power distribution to the DUs is in low voltage (375 V). The optimization of this solution requires an opportune location of the PJB, i.e. at the centre of the detector layout, in order to avoid the use of long and/or large section cables from PJB to SJBs.

The electrical power system is divided into the following subsystems:

- a Transmission System, going from shore to the deep-sea site, including the on-shore power supply, the MEOC and its terminations;
- a Distribution System, going from the off-shore MEOC termination to the DU base;

The distribution system has been designed in such a way to guarantee a voltage drop, and Joule losses, (from PJB to DU) less than 4%;

To follow this requirement the cables should have the following characteristics:

- PJB-SJBs cable: 4 Cu conductors, with 13 mm^2 cross section, 600 V nominal voltage and a maximum length of 1500 m;
- SJB-DUs cable: 4 Cu conductors with 2,5 mm^2 cross section, 600V nominal voltage and a maximum length of 400 m.

The power flow from on-shore to off-shore for the 127 DU apparatus, and the Associated Science equipment, is summarized in Table 1 and in Fig. 3.

Number of DUs	127
Power load per DU	300 W
Power load per 127 DU	38.1 kW
Interconnecting Cables Joule losses (375 V DC) < 4%	1.6 kW
Interconnecting Cables voltage drops	< 4%
Associated Science power load	10 kW
MVC losses (η = 80%)	12.4 kW
Total power off-shore	62.1 kW
Main cable Joule losses	6.7 kW
Total power losses	30 %
Power on-shore	68.8 kW

Table 1 -Power budget for the 127 DU detector.

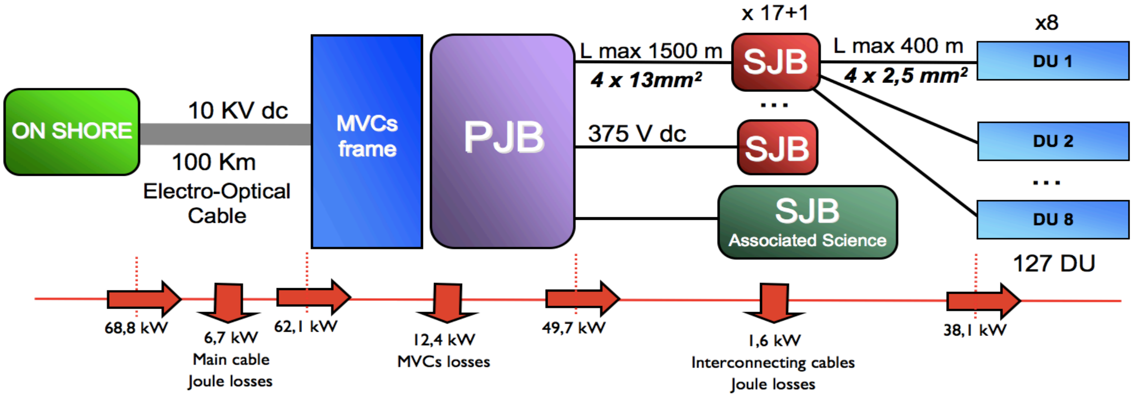

Fig. 3 - Power flow block diagram.

1.1.3 Power transmission system

The Transmission System from shore to the detector deep-sea site is in DC with sea return. Its main components are (Fig. 4):

- an on-shore 70 kW Power Feed Equipment with a 400 V AC 3-phase input voltage, a 10 kV DC output voltage and 7 A output current;
- a 10 kV DC MEOC with a single conductor and sea return;
- two earth terminations, the anode on-shore and the cathode off-shore.

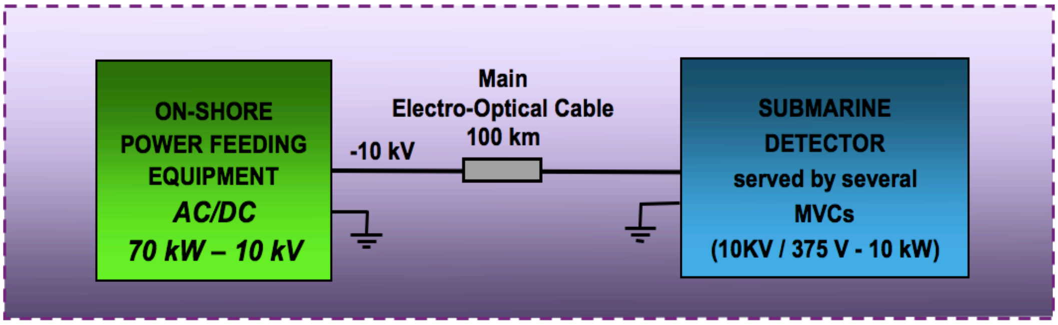

Fig. 4 – Block diagram of the power transmission system

The power distribution system goes from the off-shore MEOC termination to each DU base. The voltage conversion, from the transmission value of 10 kV to the distribution one of 375 V, is done by means of Medium Voltage Converters. We envisage to use 7 MVCs, one for redundancy, of the type developed by ALCATEL for the NEMO project, to accommodate the ~60 kW power load (included losses) located into a frame positioned close to the PJB.

The Primary Distribution System includes:

- 1 Primary Junction Box;
- 17 Secondary Junction Boxes (15 SJBs are connected such that each one serves 8 DUs, 1 SJB serves 4 DU)
- a 18th SJB is dedicated to the Associated Science equipment, providing a 10kW maximum power feed.

A schematic example of a layout that optimizes the cable lengths is shown in Fig. 2. The system is characterized by the following maximum distances:

- PJB - SJB: 1500 m;
- SJB - DU: 400 m;

The power distribution (Fig. 5) is a 375 V DC star configuration from the PJB to the SJBs and from each SJB to the 8 DUs.

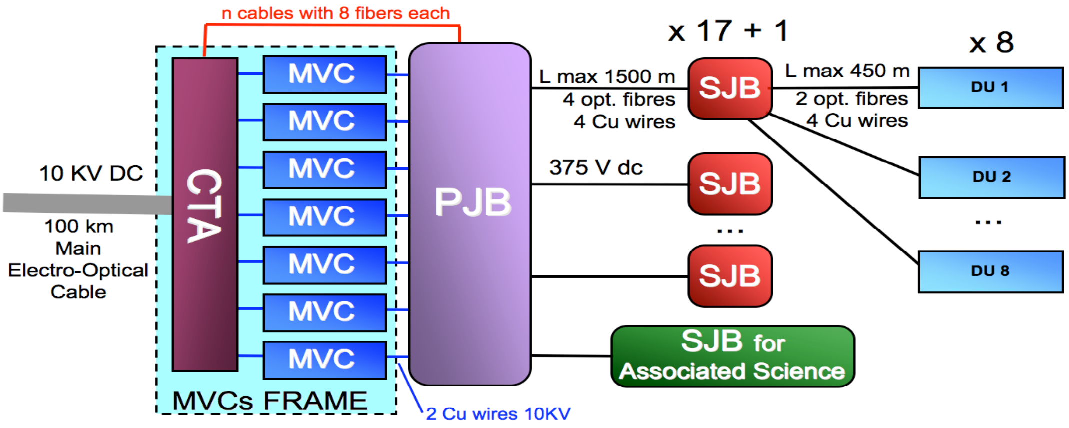

Fig. 5 – Block diagram of the Primary Distribution System.

1.1.4 Cables and Connectors

A Main Electro-Optical Cable (MEOC) will provide the connection of the detector to shore for power feeding and data bidirectional transmission. The properties of the MEOC will be more extensively described in Chapter 3.

The MEOC characteristics, according to the power transmission needs previously described in this document are summarized in **Table 1-2**.

Length [km]	100
Type of power to be transmitted	DC, one polarity + sea return
Maximum Voltage [kV]	10
Maximum Current [A]	10
Power Transmission efficiency	95%
Cable resistance [Ω/km]	1
Number of fibres	up to 48

Table 1-2 - Main Electro-Optical Cable characteristics

The MEOC has will be equipped with standard monomode G655 fibres (MFD, LEAF or NZDSF fibres).

One example of MEOC already deployed for deep-sea data and power transmission is the 100 km cable that will operate between the Capo Passero on-shore laboratory and the deep sea site at 3500m depths.

The MEOC will be connected to the MVCs through a Cable Termination Assembly box where conductors and fibres are split. The CU wires exit from the CTA (2 Cu conductors) by means of dry HV penetrators and are connected to the MVCs by means of dry HV connectors (Purely electrical). The fibres exit from the CTA, in groups of 8, with optical penetrators, and go to a Panel equipped with bulkheads ROV operated connectors (purely optical). From this Panel the fibres will be connected to the PJB by means of cables (with only 8 fibres) and purely optical deep-sea ROV operated connectors. The Panel contains also bulkheads connectors to allow the electrical connection of the 375V MVC outputs and the PJB inputs, using ROV operated deep-sea electrical connectors.

The PJB to SJB and the SJB to DU cables have to be dimensioned according to the power needs and the number of fibres required by the data transmission system.

The interlink cable between the PJB and each SJB has the following characteristics:

- 4 Cu conductors with 13 mm^2 cross section, 600 V nominal voltage
- 2 fibres for each group of 4 DUs connected. This means that the cables that will interconnect the PJB and those SJB that serve 8 DUs will contain 4 fibres.

The interlink cable between each SJB and a DU has the following characteristics:

- 4 Cu conductors with 2.5 mm^2 cross section, 600 V nominal voltage
- 2 fibres

The interlink cables are terminated with hybrid ROV mateable connectors. The sum of conductors and fibres in the interlink cables should be no more than 8 (see Fig. 10), this permits to use of hybrid COTS connectors.
This interlink EO cable connects the DU base to the secondary JB. All the designs propose to have, during the deployment, this cable wound on a reel and fixed to the anchor. The cable ends by a wet mate connector of hybrid type or by a pair of such connectors, one electrical and the other optical. The reel as well as the connector is handled by a ROV.

1.1.5 Medium Voltage Converter

At the end of the MEOC there will be a Frame Termination Assembly that will hosts:

- a cable termination assembly to permit to split power and fibre optics,
- a system of Medium Voltage Converters (MVC),
- a Splitting Box with several output wet-mateable connectors.

A MVC has been developed within the activities of the NEMO experiment by ALCATEL: this experience can be the basis of the KM3NeT future hardware.

The converter has an input of up to 10 kV DC and output of 375 VDC/28 A. The measured efficiency is greater than 87% at full load. The converter configuration is 48 Power Converter Building Blocks (PCBB) arranged as matrix of 6 parallel legs with 8 in series in each leg (Fig. 6). This arrangement allows for faults within some PCBB's without a failure of the full converter.

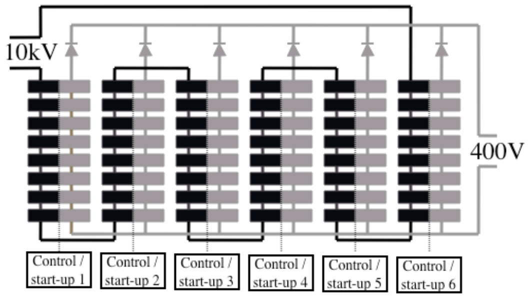

Fig. 6 – The DC/DC Medium Voltage Converter layout

The PCBB is a pulse width modulated switching forward converter with an input of 200 V and an output of 50 V at around 200 W. Each block has four MOSFETs, two working as a primary switch and two on the secondary side as a synchronous rectifier. A block diagram of the circuit is shown in Fig. 7. The various transformers are able to withstand continuous 10kV operation in a dielectric fluid.

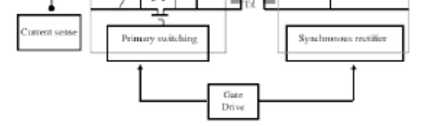

Fig. 7 – The DC/DC Medium Voltage Converter PCBB block diagram

The entire power converter is housed in a pressure vessel, Fluorinert® filled to facilitate the cooling and reduce voltage clearances. An entire stack, that include eight PCBB in four boards and a control board it's shown in Fig. 8.

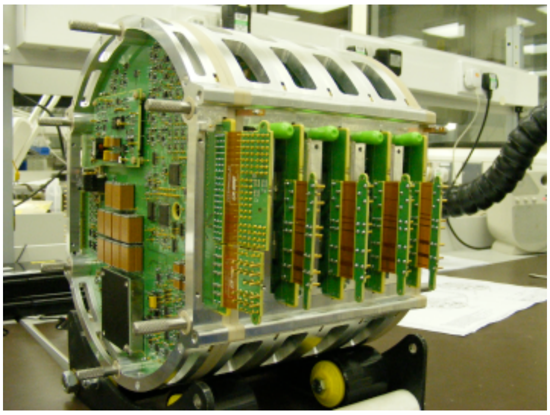

Fig. 8 – The DC/DC MVC complete parallel "stack"

Its final arrangement, it's shown in Fig. 9.

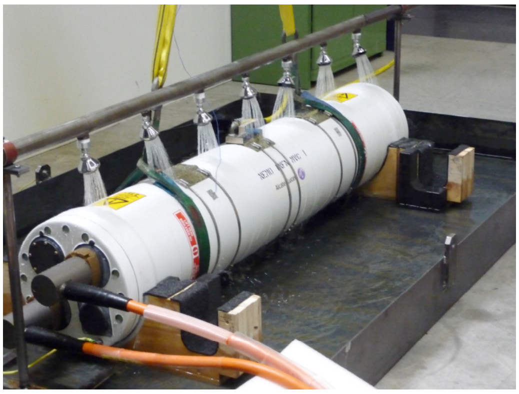

Fig. 9 – The Medium Voltage Converter complete assembly

After several years of design, development, assembly and testing, the MVC delivered on September 2009. Several tests have been carried out to verify the functionality and performance of the MVC in particular working conditions: long feeding lines from the 10 kV power supply to the MVC (100 km), long interconnecting cables of the MVC output with the electrical loads and distributed switching DC/DC converters as electrical loads.

The results of the tests were positive as the MVC worked properly without causing any oscillation or instability in the system. The main characteristics of the MVC are showed in Table 1-3.

Input Voltage	5,7 ÷ 10 kV
Output Voltage	375 V
Output current	25 A
Input shut down voltage	5,2 kV
Efficency at 6kV, full load	88,9%
Efficency at 10kV, full load	85,4%
Voltage undershoot at 10kV -10% to 90% step up	40 V
Voltage overshoot at 10kV -90% to 10% step down	43V
Output Ripple Voltage	1,5 Vrms at 100 kHz

Table 1-3 - Medium Voltage Converter characteristics

1.1.6 Junction boxes

The seafloor network will consist of a main electro−optical cable running from the shore to a main junction box in the deep sea and of a network of secondary junction boxes linked by electrooptical cables and connecting to the telescope detection units and the associated sciences nodes. The final design of the network is still under development and may incorporate redundancy to mitigate single point failures.

1.1.7 Primary Junction Box

The block diagram of the Primary Junction Box is shown in Fig. 10. Its main functions are:

- to accept the 375 V power from the Medium Voltage Converters (MVC). Several MVC units will be used to accommodate the total power needs;
- to distribute power to the Secondary Junction Boxes (SJB). The input power lines from MVCs will be connected inside the PJB in such a way that a SJB can be feed by more than one MVC providing the needed redundancy (Fig. 10);
- to monitor and control all the electrical parameters of the outputs lines;
- to remotely actuate the relays that connect the SJB to the MVC system, to switch on and off the feed lines during normal operation and to isolate a faulty line;

- to communicate to shore by means of optical fibres.

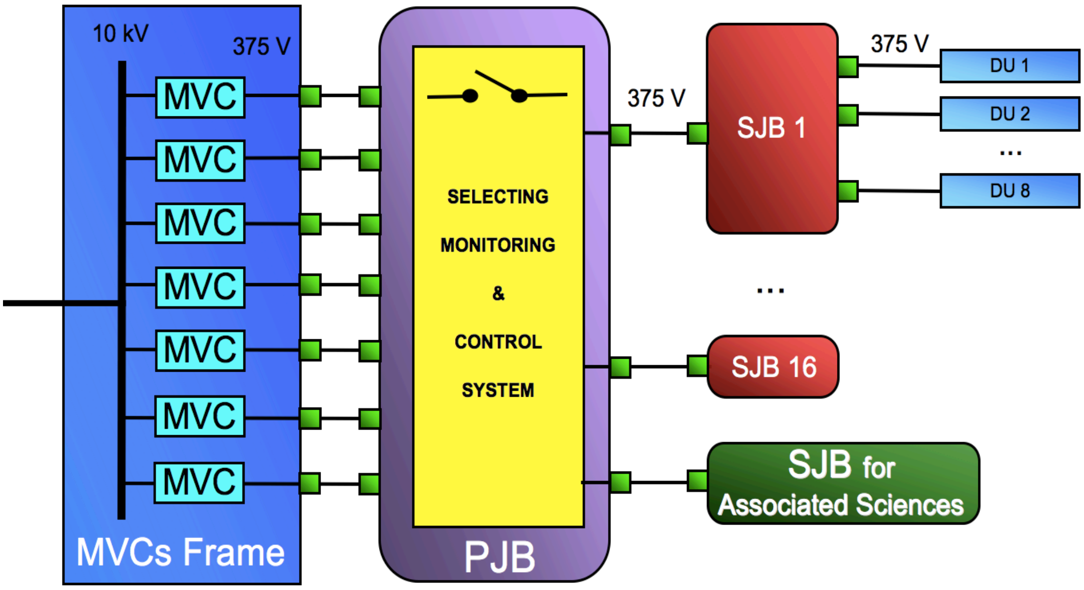

Fig. 10 – Block diagram of the Primary Junction Box power transmission.

The final design of the PJB is not available. Two PJBs have been developed in the framework of the projects ANTARES and NEMO. The final project will be based on the achieved experience.

The ANTARES junction box structure, illustrated in Fig. 11, is based on 1 m diameter titanium pressure sphere, with hemispheres separated by a central titanium cylinder (“belt”) through which all power and data connections pass to the exterior.

Fig. 11 – The ANTARES JB on the deck of the deployment ship.

The JB internal pressure is 1 bar while the ambient external sea pressure is ~250 bar. Each hemisphere is sealed to the belt with two concentric ‘O’ rings. The lower hemisphere contains an oil[1]-immersed 24KVA transformer (the ANTARES power transmission is in AC) while the upper hemisphere contains the power system slow control electronics. Following component installation, the JB sphere was qualified in a 24 hour pressure test at 310 bar (20% overpressure) in the 2.5 m diameter caisson at Comex S.A., Marseille. The sphere is supported within a rectangular titanium transit cage suspended from a pivoting arm during deployment. The cage incorporated an acoustic transponder to allow triangulation of the junction box position during deployment, an electrode for the return of current to the shore, an entry guide to protect the undersea cable from scuffing during the deployment procedure, and a plugboard equipped with 16 deep sea-mateable electro-optical connectors allowing umbilical cable connections to junction box outputs using the manipulator arm of a manned or remotely operated submersible vehicle.

The NEMO Junction Box is a key element in the streamline between the shore station and the NEMO neutrino telescope. It has been built and operated, for the 4 floors NEMO-tower deployed in the NEMO test site, at 2100m depths, in front of the Catania port. It is located at the maximum depth close to the apparatus, and it is connected to one side to the MEOC originating from the coast and to the other side to the elements of the telescope. Its functions are manifold and include:

- the electrical and data transmission;
- the control of the power feedings systems connected to the JB;
- optical and electrical deep-sea mateable connectors that can be operated by Remote Operated Vehicle (ROV)

It has been designed to host and protect the opto-electronic boards, dedicated to the distribution and the control of the power supply and digitized signals, from the effects of corrosion and pressure. The JB mechanics has been produced developing an alternative design to the standard Titanium pressure vessels. The basic idea consists in decoupling the pressure and the corrosion problems. The NEMO JB is realized by a pressure resistant steel vessel hosted in a fibreglass container. The volume between the inner steel vessel, capable to resist to the external pressure, and the fibreglass container is filled with oil[2] in such a way that the external fibreglass container, capable to resist to long term corrosion, is in equi-pressure. This solution improves the reliability and reduces costs by avoiding the use of expensive alloys.

The NEMO JB (Fig. 12) is composed by:

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[1] Nynas 10GBN napthalene-based transformer oil, meeting ASTM spec D3487 type 1

[2] DOW CORNING® 561 Silicone transformer liquid

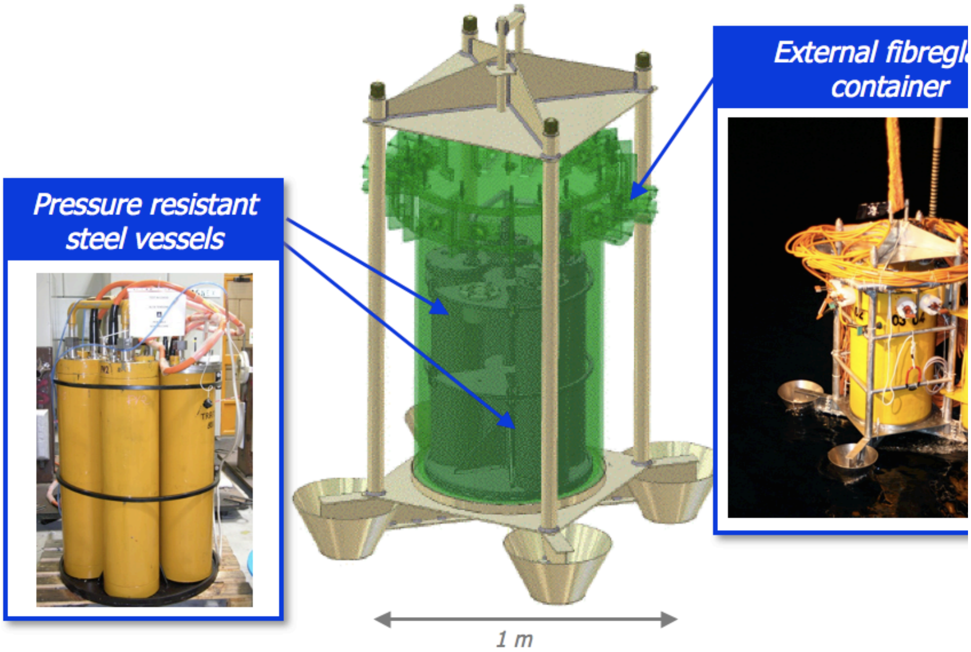

Fig. 12 – The NEMO Junction Box.

External components:

- The glass-reinforced plastic container, with an internal volume of 1.5 m^3;
- The external frame;
- One pressure compensator for the internal vessel-fibreglass oil circuit;
- One acoustic beacon for the positioning system;

Internal components:

- Four Pressure Vessels, hosting transformers and electronics boards;
- One Splitting Box (SB) to splice fibres and wires;
- The internal frame.

The aluminium external frame has been designed to guarantee feasible and reliable sea operations and deployment as well as good stability on the sea-ground; it hosts the glass-reinforced plastic container. The glass-reinforced plastic container, hosts the bulkheads of ROV operated deep-sea mateable connectors.

Several pressure vessels contain the control boards of the NEMO power supply and data transmission systems. Since the NEMO JB has been built to be operated at 2100m depths in front of the Catania port, the pressure vessels have been designed to withstand an external pressure of 350 bars. Therefore the electronics board there contained can operate when needed either in an oil bath or in air. This choice also does not lead to a significant increase of the Pressure Vessels costs and it allows an absolute flexibility in the project choices about the control electronics.

1.1.8 Secondary Junction Box

Each SJB serves a group of no more than 8 DUs and is located close to one DU such that the distance to the other DUs is less tan 400m. Its function is to distribute the power coming from the PJB to 8 DUs. The power distribution network inside the SJB is shown in Fig. 13.

The SJB will host:

- a Power Feed System able to supply all the internal loads;
- a Monitoring & Control System able to switch on and off the output lines and to monitor all the lines electrical parameters;
- input and output 600 V wet mateable connector, spare included. The sum of conductors and fibres in the connector should not exceed 8 (see Fig. 10) to allow the use of hybrid COTS connectors.

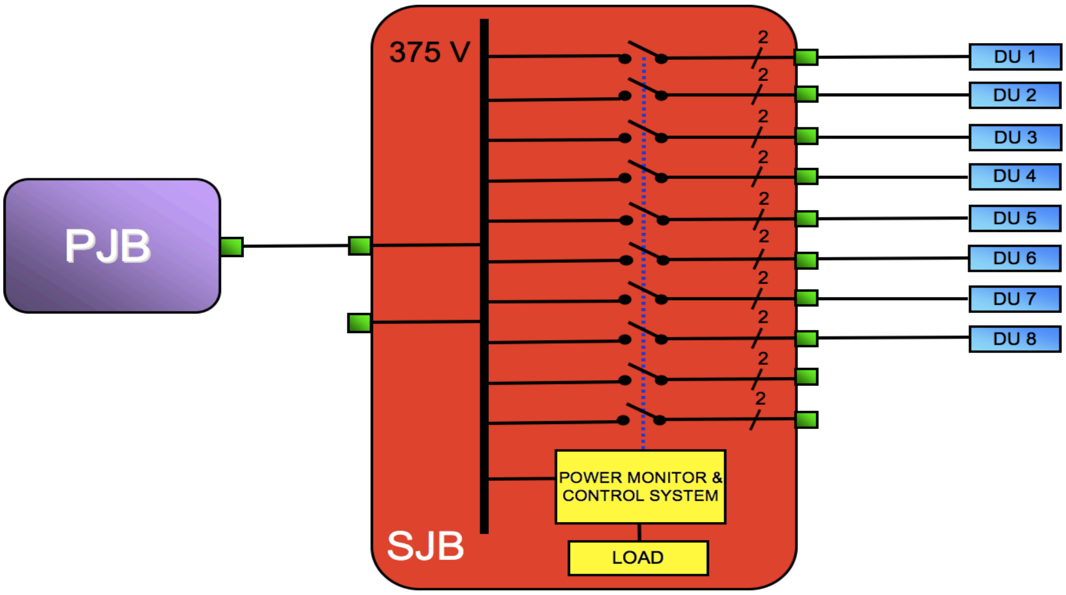

Fig. 13 – Block diagram of the Secondary Junction Box.

In the proposed scheme, for redundancy, each SJB is equipped with one input and two output spare connectors.

1.1.9 Power and Fiber Optical data connection with a "ring" layout

Fig. 14 shows, not in scale, a possible ring-configured geometry of junction boxes arranged around the circumference of the neutrino telescope. All JBs are ‘primary’ in the sense that they are attached to the main electro-optical cable from the shore and contain the MVC (to reduce the cable high voltage down to around 375 V DC) for supply to the detection units through radial interconnecting cables equipped with ROV wet mate-able connectors.

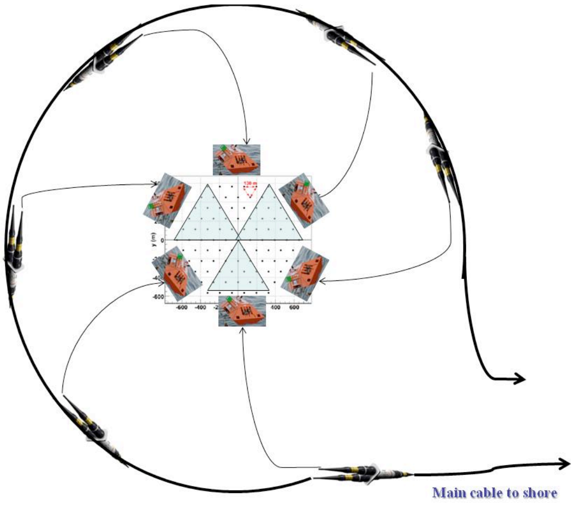

Fig. 14 – Possible ring geometry for sea floor infrastructure of junction boxes.

The JBs are connected to the circulating cable ring using commercially-available branching units (BUs) which allow for power to be switched individually onto each output arm. All connections of JBs and BUs in the circumferential ring use the same cable type as in the long MEOC. Furthermore, all connections are ‘connector-less’; instead using ‘penetrators’ conforming to the Universal Joint (UJ: [REF: Universal Jointing Consortium. http://www. ujconsortium.com]) standard of industry qualified components for the termination, repair and jointing of deep sea telecommunications cables from a variety of manufacturers.

The use of UJ technology allows for the scaled deployment of the ring topology, as illustrated in Fig. 15-left and Fig. 15-right.

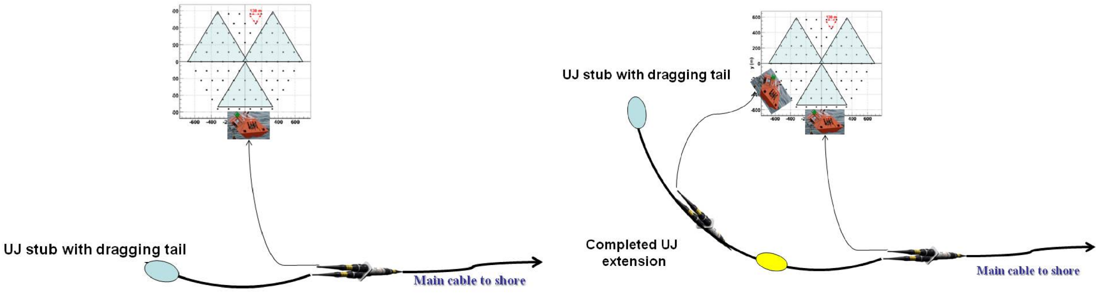

Fig. 15 – Illustration of the progressive deployment of a circumferential ring sea floor power and data flow topology. The drawing is not in scale.

In Fig. 15-left the first JB is installed together with its BU and an unconnected, recoverable cable stub terminated in a blind UJ jointing box and equipped with a ‘dragging tail’ allowing for later lifting with a trawled grapnel. This cable stub and its dragging tail have a length of at least twice the water depth, a factor generally considered the safe minimum for grapnel recovery by cable ship. The cable link between the BU and the JB has a similar length to allow recovery of the JB to the surface for repair without disturbance of the rest of the ring. Fig. 15-right illustrates the second phase of the deployment: the first formerly-blind joint box has been replaced with a through joint to allow connection of the second BU and its dependant JB. The second cable stub will be recovered for later extension of the network as the deployment of detection units advances. It can be seen from Fig. 15 that the circumferential ring can connect to a second site-to-shore cable, allowing a two-fold redundancy in power path and data fibre connection to the shore. The length effects of the circumferential ring must be accommodated in the data transmission system; for example a full circumferential network deployed at 3000m depth would exceed 36 km, not including the site-to-shore cables or the BU-JB spurs.

2. Deployment and maintenance

An essential aspect of the design is the deployment concept. The detection units described below are transported and deployed into the sea as compact packages. The package is dimensioned to fit in the space of a standard transport container so as to have the possibility of final integration at distributed sites and easy transport to the sea deployment base. Each compact package is deployed in the sea, lowered to the seabed and then unfurled to deploy to the final height. It is felt that security and reliability of detector deployment must be an overriding consideration in the neutrino telescope design.

2.1 Deployment and connection

The detector deployment concept is based on the idea of deploying the DUs as compact packages to the seabed.

After the correct positioning on the seabed, the structure is connected to the sea-floor cable network. Unfurling of the DU to reach its working configuration is obtained by a actuating an acoustic release system. The DU self-unfurls under the pull provided by the buoy.

This deployment concept has several advantages:

- easy handling of the structures on-shore for loading on the surface vessel;
- reduced space occupation on the ship deck that allows to increase the number of structures to be deployed in a single operation;
- reduced time needed to lift and immerse the structure in the water, with increased safety for the operating personnel.

2.1.1 DU deployment

During the deployment the DU is a compact package with the shape of a parallelepiped and size that fits in the space of a 40’ container. This package has to be deployed and positioned at depths beyond 2500 m. The final working configuration will be reached, after deployment and connection of the structure, by remotely actuating an acoustic release system. The unfurling of the structure will be driven by the pull of the top buoy.

The operation sequence is the following:

- Lifting of the structure on the sea surface vessel deck. This operation is performed using the sea surface vessel’s deck equipment.
- Immersion of the structure in the water. This operation is performed using the sea surface vessel’s deck equipment.
- Lowering of the structure close to the seabed. This operation requires a winch hosting a cable length sufficient for the site depth.
- Positioning of the structure on the seabed. The required accuracy (order of few metres) require the availability of an acoustic Long Base Line (LBL).

- Release of the structure. This operation will be performed by remotely actuating an acoustic release system placed at the end of the deployment cable.

2.1.2 Junction Boxes deployment

A design of the Junction Box has not been developed yet. For the deployment considerations we will assume that each JB is a structure with size 3 m x 3 m, a height of 2 m and a weight of approximately 3000 kg.

The deployment procedure is analogous to the one described for the tower.

2.1.3 DUs and JBs connection

After the deployment of the telescope components an ROV will be used for their connection to the seabed network for power supply and data transfer. The ROVs are described in some detail in the following paragraph “Underwater vessels”.

The DUs and JBs are interconnected by a network of electro-optical cables with lengths of the order of a few hundreds metres. These cables have to be accurately laid on the seafloor along well-determined paths in order to avoid damages to this network during successive deployment of telescope components.

Interlink cables will be deployed to the seabed on dedicated drum and then laid with the ROV with a technique well tested in the installation of ANTARES.

2.2 Vessels

The surface and deep-sea vessels needed are:

- a sea surface vessel, used to transfer, deploy and install components of the deep sea neutrino telescope at the bottom of the sea, equipped with a Dynamic Positioning (DP) system;
- a deep-sea Remotely Operated Vehicle (ROV).

Other ancillary equipments are also needed to:

- precisely position the detection units on the seabed;
- deploy and lay on the seabed the cables interlinking the detection units and the junction boxes;
- operate wet mateable connectors.

2.3 Underwater vessels

Operations on the seabed will be performed by means of a Remotely Operated Vehicle (ROV) controlled from the surface.

A Remotely Operated Vehicle (ROV) is an underwater robot that allows the vehicle's operator to remain in a comfortable environment while the ROV performs the work underwater. An umbilical, or tether, carries power and command and control signals to the vehicle and the status and sensory data back to the operator topside.

A light work class ROV (Fig. 16), like the one acquired by INFN and INGV for the PEGASO project, is adequate for the purpose. This ROV has been developed from a standard commercial vehicle by adding some dedicated equipment specifically designed for the installation of a km^3 scientific apparatus. In particular:

- the maximum operating depth has been extended down to 4000 mwd;
- the length of the tether cable between the Tether Management System (TMS) and the ROV has been increased to 250 m to allow operations inside the array;
- a system for connection/disconnection of wet-mateable connectors has been added; a connector cleaning system has been added.
- two manipulators, each with five degrees of freadom

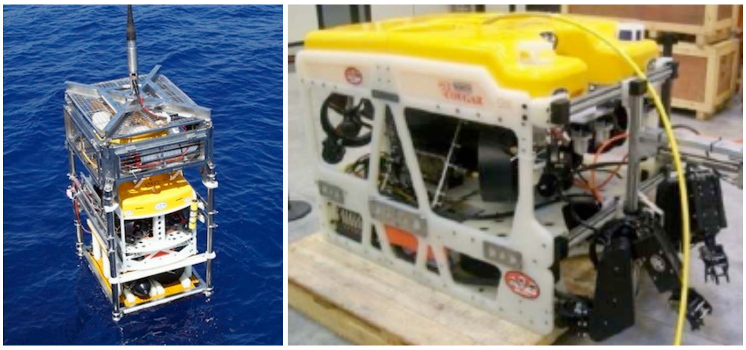

Fig. 16 - The light class PEGASO's ROV

Here below we list the main characteristics of the NEMO ROV.

ROV Specifications	Seaeye Cougar-XT
Depth Rating	4000 msw
Length	1515 mm
Height	790 mm
Width	1000 mm
Launch Weight	344 kg
Forward Speed	**> 3.2 knots**
Thrust Fwd	**170 kgf**
Thrust Lateral	**120 kgf**
Thrust Vertical	**110 kgf**
Payload	80 kg

Table 2-1 - The NEMO ROV characteristics

3. Common infrastructure

3.1 Electro-optical cable site-to-shore

A Main Electro-Optical Cable (MEOC) linking the Primary Junction Box to the on-shore equipment will provide the connection for power feeding and data bidirectional transmission.

3.1.1 Main electro-optical cable design

The design requirements for the KM3NeT site-to-shore cable are compatible with the standard capabilities of telecommunications cables, for which a wide range of industry-approved standard connection boxes, couplings and penetrators exist, which can be readily adapted to interface with scientific equipment. The low failure rate among the large number of such components in service suggests mean times between failures of several thousand years.

As standard, a submarine telecommunications cable has to provide a service life of at least 25 years. It must be easy to deploy and repair at sea. The longevity of the installed cable depends on minimizing the strain induced on the optical fibres.

The cable structure, which houses the optical fibres and electrical conductors, must survive both the rigors of installation (torsion, tension due to its own weight and ship movement) and the seabed conditions (high ambient pressure, abrasion risk, unsupported span, etc.).

At present all the major cable manufacturers deliver telecommunications cables with a number of fibres that does not routinely exceed 48. This is mainly due to the advent of Dense Wave-length Division Multiplexing (DWDM) technology and to the requirements of simplifying the cable mechanics. The fibre types used for submarine transmission are optimised for minimum attenuation over the full C-band (1530-1570 nm) with dispersion characteristics that depend on the application. The cable optical properties are an integral part of the optical communications system specification. The MEOC has to be equipped with standard monomode G655 fibres (MFD, LEAF or NZDSF fibres).

A monopolar system incorporates a current return via the seawater and will generally result in the smallest cable dimension and weight. Due to the extremely small resistance in the sea return this system has low power losses. Cables usable for this system are in fact the most commonly used in the telecommunications industry. To allow for the current return via the sea this system must incorporate sea electrodes both at the shore and in the deep sea. An example of such a cable is shown in Figure 4. The most significant technical problem with a DC monopolar system is the danger of corrosion of neighbouring structures and installations. Due to electrochemical reactions on the sea-return electrodes chlorine gas may be generated. Where such a system is used these issues must be addressed.

One example of such a type of electro-optical cable already deployed for deep-sea data and power transmission is the 100 km cable that will operate between the Capo Passero on-shore laboratory and the deep sea site at 3500m depths. It is a DC cable, manufactured by Alcatel-Lucent [2] and deployed in July 2007. It carries a single electrical conductor, that can be operated up to 10 kV DC allowing a power transport of more than 50 kW, and 20 single mode ITU-T G655-compatible optical fibres for data transmission. The cable total length is about 100 km.

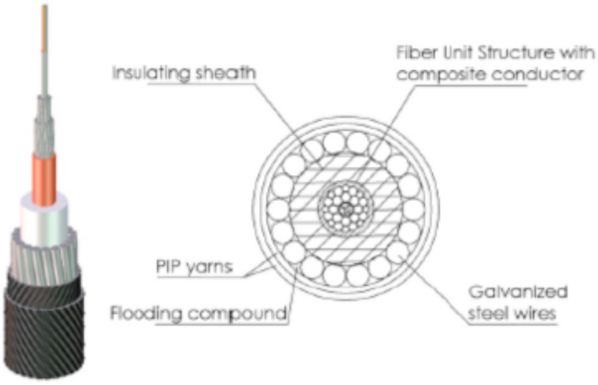

Fig. 17 – Internal structure of a standard monopolar submarine cable.

The KM3NeT MEOC characteristics for the data/power transmission previously described in this document are summarized in Table 3-1.

Length [km]	100
Type of power to be transmitted	DC, one polarity + sea return
Maximum Voltage [kV]	10
Maximum Current [A]	10
Power Transmission efficiency	95%
Cable resistance [Ω/km]	1
Number of fibres	48

Table 3-1 - Main Electro-Optical Cable characteristics

Submarine cable armouring is selected to be compatible with the specific route; therefore the cable mechanical characteristics are an integral component of the overall system design.
The final characteristics of the MEOC will also strongly depend on the deployment site: the cable route from the on-shore laboratory to the deep-sea site will define the length of the different MEOC parts (Double Armoured, Single Armoured, Light Weight, Fig. 18) and the number of joints needed (Joint boxes DA-SA, SA-LW, DA-DA, SA-SA, LW-LW). These Joints, that are part of the long MEOC to be deployed, have to be available, and ready, during the Telescope operation, for any repair intervention will be needed.

Fig. 18 – Examples of different armoring on submarine cables.

3.1.2 Main electro-optical cable maintenance

The cost of a submarine cable repair at sea is substantial. However, since 1999, under the Mediterranean Cable Maintenance Agreement (MECMA) cable ships, fully equipped with Remote Operated submarine Vehicles (ROVs), are maintained on constant readiness at Catania (Italy) and La Seyne-sur-Mer (France), (Fig. 19). These ships provide repair services for subsea cables owned by member organisations (cable operators: around 44 as of 2009). The insurance character of this agreement offers members a repair capability for an affordable yearly contribution in proportion to the relevant cable mileage. Two of the pilot projects are members of MECMA.

The five major submarine cable manufacturing companies have formed the Universal Jointing Consortium which offers qualified and proven jointing techniques for a wide range of cable types (“Universal Joint” (UJ) and “Universal Quick Joint” (UQJ)). MECMA ships support universal jointing.

Virtually all reported submarine cable failures are due to human activity, notably fishing and anchor falls in shallow water, although natural chafing, abrasion and earthquakes in the deep ocean also occur, as shown in Fig. 20. To mitigate these risks, careful route planning is essential, and sea-bed burial is used where circumstances require it.

Fig. 19 – The MECMA consortium with the two cable-ship operatoring bases and storage depots.

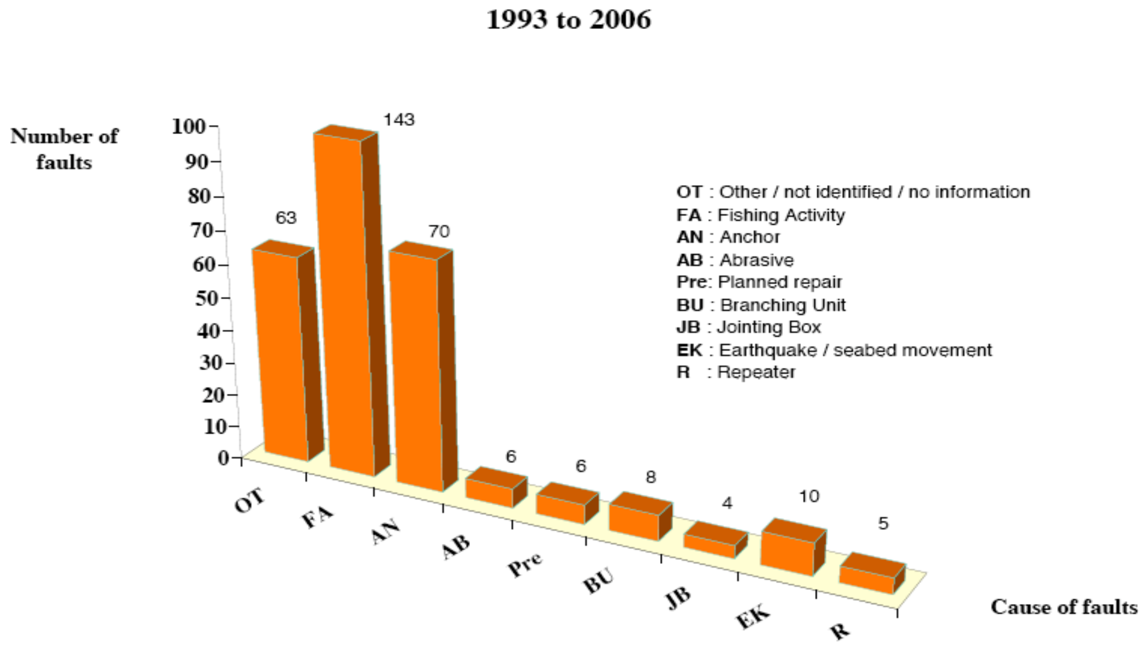

Fig. 20 – Submarine cables: causes of fault. (MECMA 2008.

3.2 Shore infrastructure

3.2.1 Connection to deep sea for data and power

The Shore Station Power Feeding Equipment (PFE) will provide the connection to the local utility power of both the of the off-shore and on-shore components of the Telescope. The PFE will also act as emergency back-up power storage, the AC and DC monitoring and control, a protection against lightning, surge and spike. The PFE will provide the connection to the current return electrode and the connection to the KM3NeT backbone cable. The PFE will utilize the local public utility 400 VAC, convert it to 240VAC for the low voltage equipment and to medium voltage DC for distribution to the seafloor equipment. In order to maintain the availability of the KM3NeT network during occasional power interruptions, a backup power system will be required to provide power during these interruptions. An UPS would be provided for sufficient time to reliably start a motor generator and then the generator would provide power until the utility power was restored.

The primary function of the PFE is to generate the nominal -10kVDC for transmission to the seafloor cable network. This will require a 400VAC/10kVDC power supply unit (PSU).

The PSU will have 2 output connections: the single conductor backbone cable and the current return electrode.The backbone cable conductor will be connected to the negative terminal of the PSU and the electrode will be connected to the positive terminal of the PSU. This polarity is used to minimize consumption of the remote seafloor electrodes (cathodes) that are difficult to maintain.

The shore electrode (anode) will be consumed but this can be made arbitrarily large and can be maintained/replaced, if necessary.