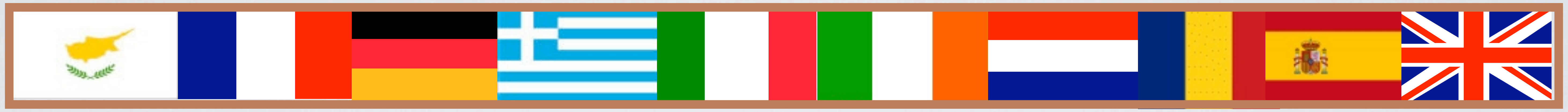
Power and Submarine Cable System for the Cubic Kilometer Neutrino Telescope

M. Sedita
INFN-LNS
on behalf the KM3NeT Collaboration

EU FP6 Design Study KM3NET Project

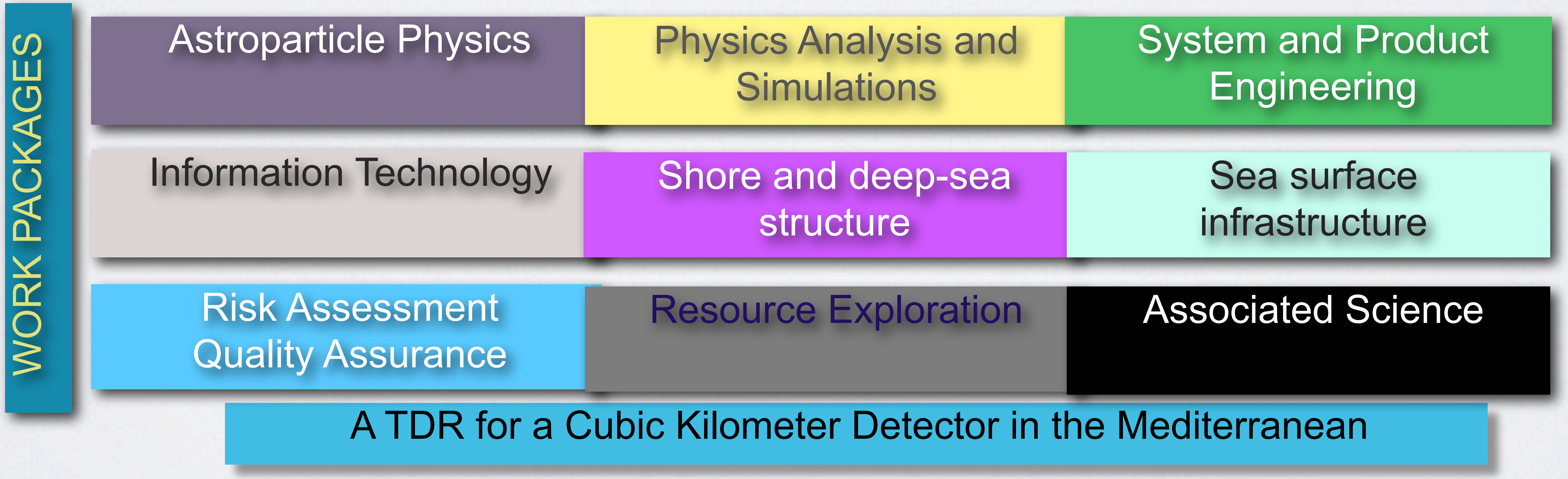


Collaboration of 10 Countries, 41 Institutions

- Cyprus: Univ. Cyprus
- France: CEA/Saclay, CNRS/IN2P3 (APC Paris, CPP Marseille, IreS Strasbourg), Univ. Haute Alsace/GRPHE, IFREMER
- Germany: Univ. Erlangen, Univ. Kiel, Univ. Tübingen
- Greece: HCMR Anavissos, HOU Patras, NCSR Athens, NOA/Nestor Athens, Univ. Athens
- Ireland: DIAS Dublin
- Italy: CNR/ISMAR, INFN (Bari, Bologna, Catania, LNS Catania, LNF Frascati, Genova, Messina, Pisa, Roma-1), INGV, Tecnomare SpA.
- Netherlands: NIKHEF/FOM, Univ. Amsterdam, Univ. Utrecht, KVI/Univ. Groningen, NIOZ
- Spain: IFIC/CSIC Valencia, Univ. Valencia, U.P. Valencia
- United Kingdom: Univ. Leeds, Univ. Sheffield, Univ. Liverpool, OceanLab (Univ. Aberdeen)

Aim to design a deep-sea km^3-scale observatory for high energy neutrino astronomy and an associated platform for deep-sea science

Request funded for 3 years - end product will be a TDR for KM3 in the Mediterranean Sea

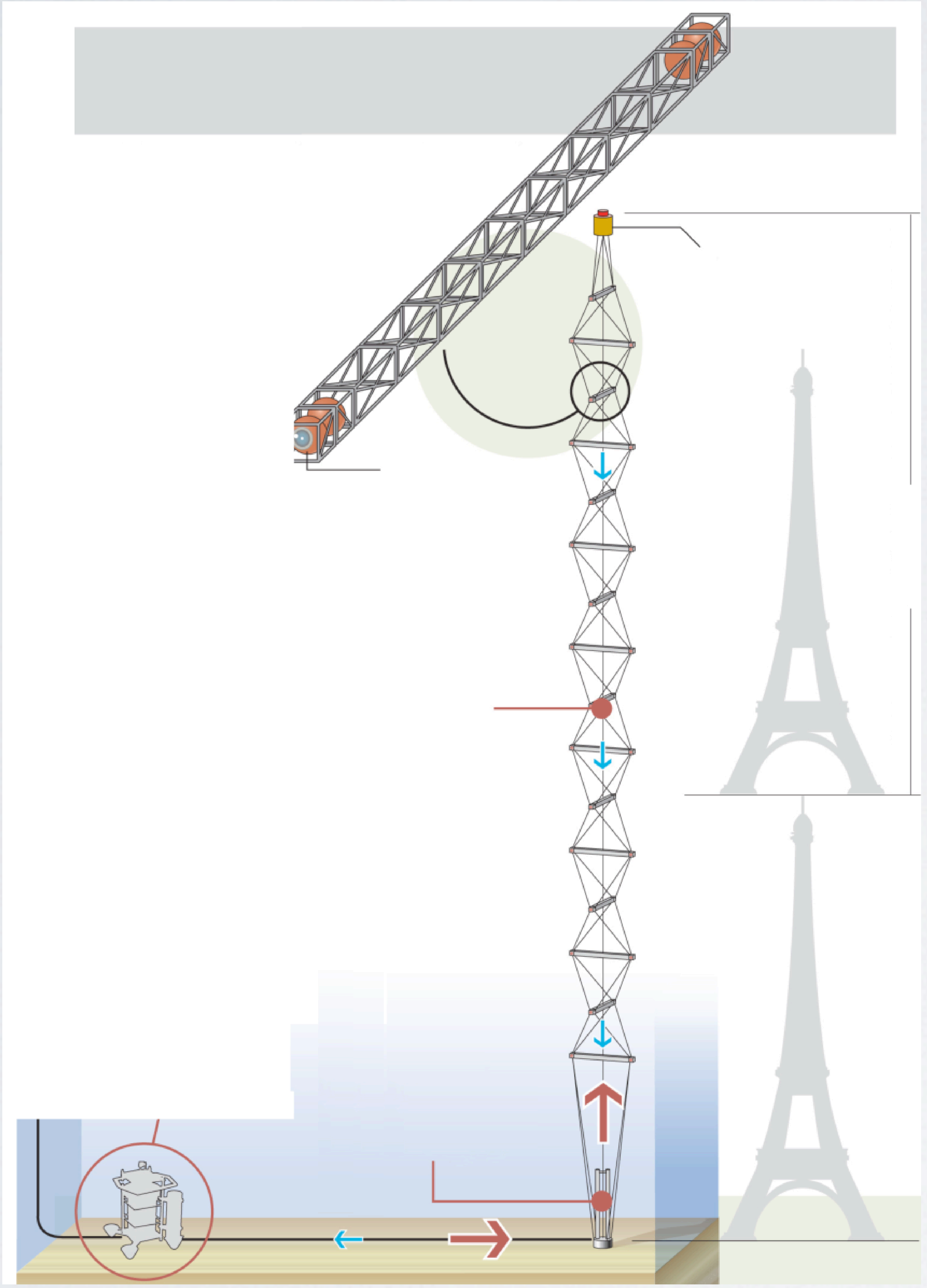


Mediterranean Neutrino Sites

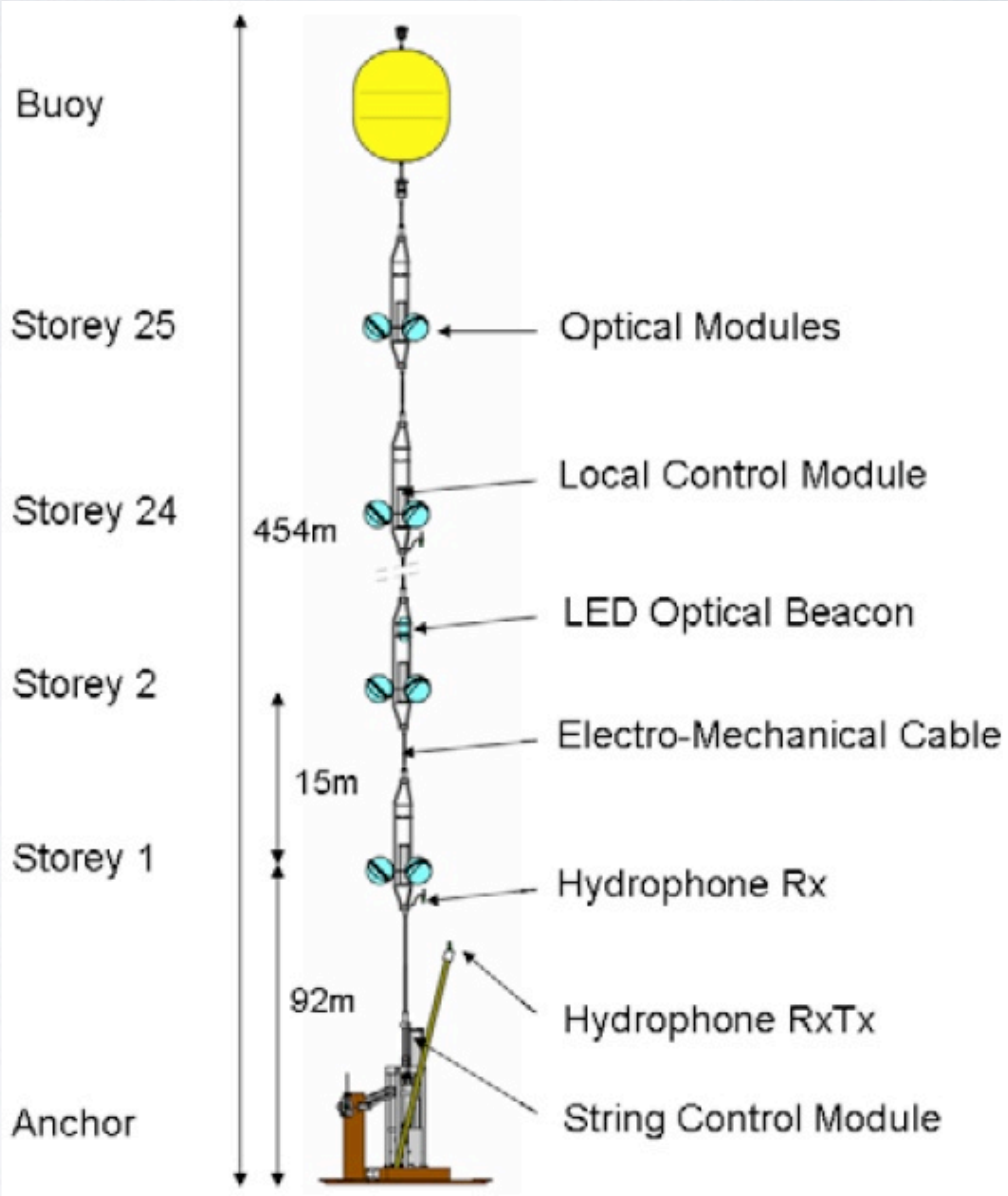
The Mediterranean Sea offers optimal conditions

- water quality, depth, temperature, ...
- existing infrastructure
- current expertise for sea water ν telescopes concentrated in European countries
- a perfect stage for a large Europe-led science project

Detection Unit Structure
(up to 150 anchored to sea floor power distribution network)



Tower Structure



String Structure

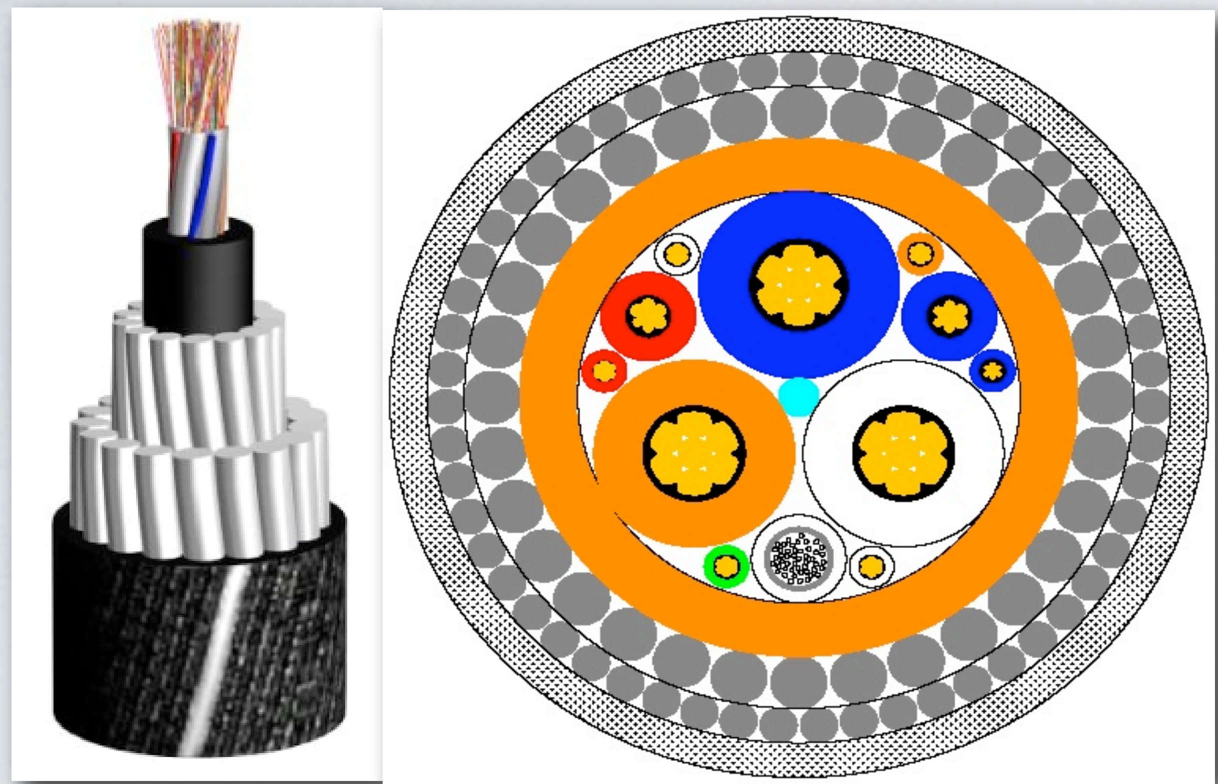
Main Considerations

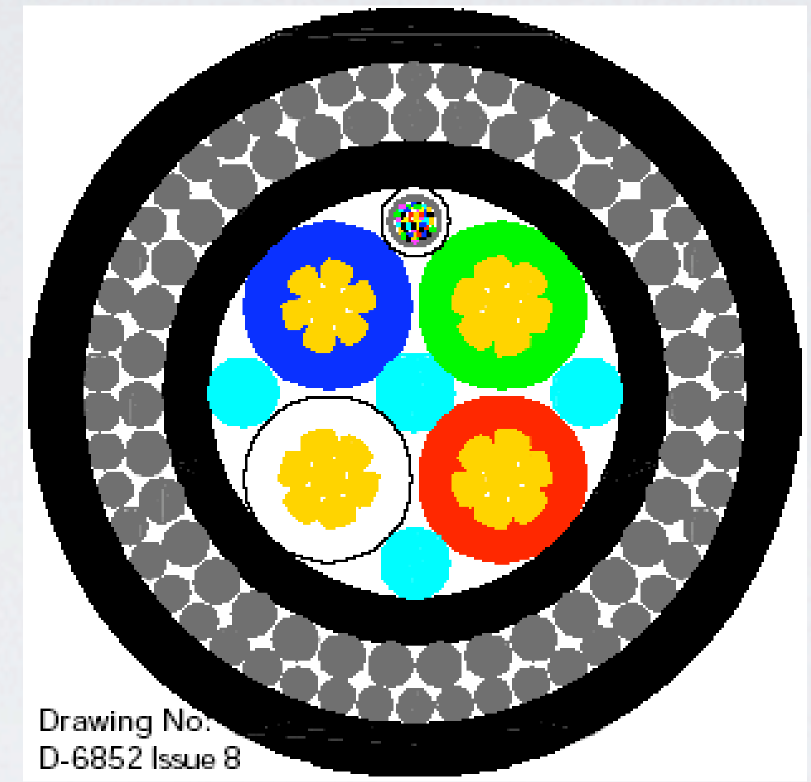
- Submarine Electro-Optical Cable Requirement
- On Shore Energy Power Requirement
- Cable Deployment Activity
- Off Shore Energy Power Conversion
- Subsea Distribution Network
- Electro-Optical Submarine Connection Systems
- Installation and Maintenance Issue

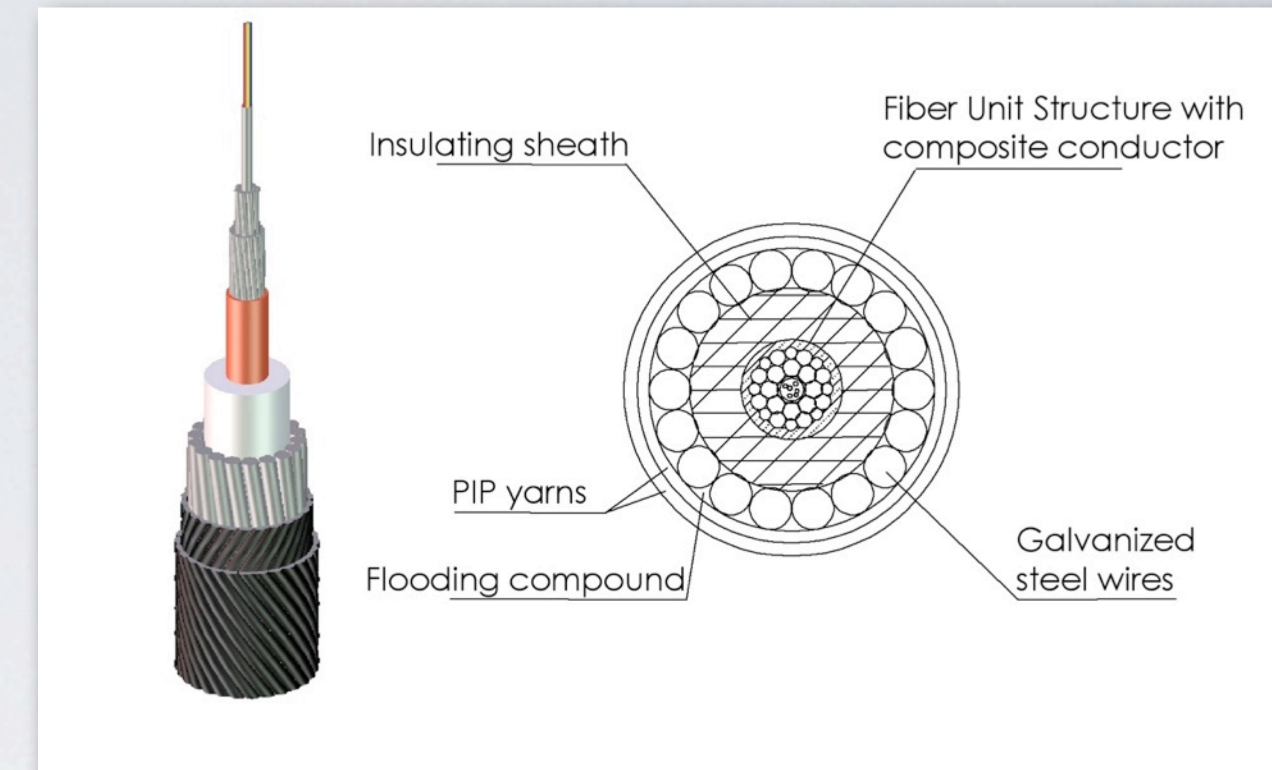
Estimated power for the km^3 included
Sea Science nodes

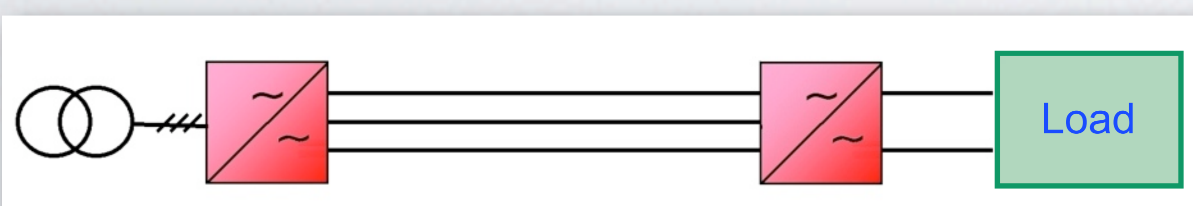
$\approx$50 kW

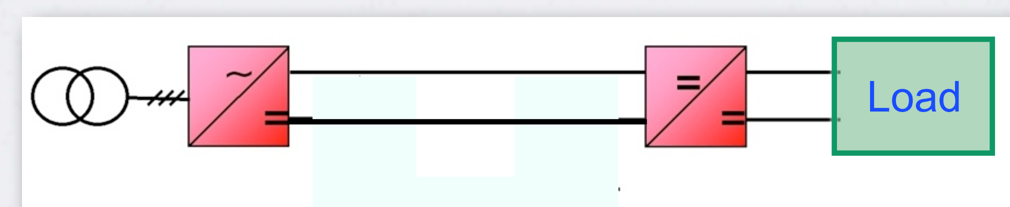
AC/DC Comparison

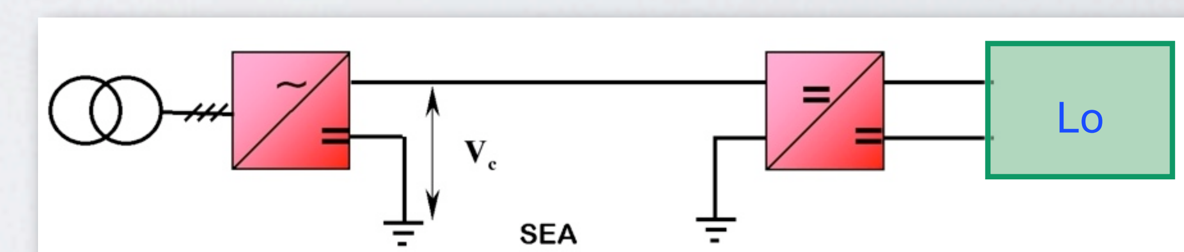












AC Three-phase 3x50 mm^2

Power loss kW 150
230kW to transmit 80kW
Voltage drop kV 3.5
Required supply voltage kV 5.5

DC Bipolar 4x35mm^2

Power loss kW 85
165kW to transmit 80 kW
Voltage drop kV 2.1
Required supply voltage (DC) kV 4.1

DC Monopolar

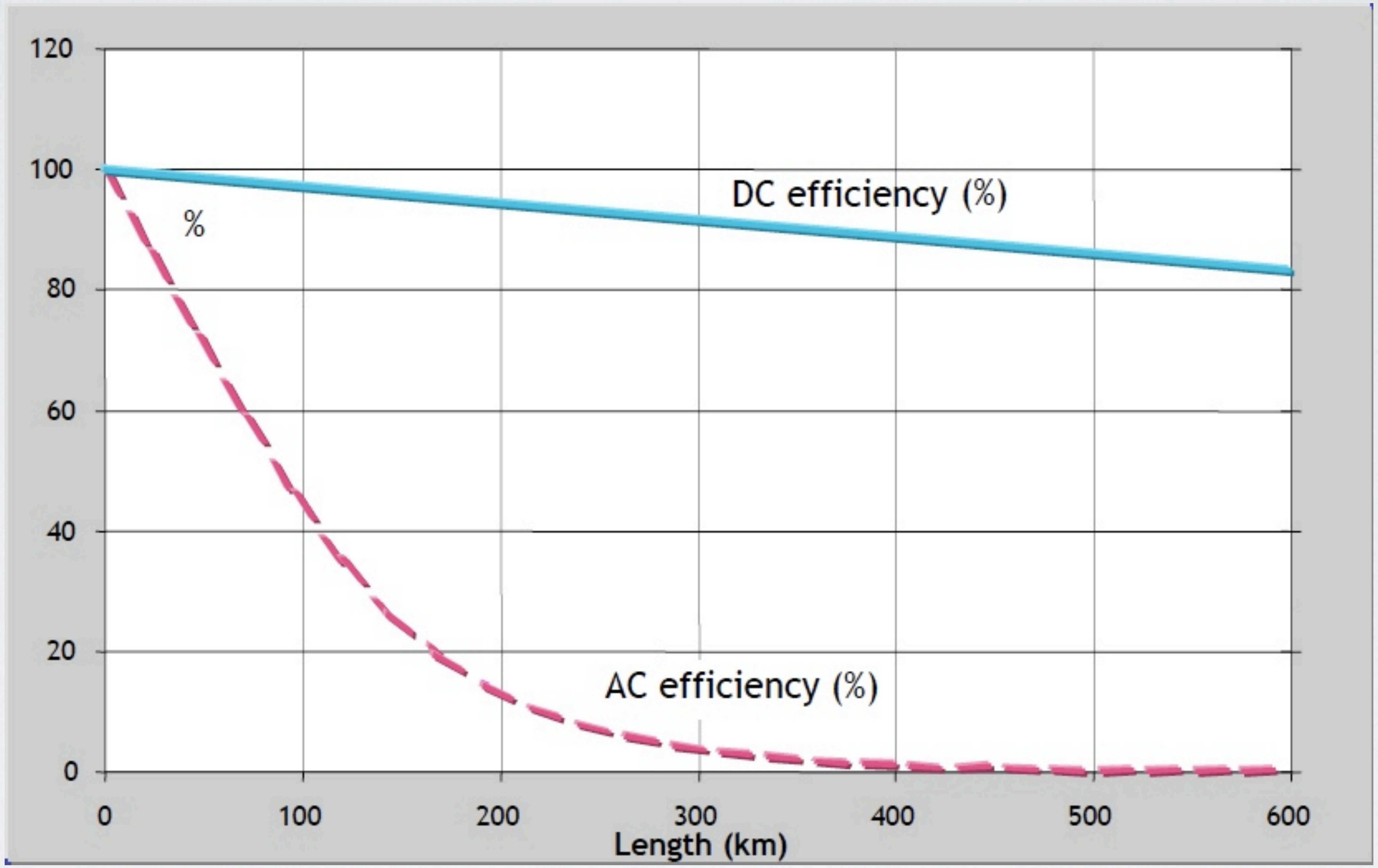
Power loss kW 14
100 kW to transmit 86 kW
Voltage drop kV 1.4
Required supply voltage (DC) kV 10

AC/DC Comparison

Lenght 100 km	AC Triphase	Monopolar DC Sea Return
Cable Outer Diameter	44 mm	17 mm
Conductor Diameter	3 x 16 mm^2	Copper Shield
DC Resistance (per conductor)	1.25 Ω/km	1.4 Ω/km
Weight Air/Water	4.8-3.2 Kg/m	0.90-0.57 Kg/m
Cable Breaking load	680 kN	70 kN
Operating Tension	190 kN	30 kN
Min. Dynamic Bending	1,400 mm	500LW/900DA mm
Working Voltage Limit	6.6 kV	10 kV
Drop Voltage	950 V	1,400 V
Current	4.5 A	10 A
Max Deliverable Power	30 kW	100 kW
Cost including deployment	8 M€	2.5 M€

AC/DC Efficiency Comparison

Monopolar solution AC could be used with acceptable efficiency below 50 km of distance (Antares). Monopolar DC solution for longer distance (NEMO).



Sea Return Electrode

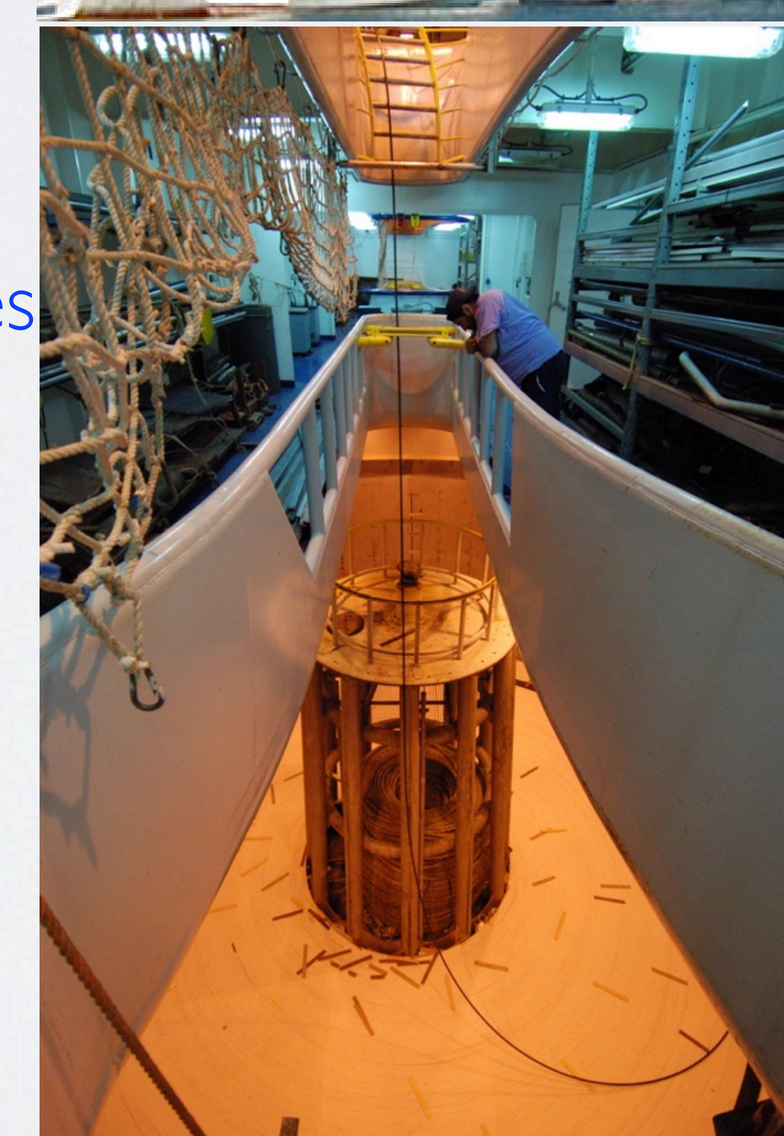
Nemo Phase 2 Cable Conclusion

By adapting terrestrial AC utility practice to an undersea application, a fault-tolerant power delivery system can be built.
The difference from utility power delivery approaches for long distance is the use of DC, which is justified by high cost of AC, (Cable and Deployment) and high efficiency loss.

The shipment and deployment system is in favour of standard telecom monopolar cable

Standard rail transport for telecom cables

Standard Telecom Cableship

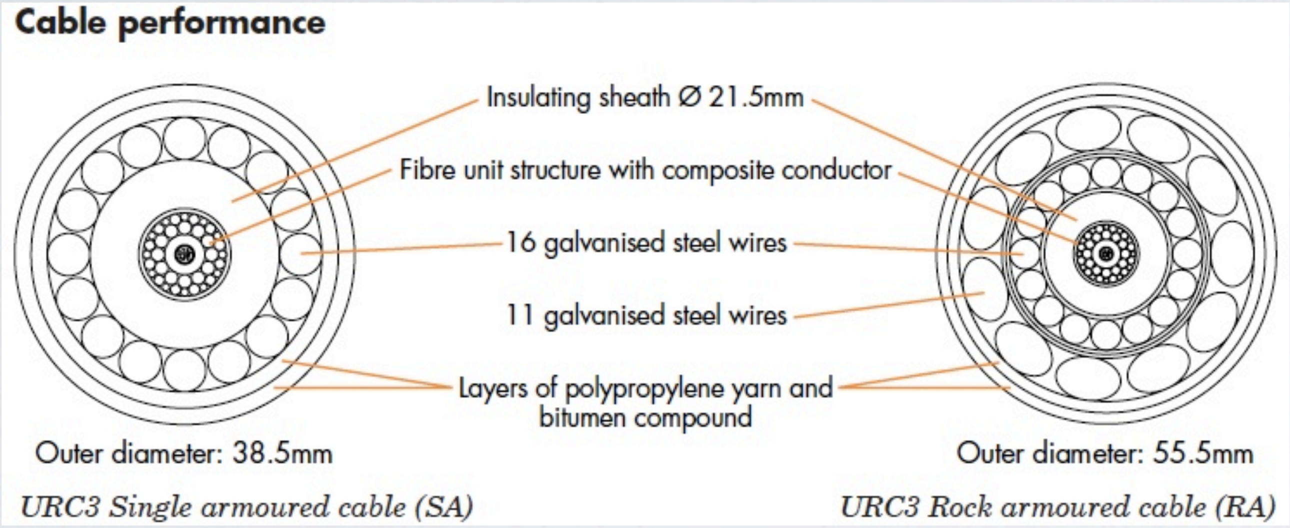


Inside cable storage

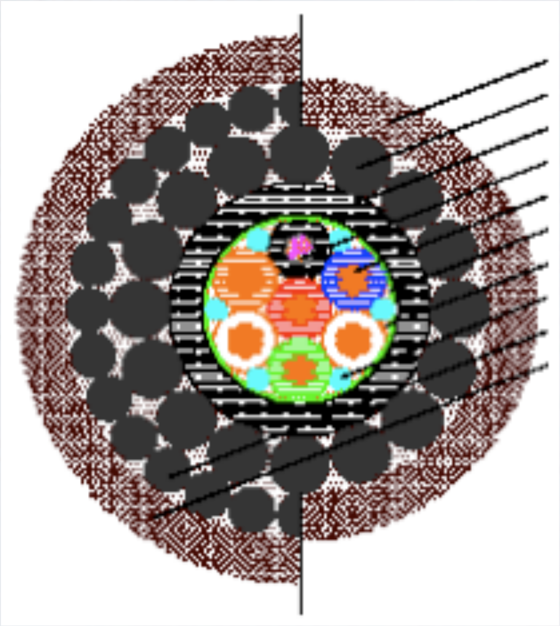
Energy Cableship

Outside cable storage

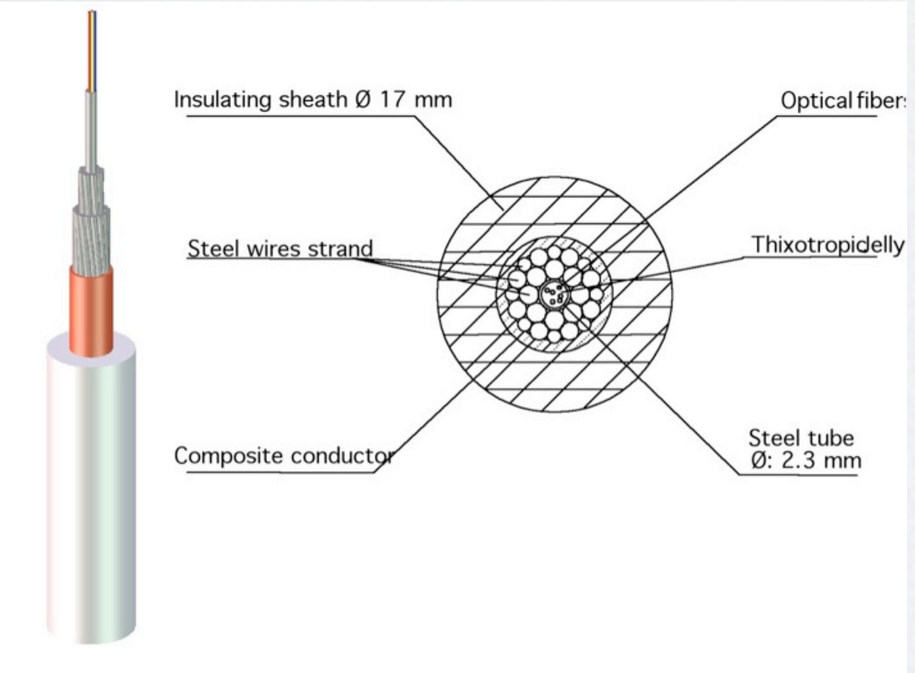
Operating Submarine Cables in the Mediterranean Neutrino Experiments



Antares Cable: Alcatel URC-3
21.5 mm
Fibers Number 48
40 km length
Unipolar AC solution



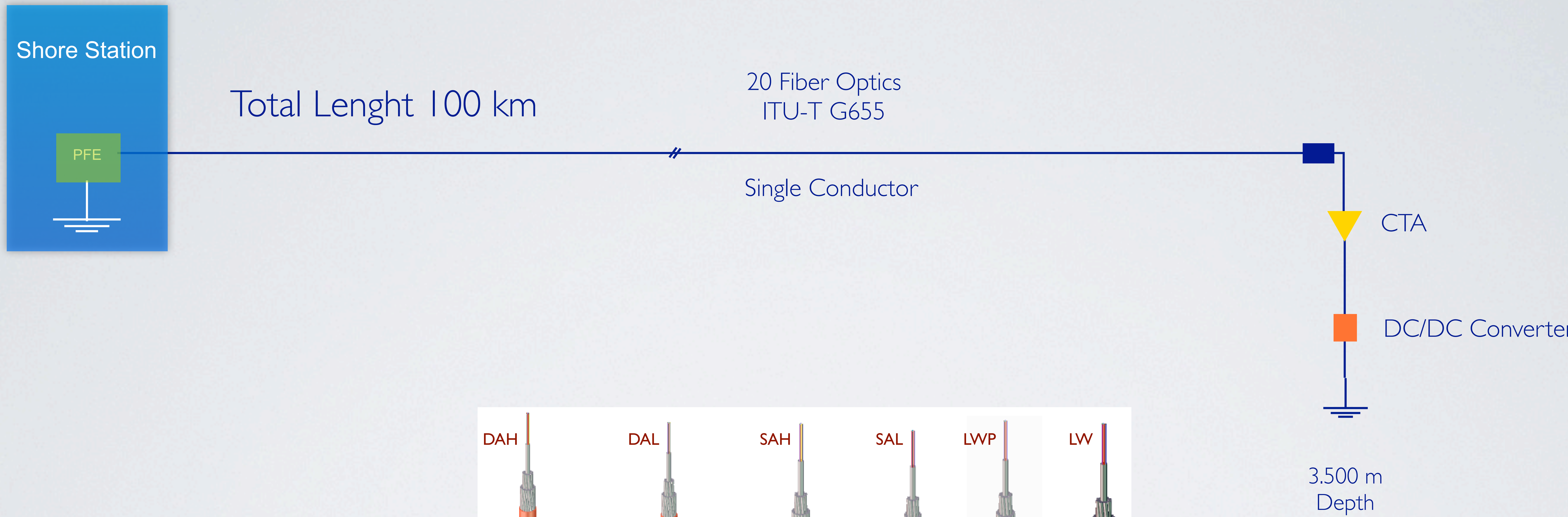
NEMO Phase 1 Cable: Nexans R 4.2/3.2
6 Electrical Conductors
Fibers Number 10
28 km length
3 Phases AC solution



NEMO Phase 2 Cable: Alcatel OALC 4 - 17 mm Type 31
Fibers Number 20
100 km length
Unipolar DC solution

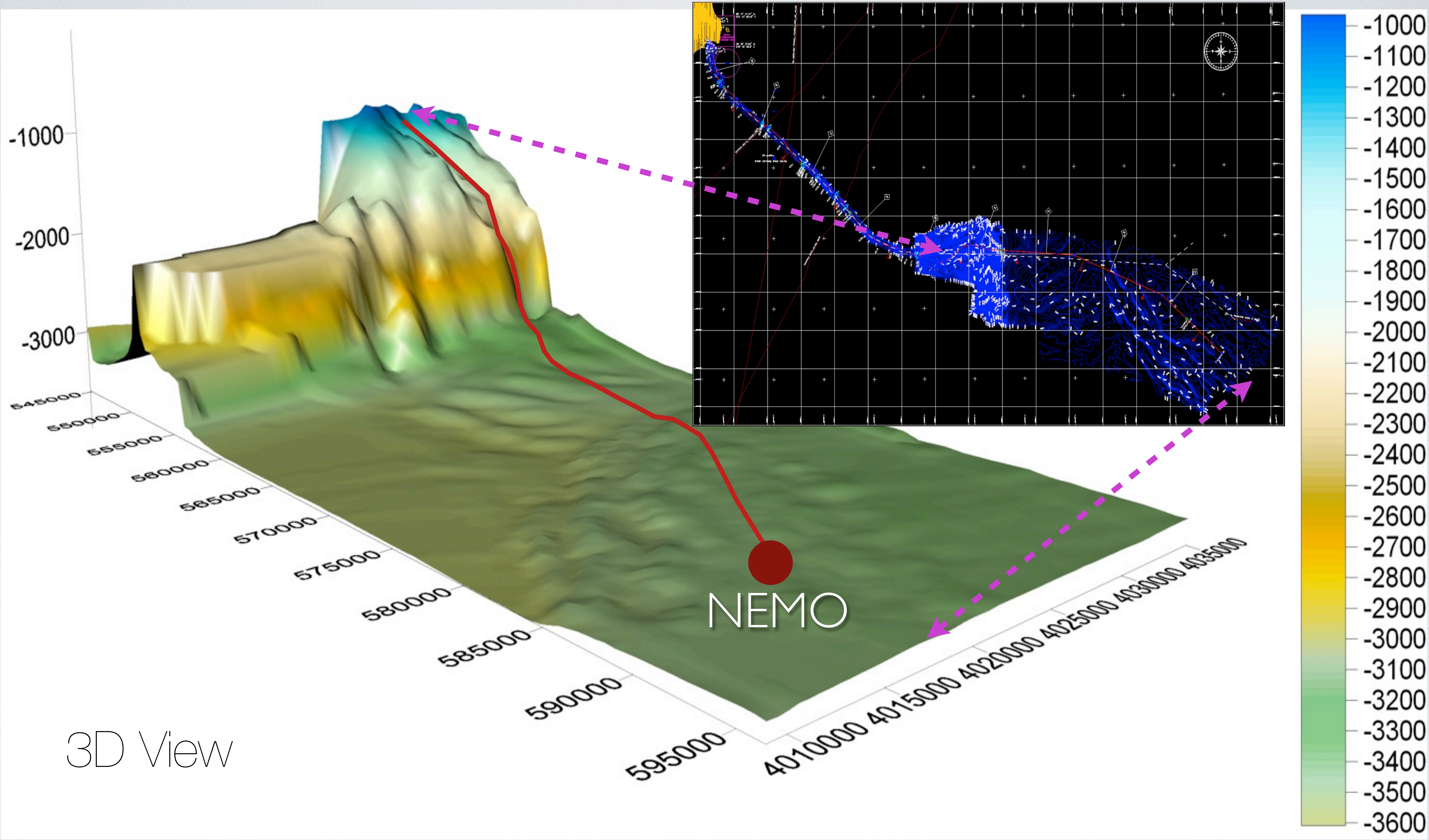
NeMO Phase 2 Laid July 2007

Alcatel OALC 4 - 17 mm Type 31 (Unrepeatered)



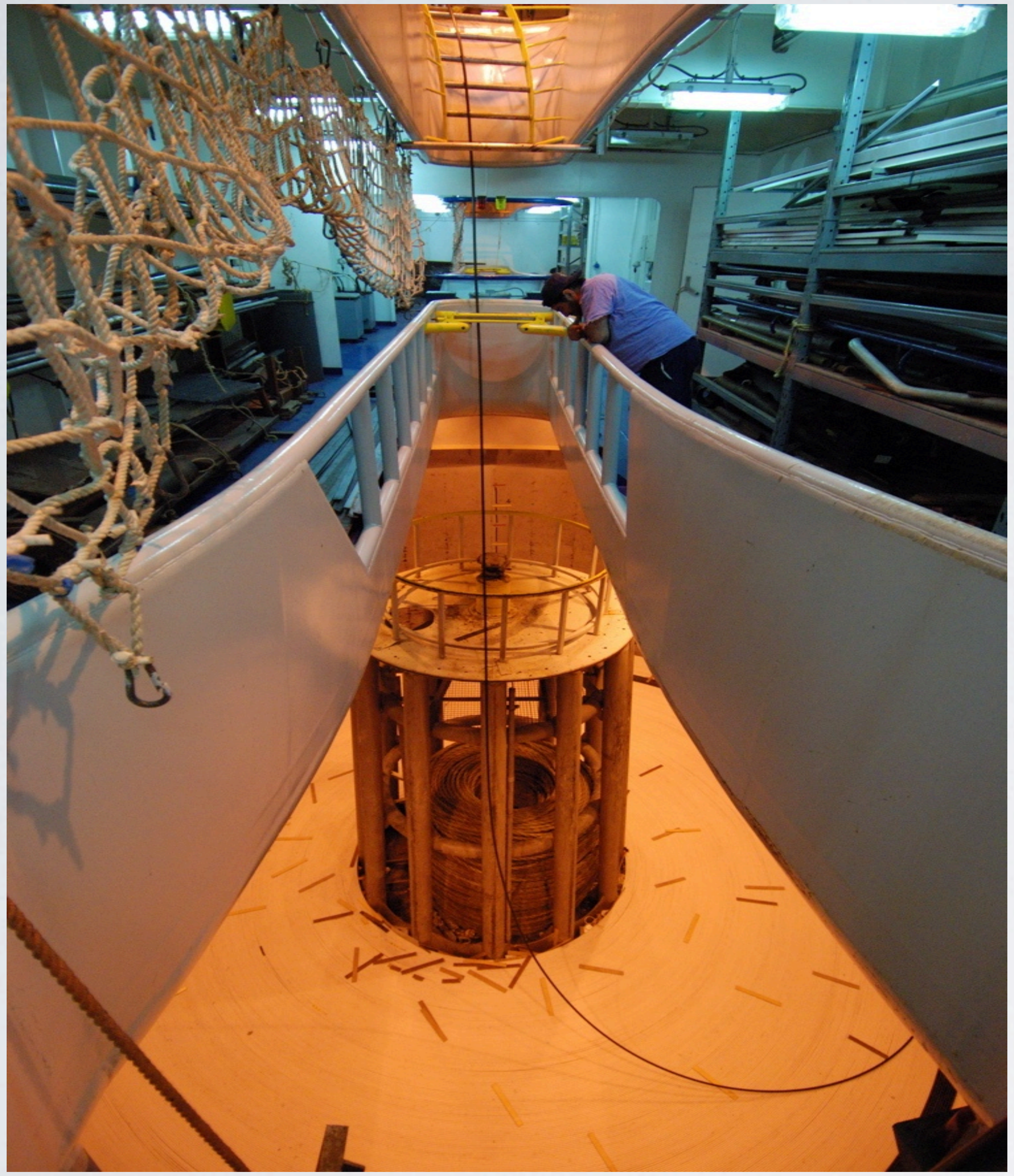
Alcatel OALC - 4
17 mm Type 30

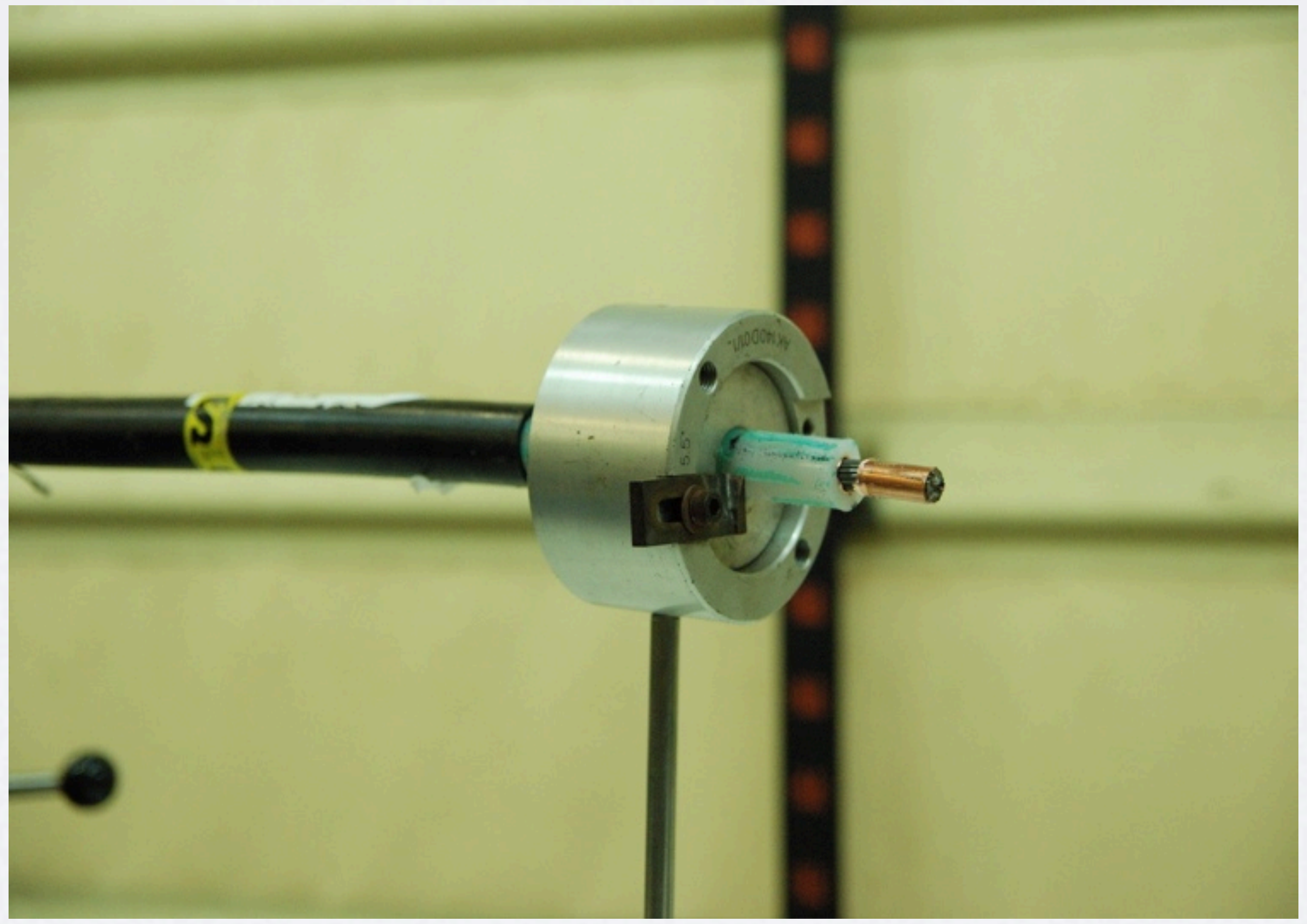
Bathymetry of the cable path and termination area an example



Cable Deployment

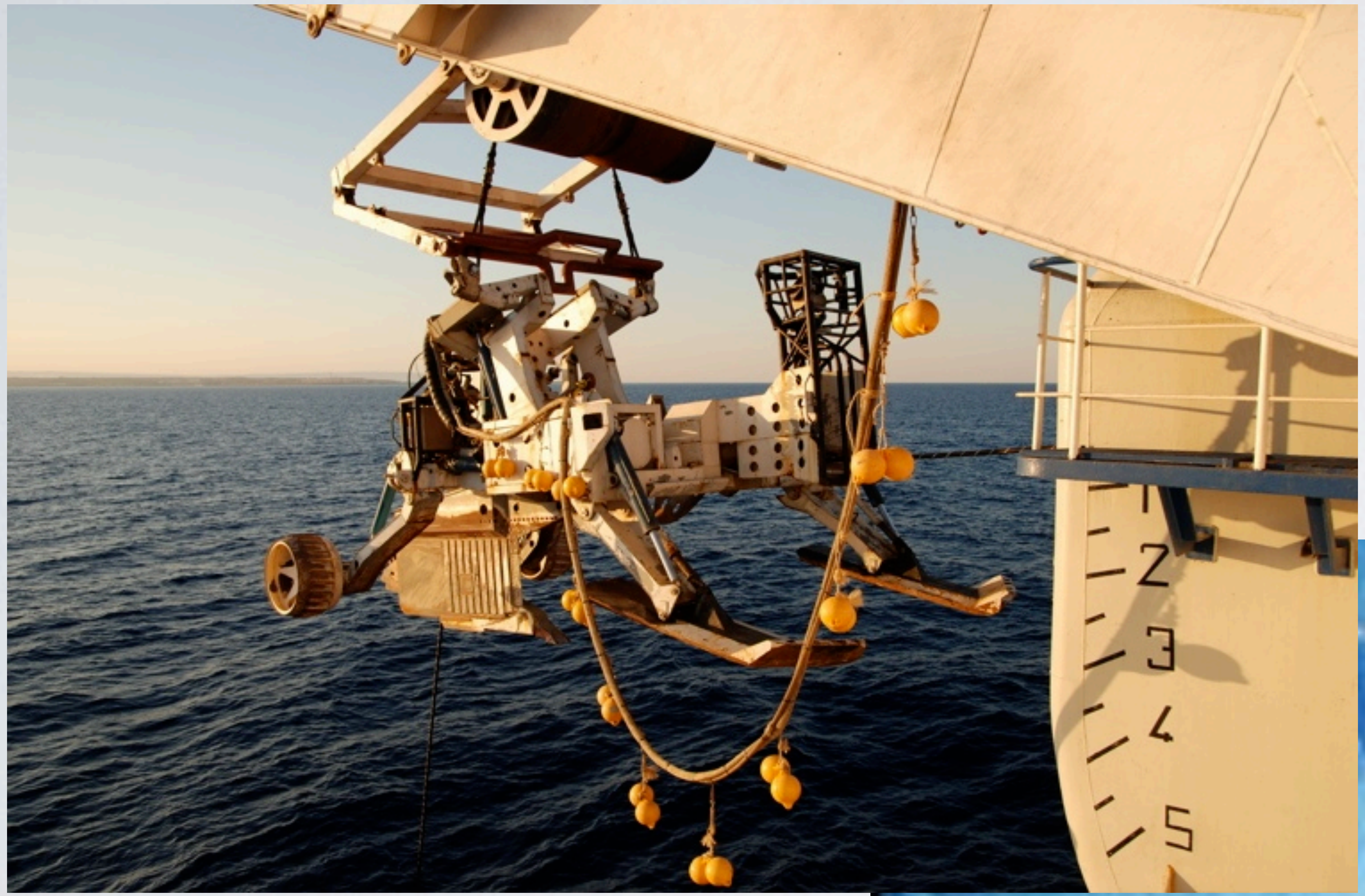
Cable Deployment



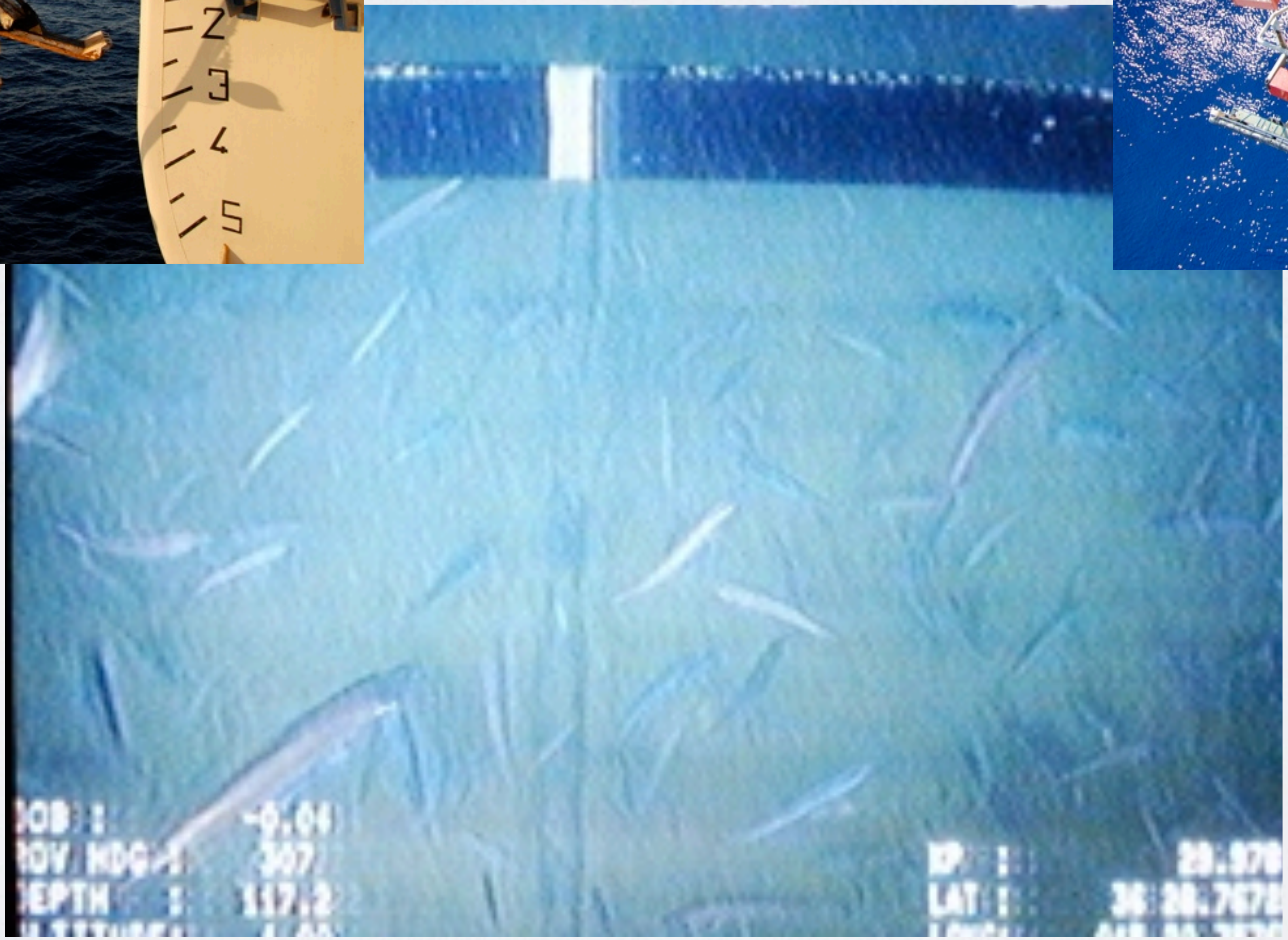


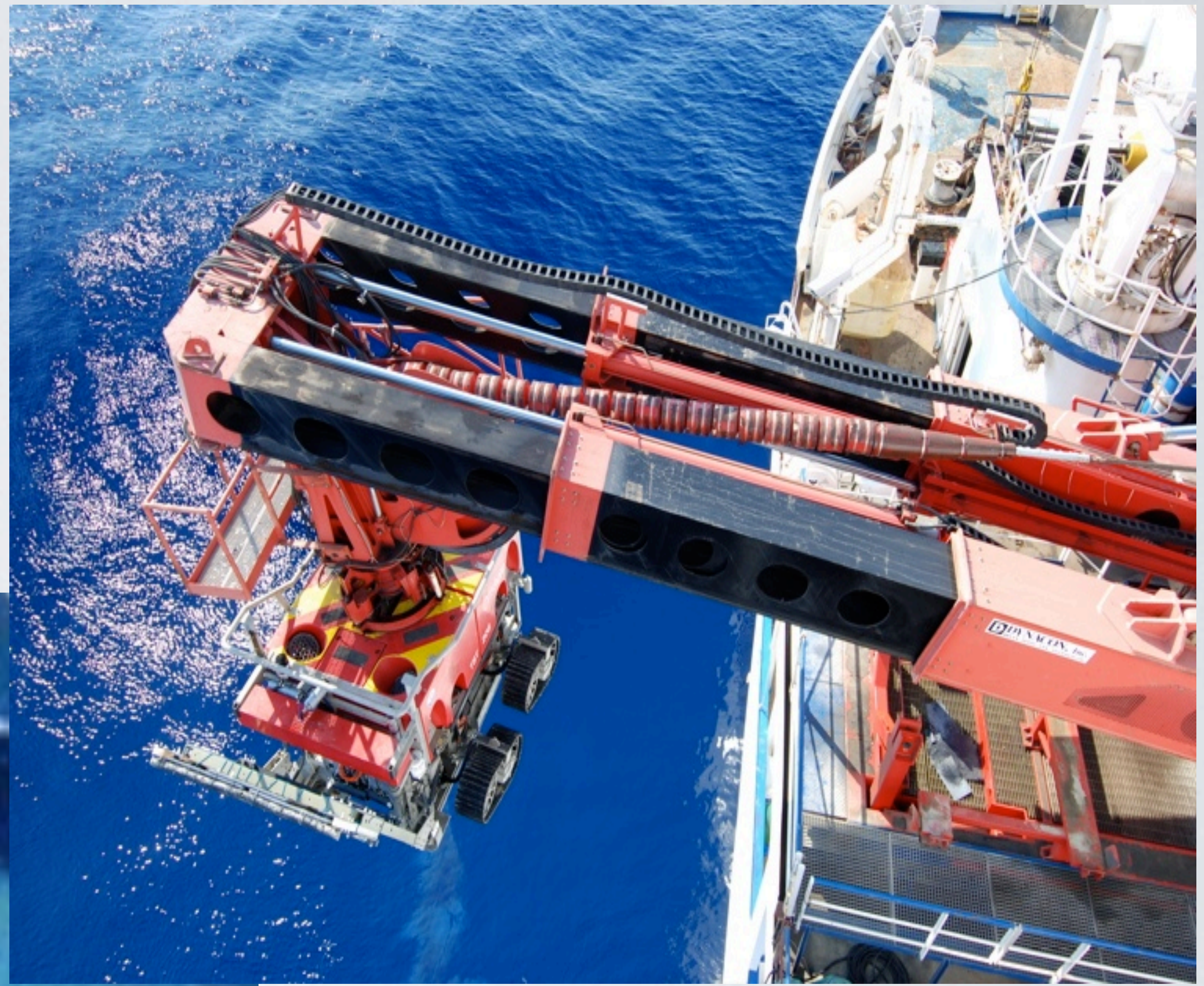

Cable Deployment

The Burial Activity



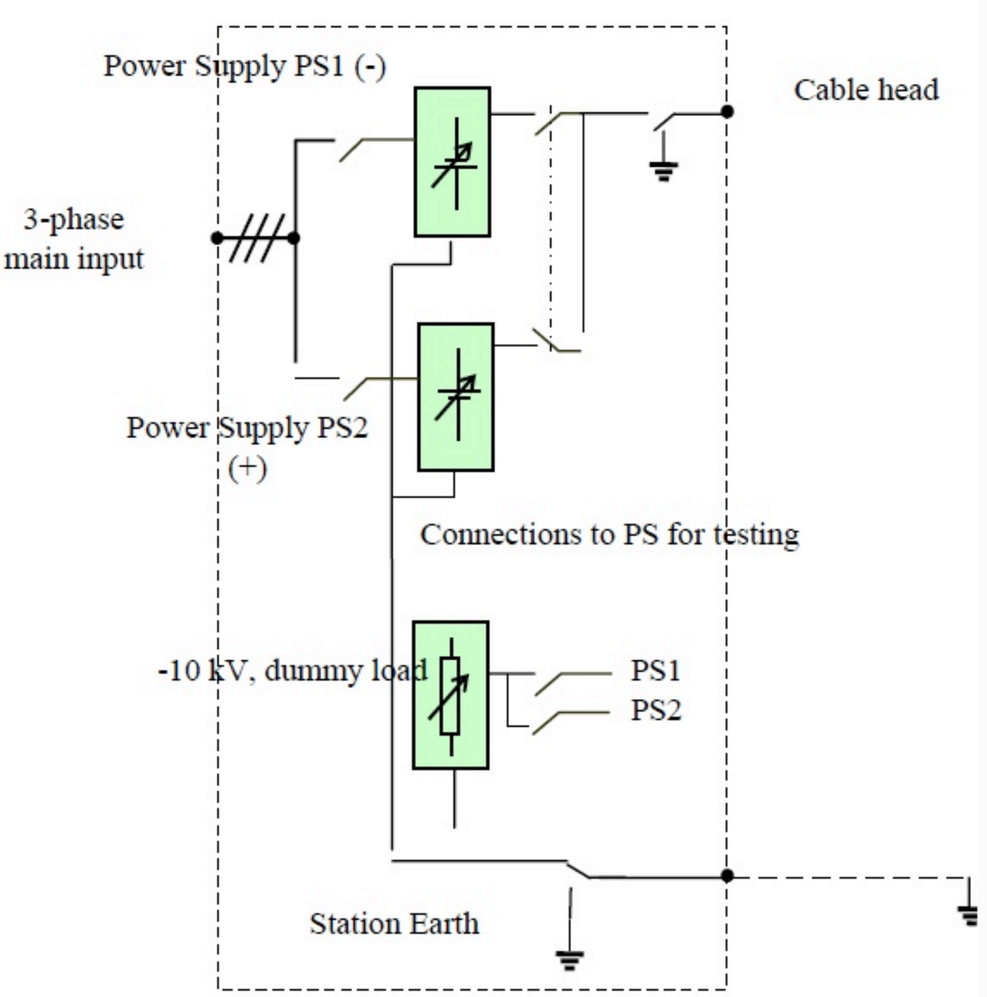
Soft Soil

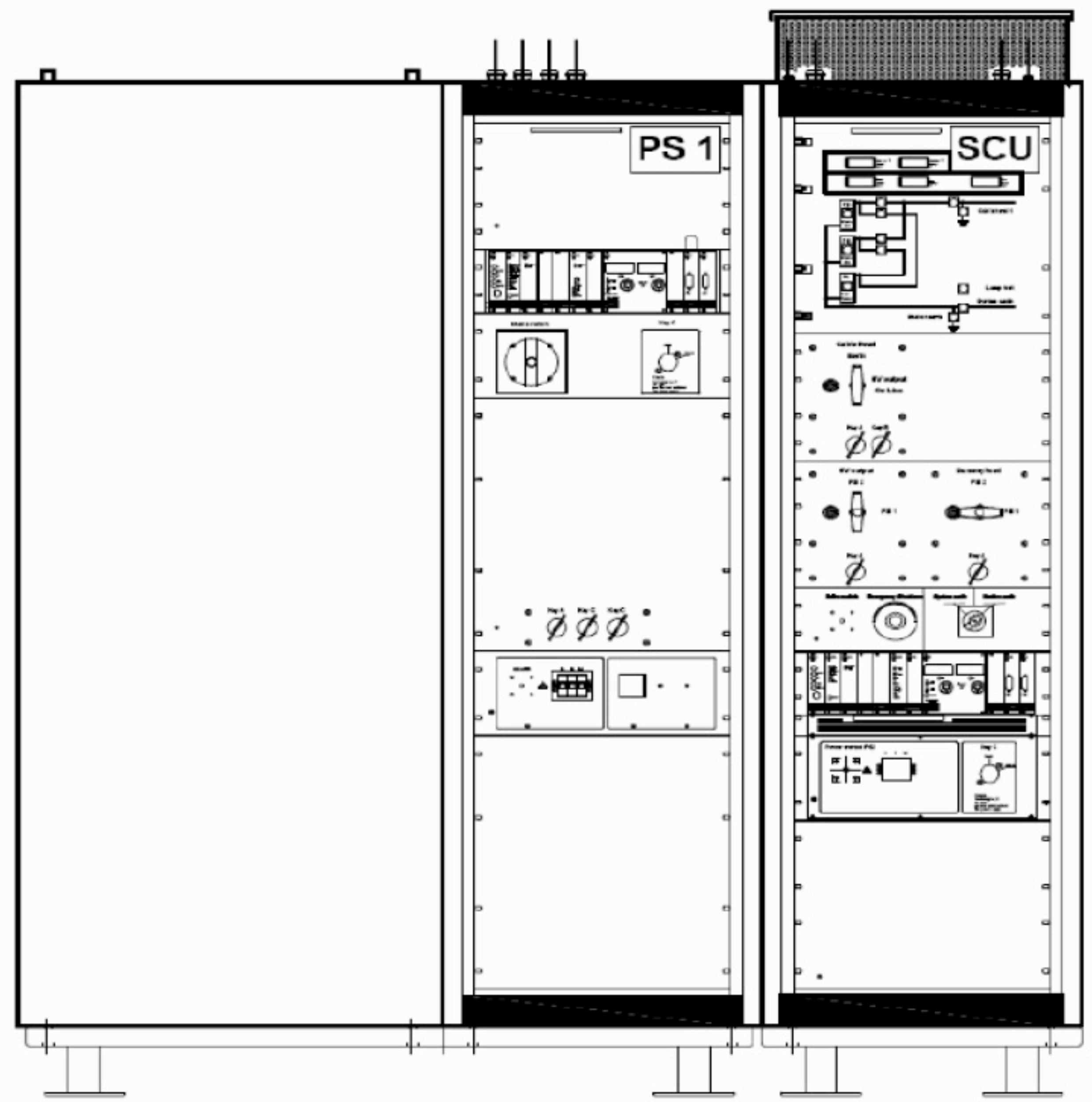




Firm Soil

Nemo Phase 2 Power Feeding Equipment





Main parameters:

Switch control unit, consisting of:

- Main machine interface to control the setting of different operation modes
- Dummy load, 10kV, 5kW

Electrical data:

Output voltages and currents:

0 … 10 kV negative @ 0 … 5 A

0 … 1.5 kV positive @ 1.4 A

Input voltage: 400V / 50Hz 3 phases + neutral + protection earth

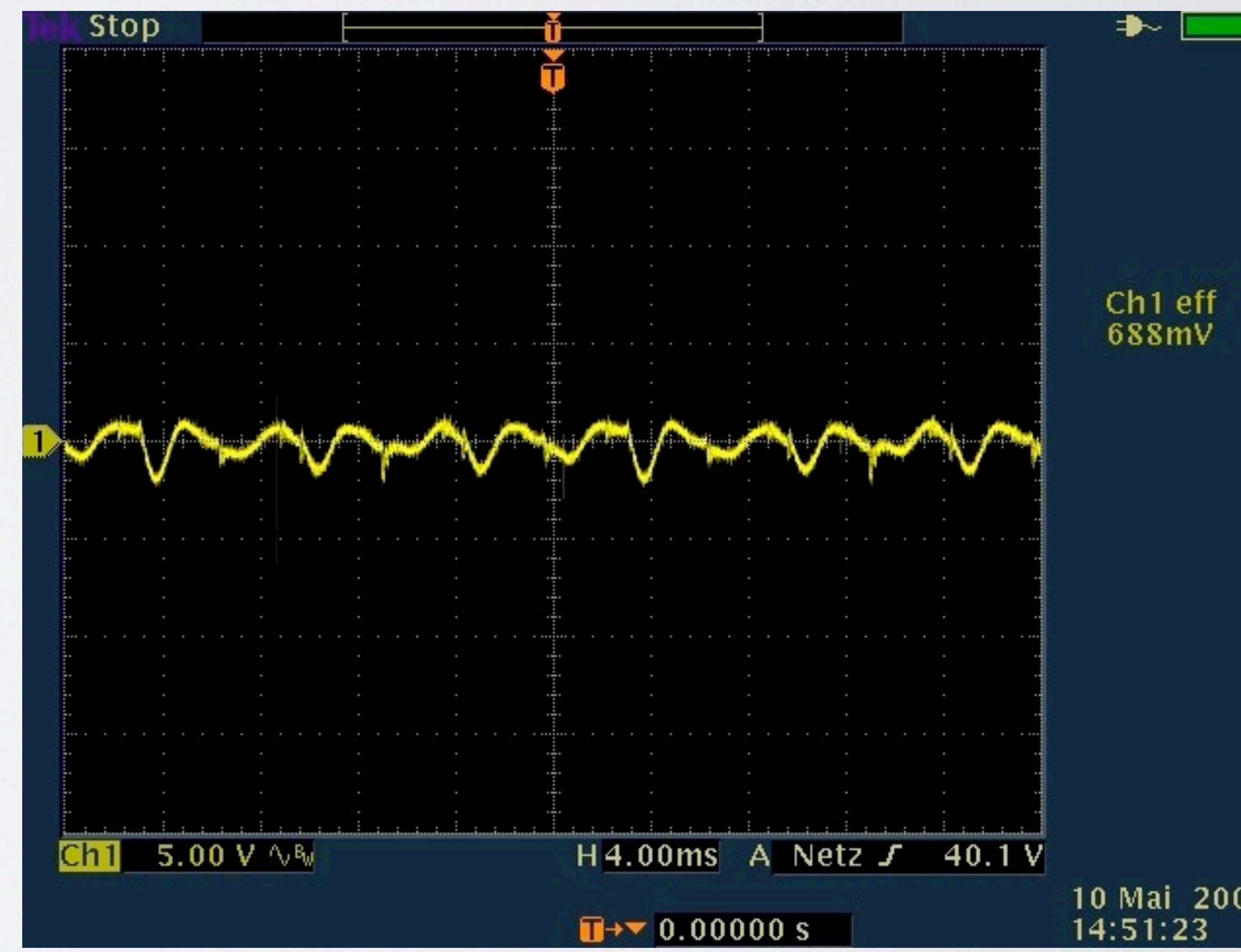
Nominal input current: 5.0 A

Maximum input current: 6 A

Mechanical data (including CTR rack):

Weight: approx. 400 kg

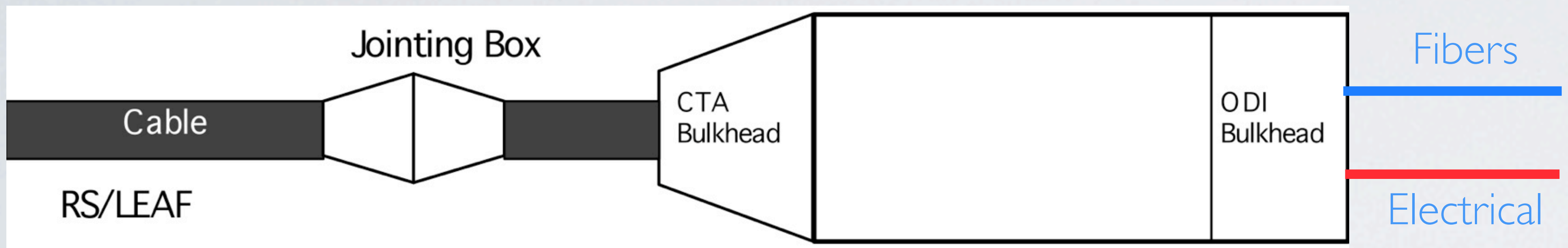
Dimensions: 600 / 2030 / 1200 mm (w/h/d)

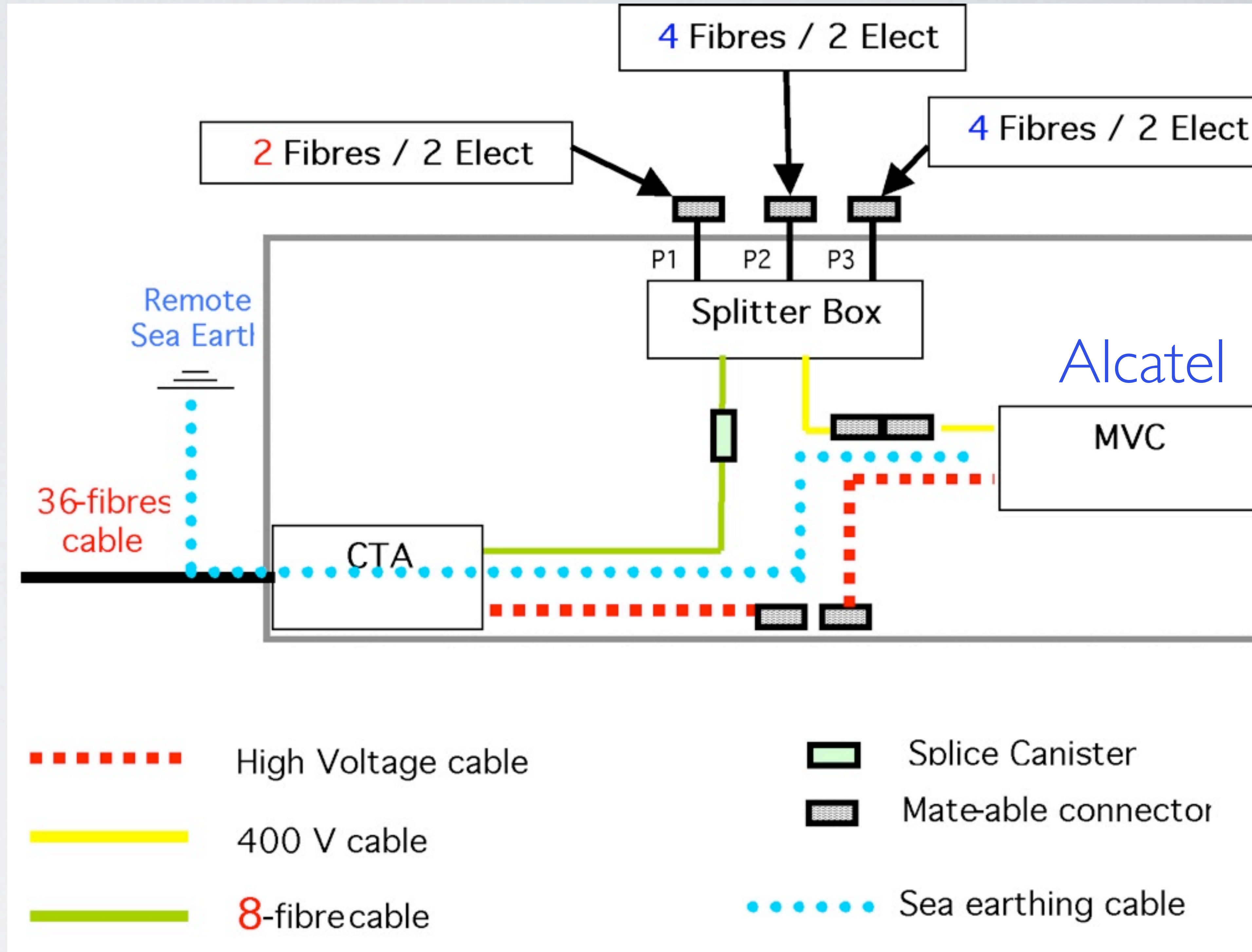


Output ripple at 10kV

Nemo Phase 2 Cable Termination

CTA Assembly





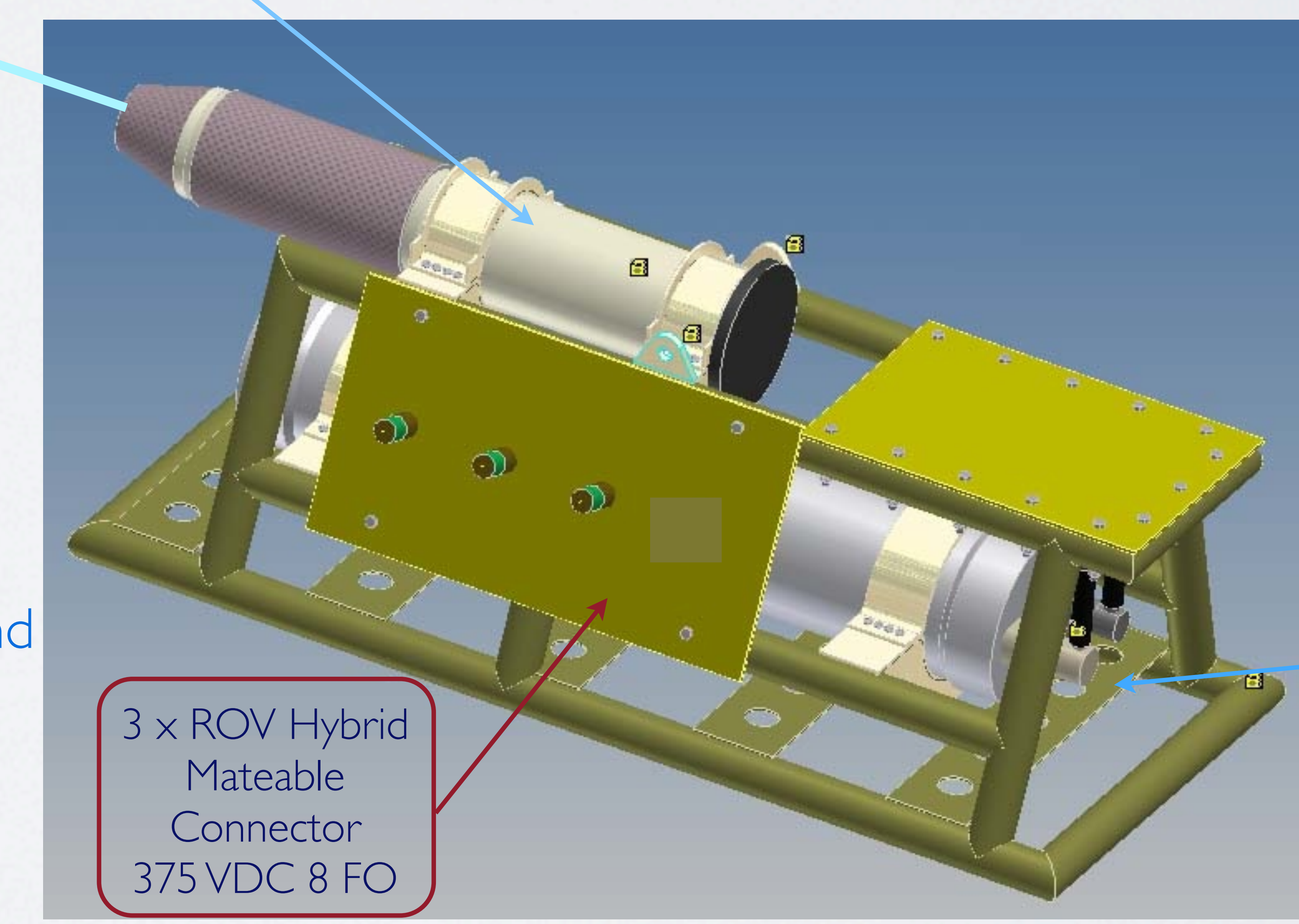
From Shore
100 km

CTA

Remote
Sea
Earth

Active surface of electrode

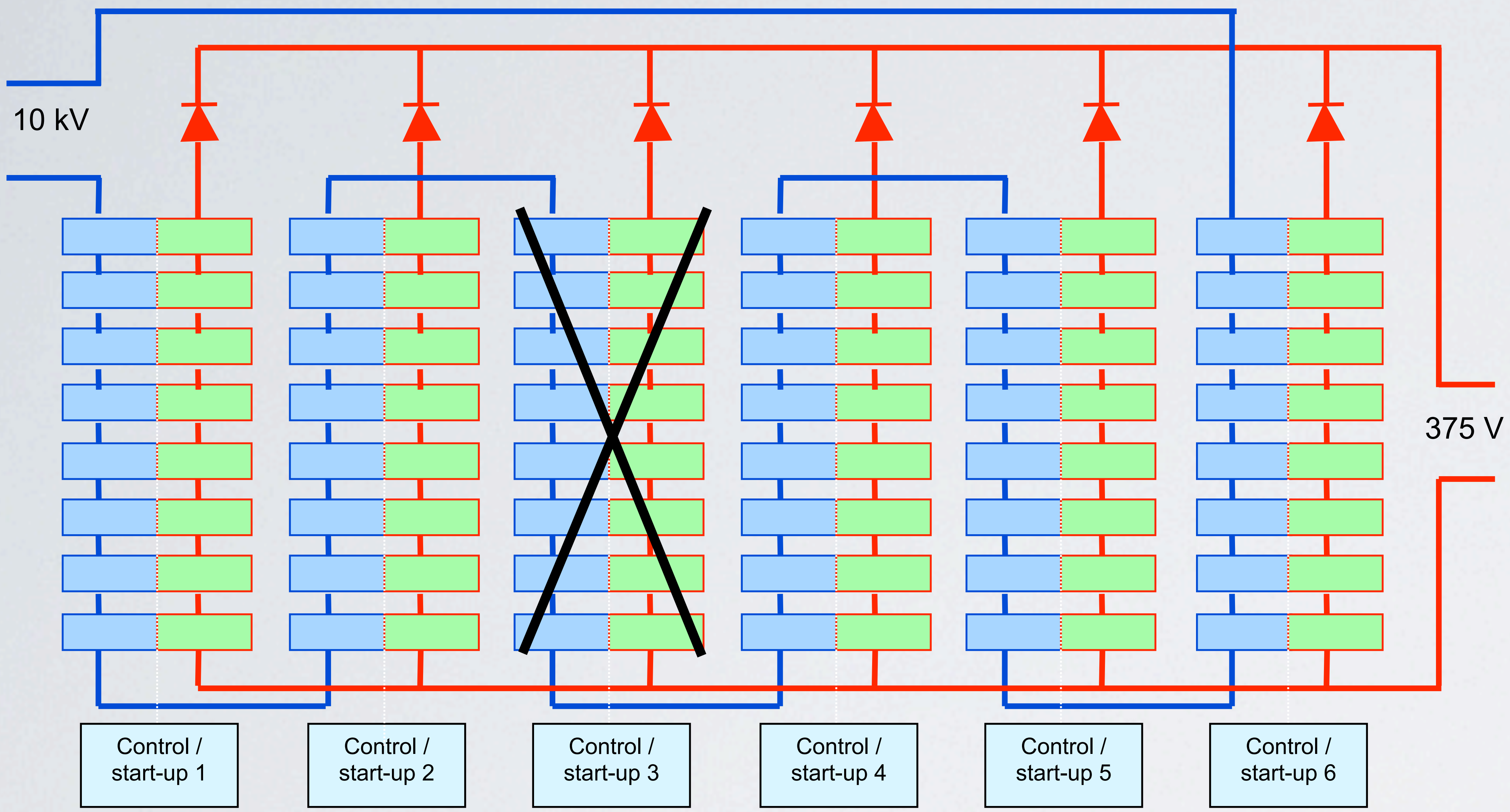
Elastomer bend
limiter

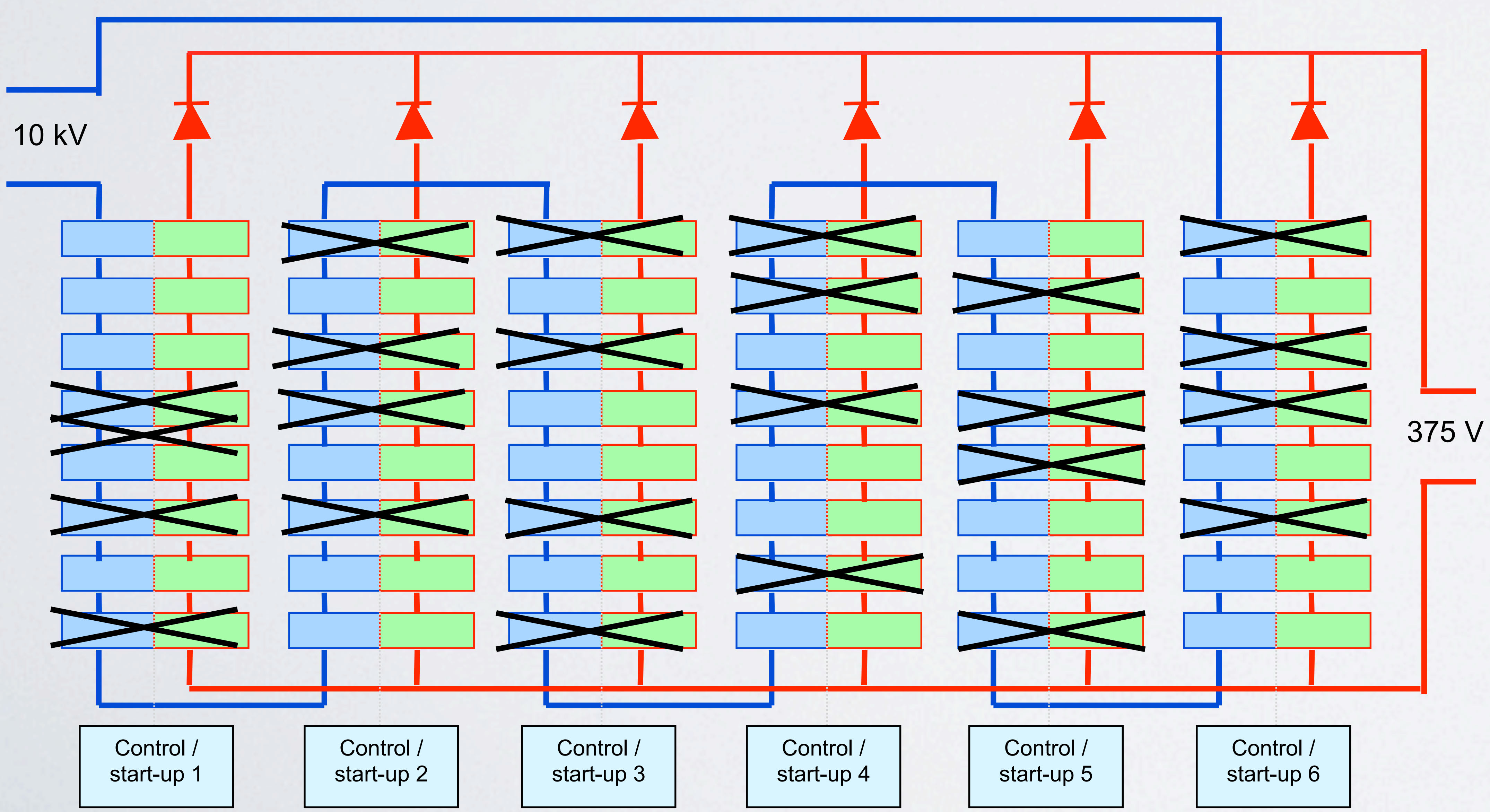


3 x ROV Hybrid
Mateable
Connector
375 VDC 8 FO

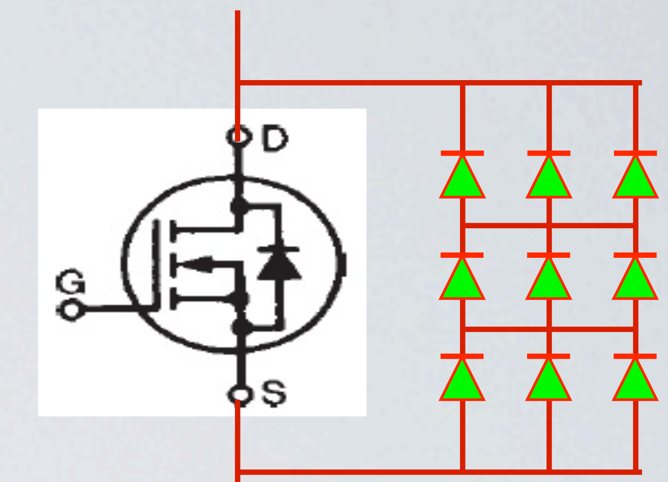
MVC

DC/DC Converter 10 KVDC/375 VDC 10kW

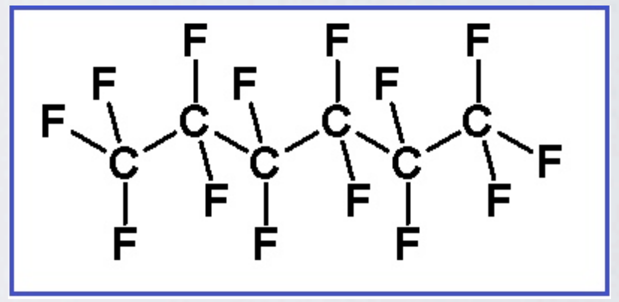




- Inputs in series
- Outputs in series / parallel matrix
- 48 sub converters each 200V to 50V - 210 W
- Inputs in series
- Outputs in series / parallel matrix
- Modular design allows for flexibility in input and output voltages.
- Output diodes allows Large scale failure of sub converter output sections or control with only reduced output current.
- Sub converters input sections fail short circuit allowing large to fail without loss of output.
- <u>Topology used in space craft by JPL NASA for the Neptune Project</u>
- Low stress design
- 600V transistors used to switch 200V
- Devices capable of working at 100°C used at 36°C.
- Heat Transfer by Fluorinert FC-77

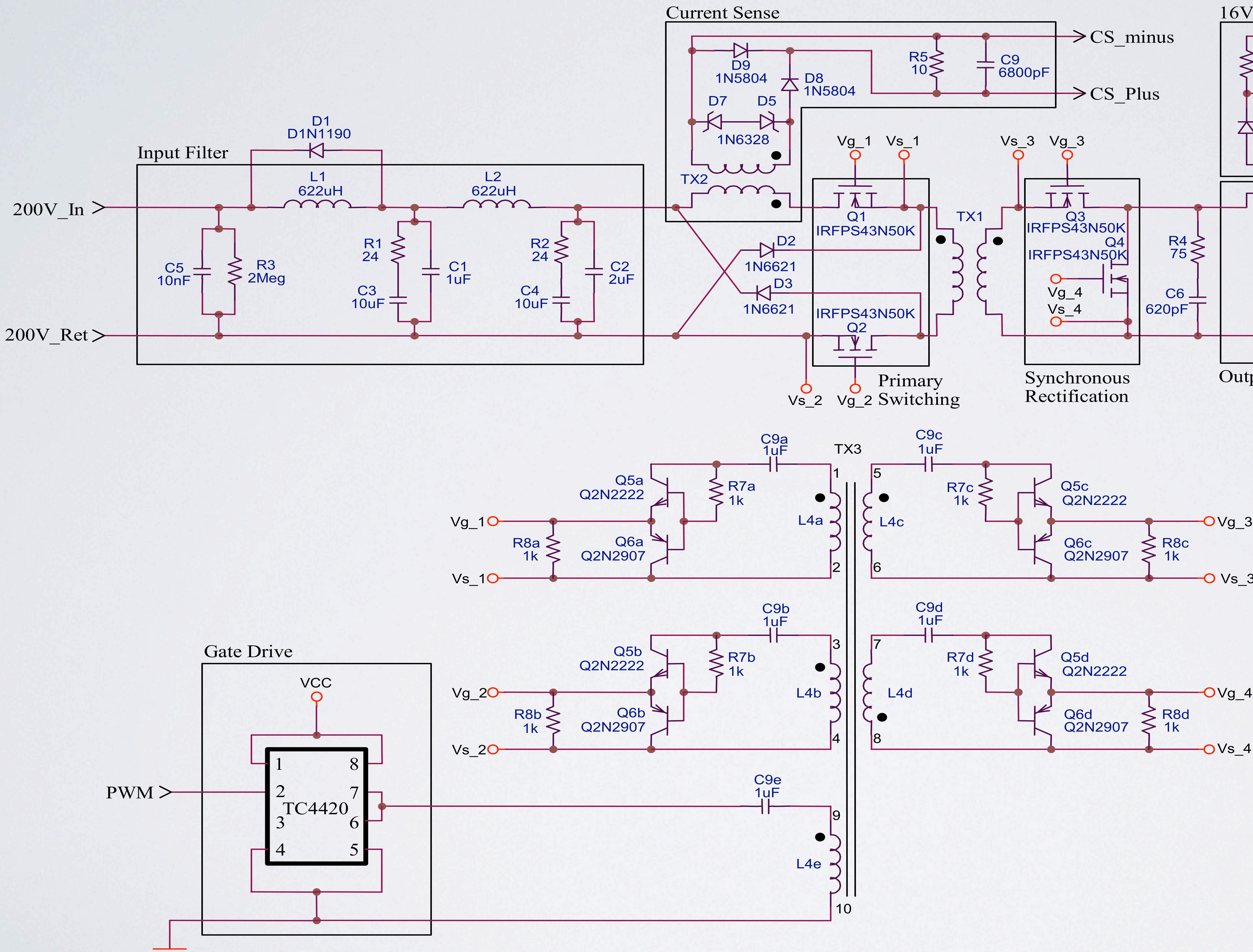


In the event of the FET failing Open circuit the diodes fail short circuit, typically 0.5 to 1 ohm



Fluorinert liquids are thermally and chemically stable, compatible with sensitive materials, including metals, plastics and elastomers, having a viscosity similar to water but approximately 75% greater density. The dielectric strength is in excess of 35,000 volts across a 0.1 inch gap.

DC/DC Converter Single Stage 200/50 VDC 210 W



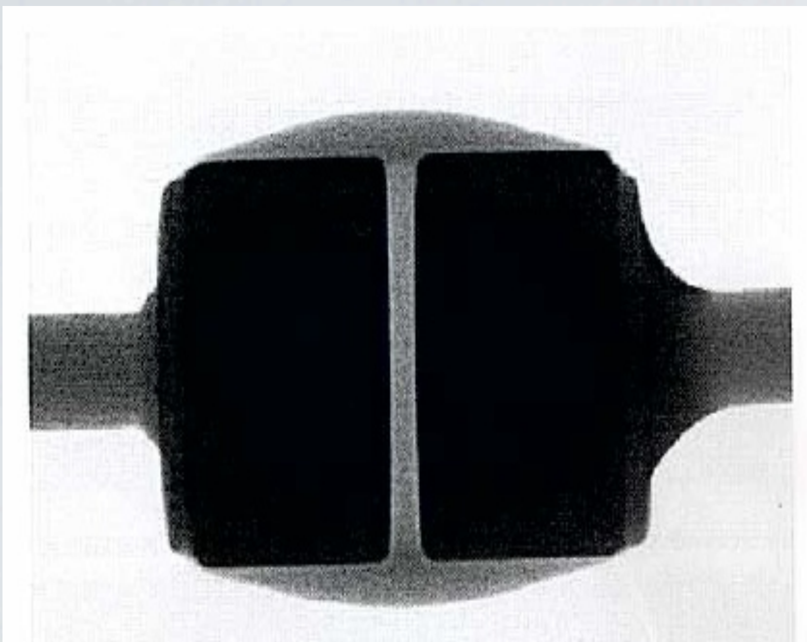
48 block x 200V to 50V, 200W

All the Input in series.

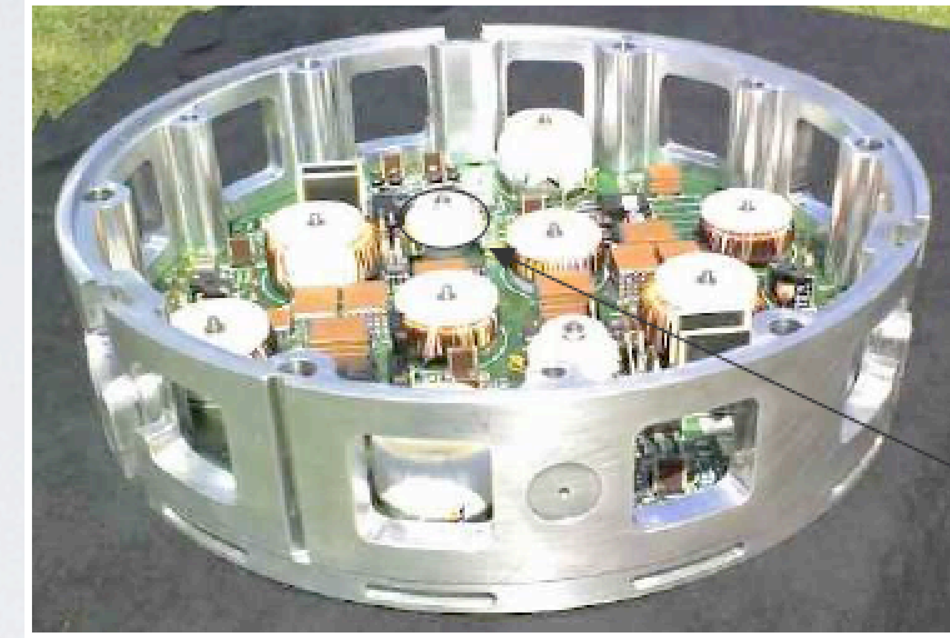
The outputs, are connected in a matrix consisting of 6 parallel legs each formed by the series connection of 8 outputs.

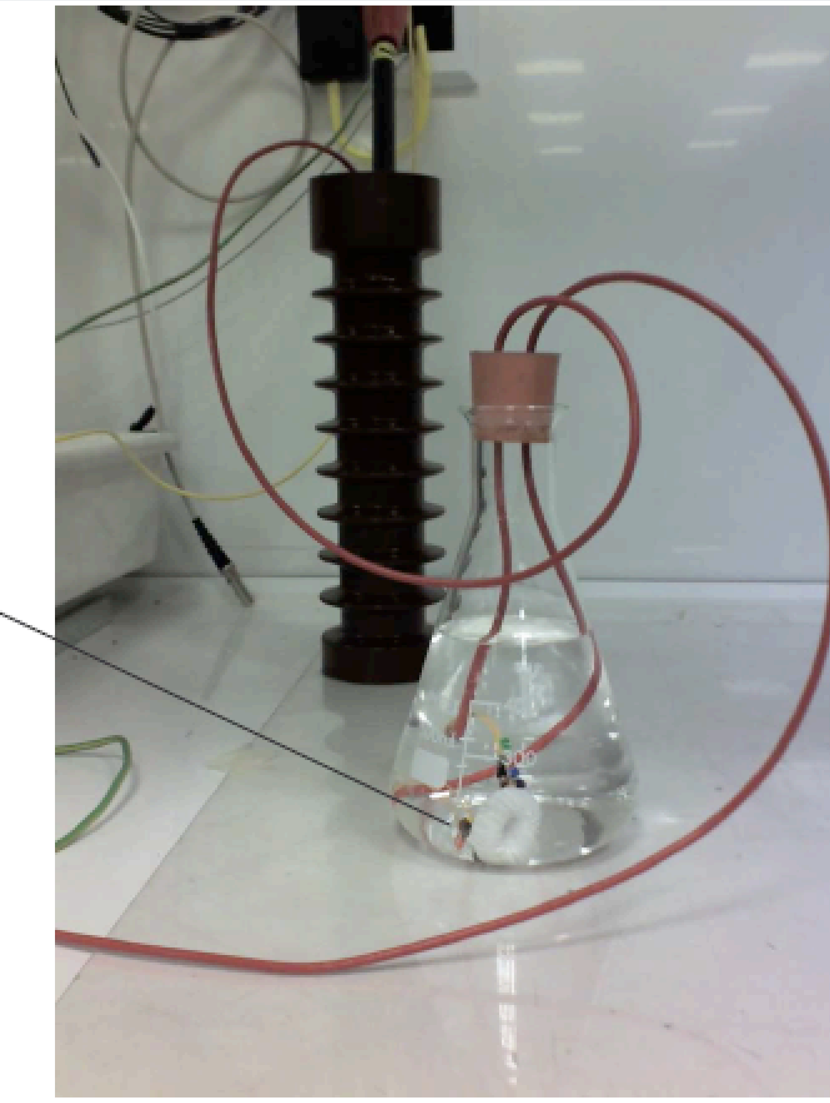
M. Sedita TWEPP-09 Paris 21-25/September 2009

MVC Component Test



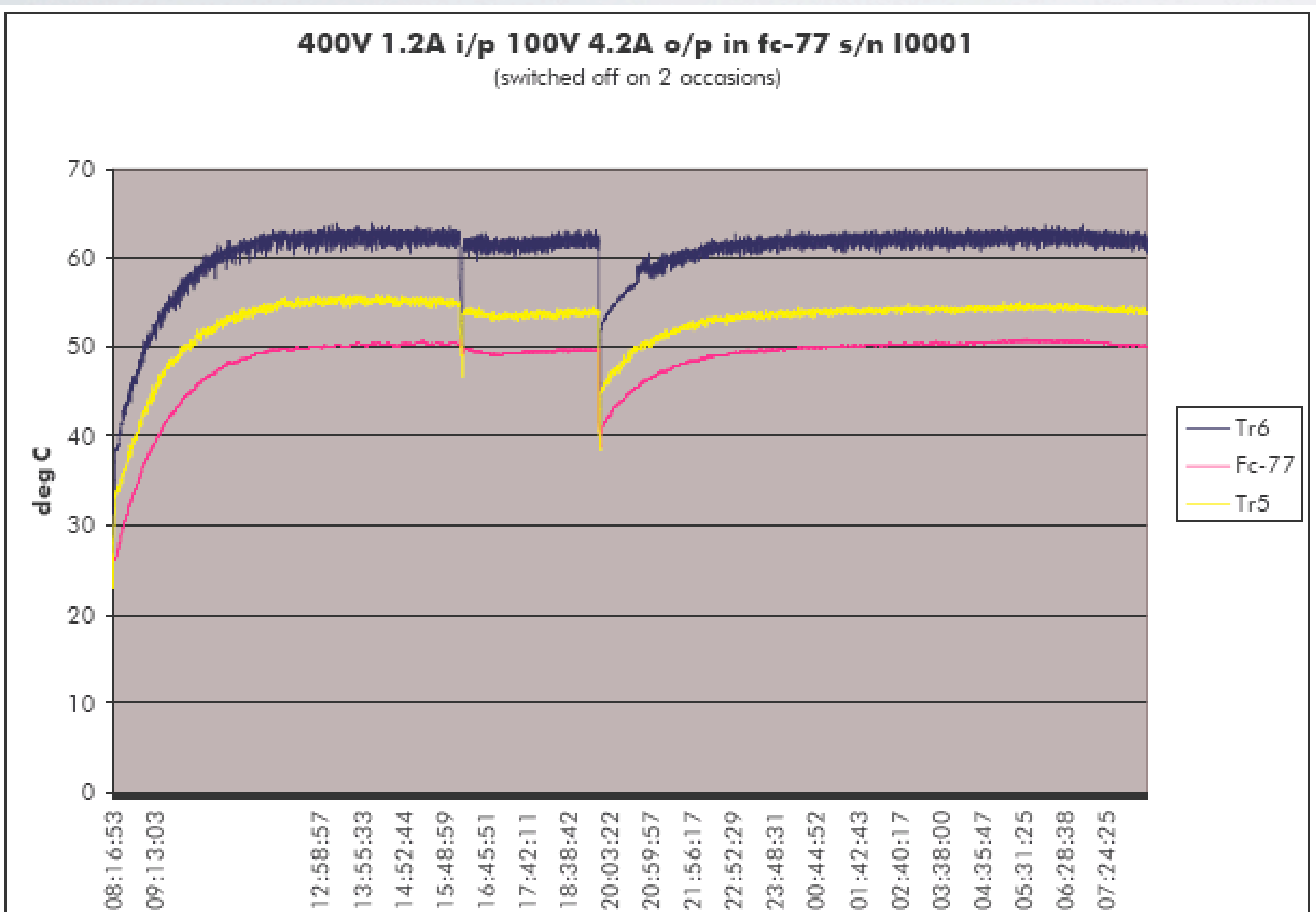
X-Ray showing plate construction. Without bond wires, rupture current greater than 150A





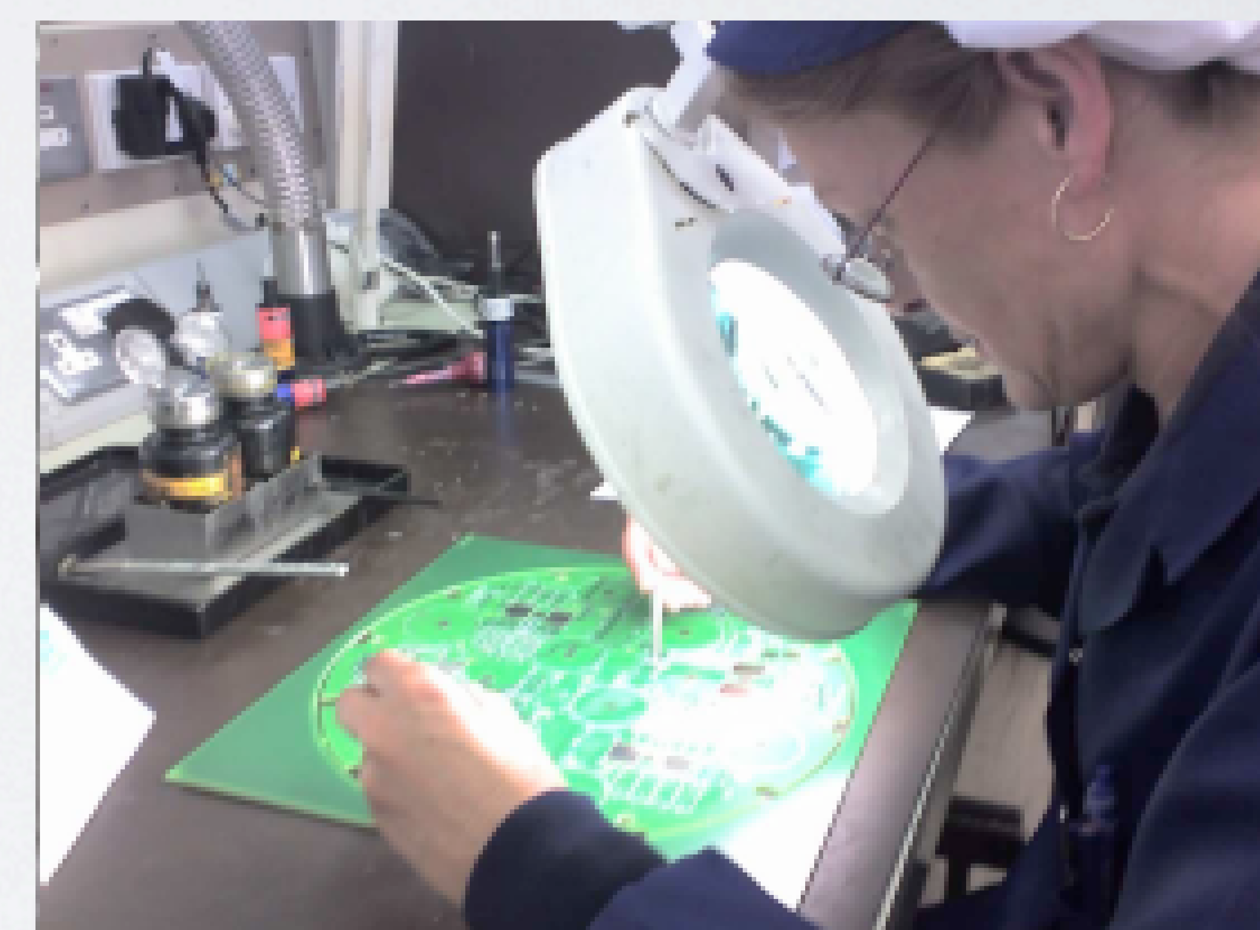
Component insulation stress

- Components tested to 25kV for 10kV use
- Exceptionally low leakage
- Key components tested for 4 wks

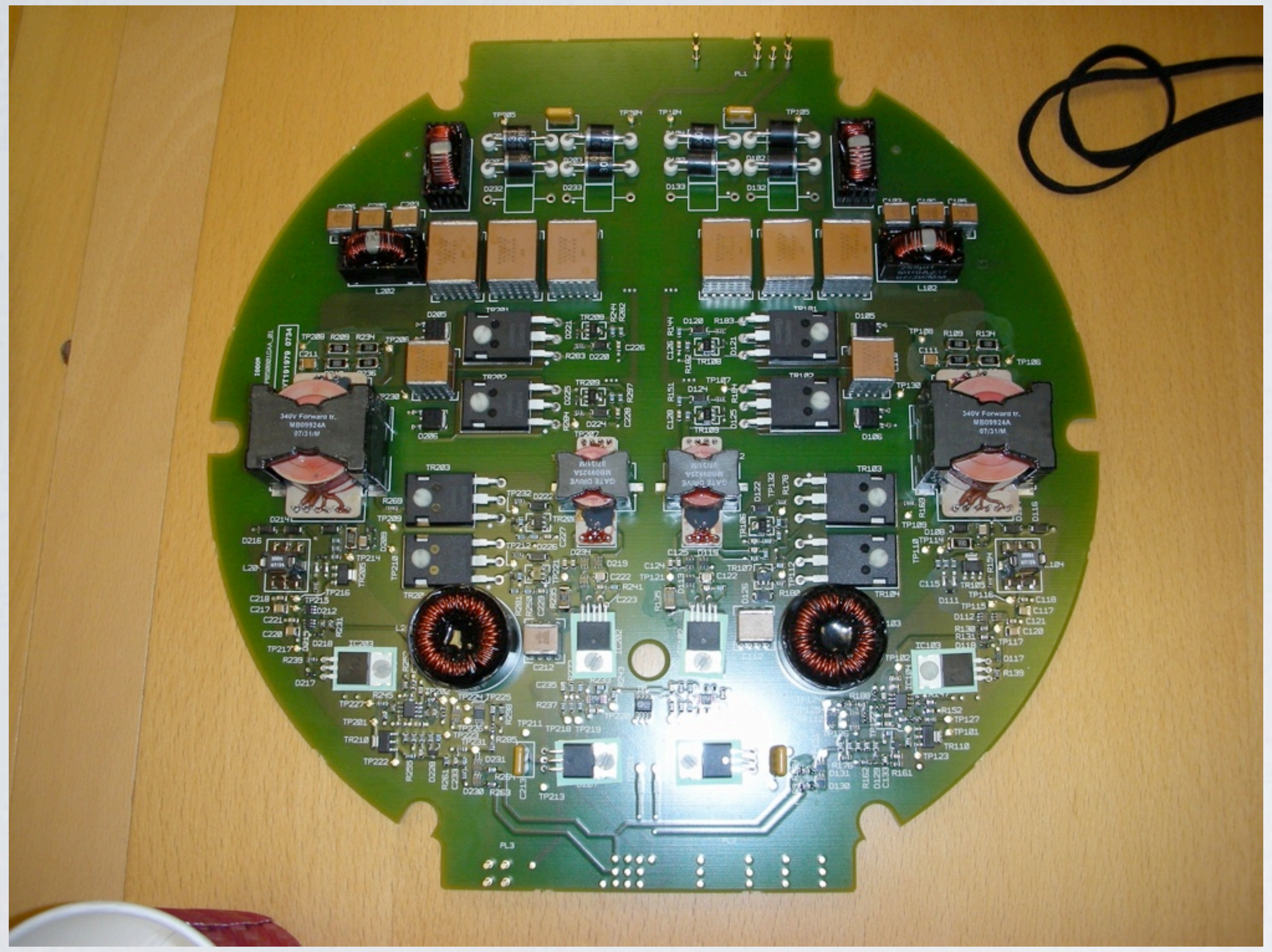


Overload stress test

- 100% overload
- 400W test, normal 200W
- 30°C simulated sea case
- Limited Fluorinert circulation
- Transistors well within limits

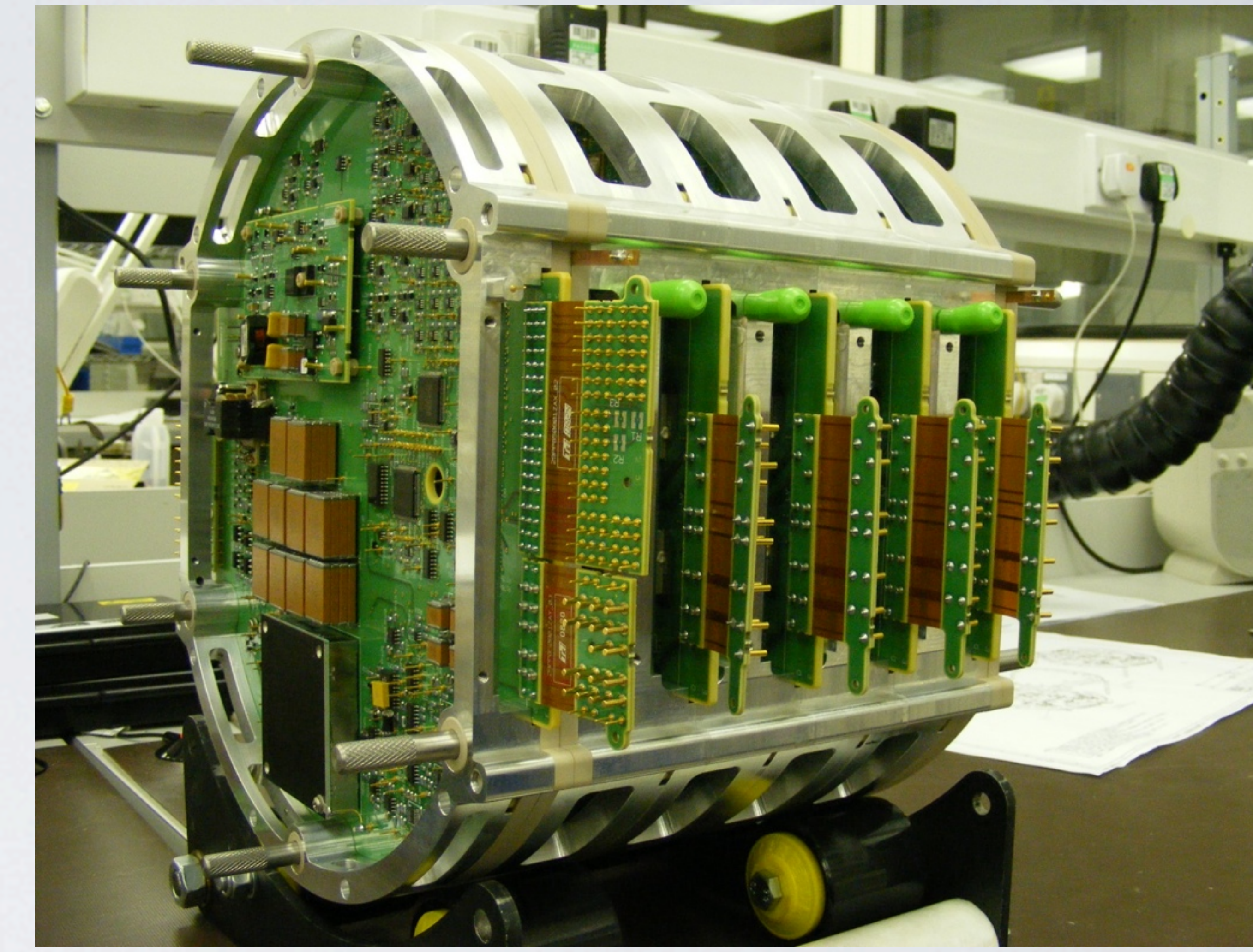


MVC Assembly



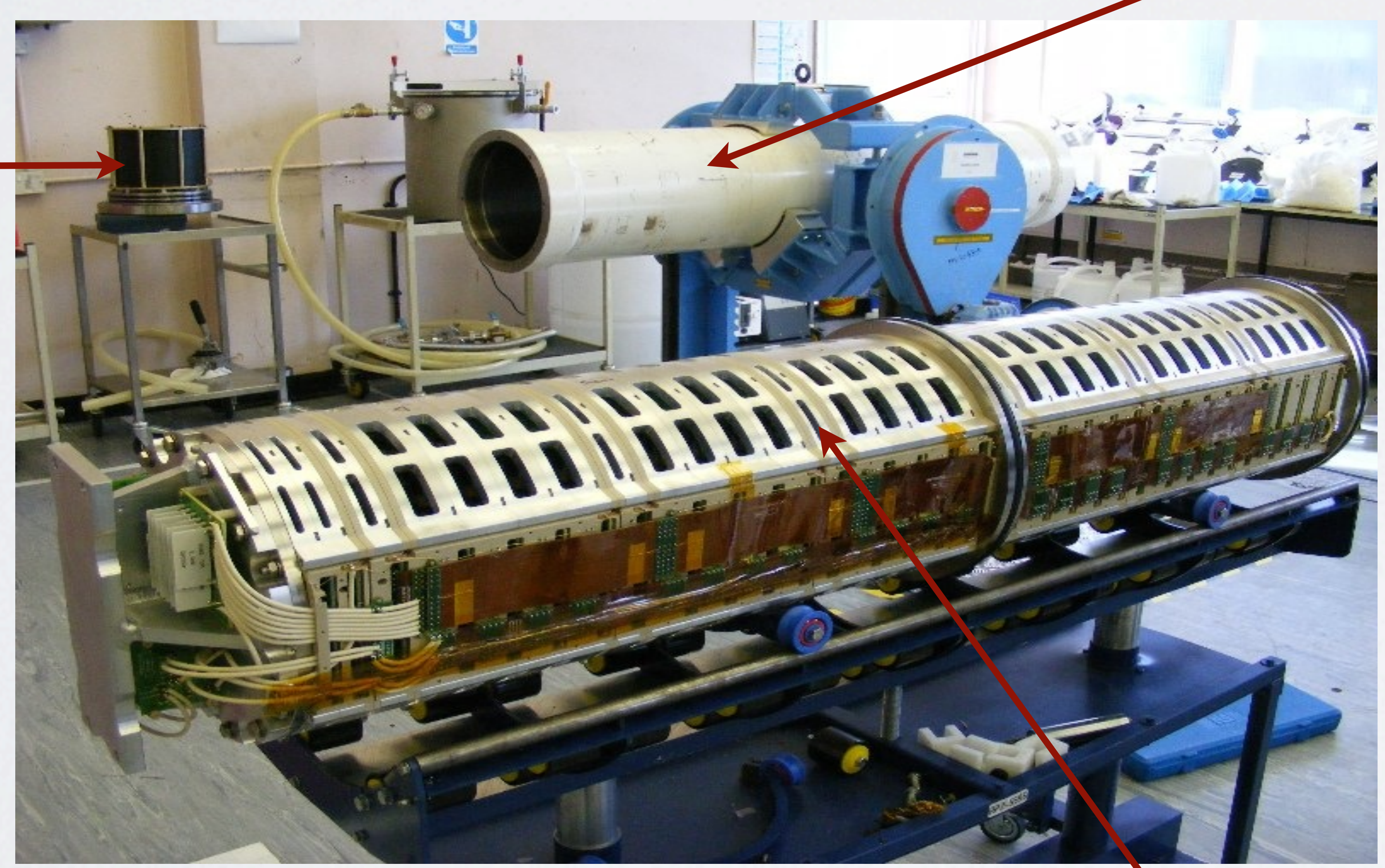
Single Board

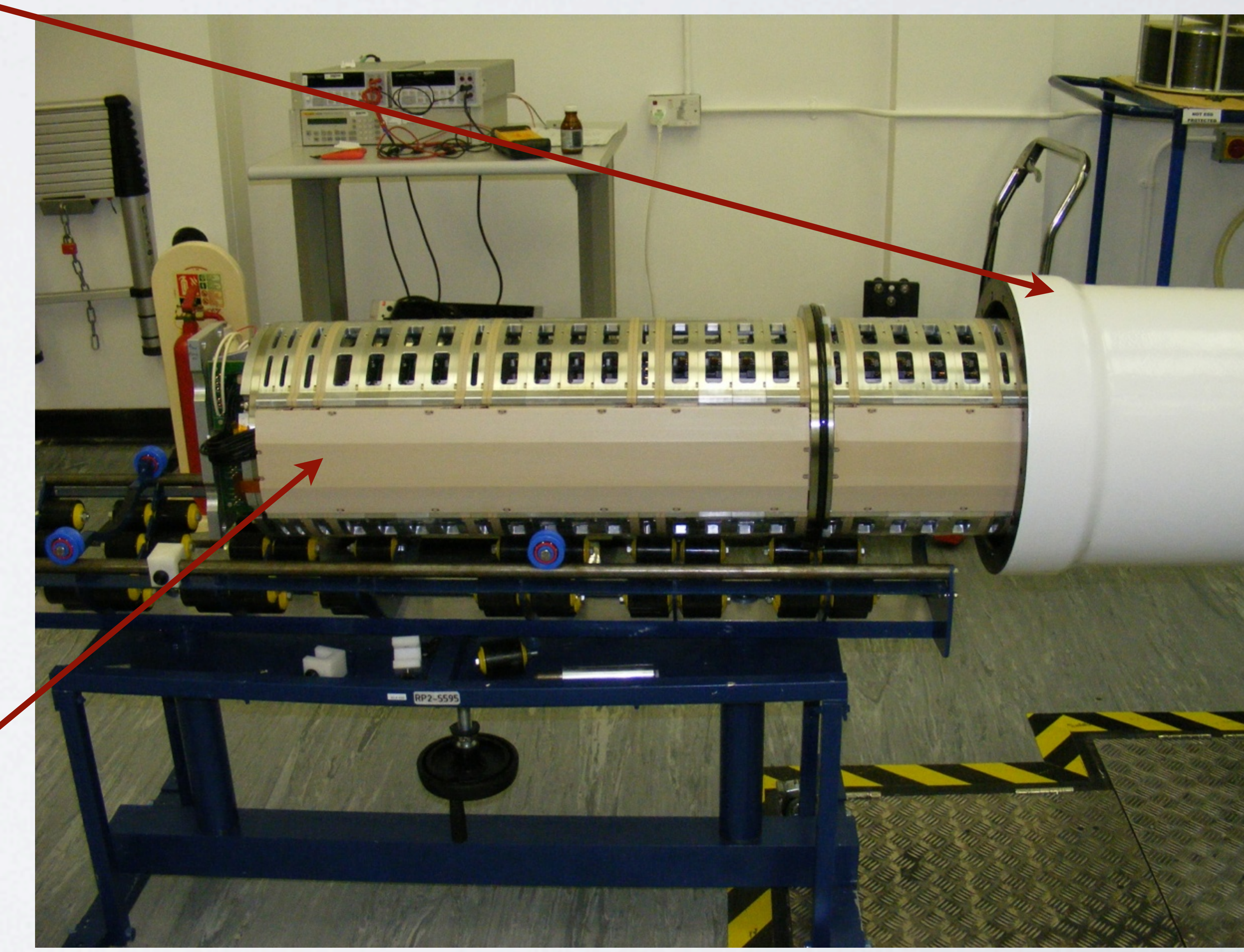
Stack Unit



MVC Vessel

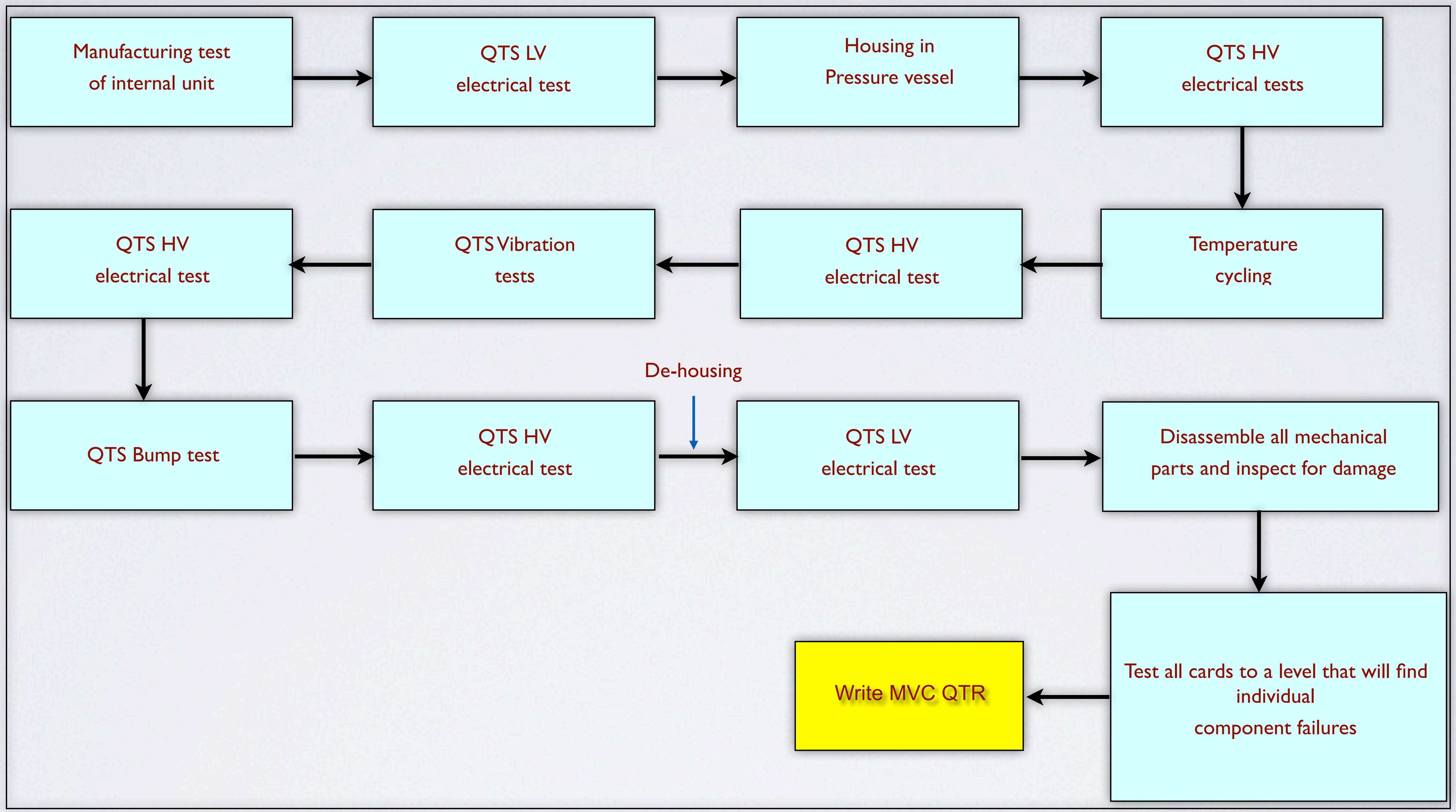
Bellow Pressure Compensation



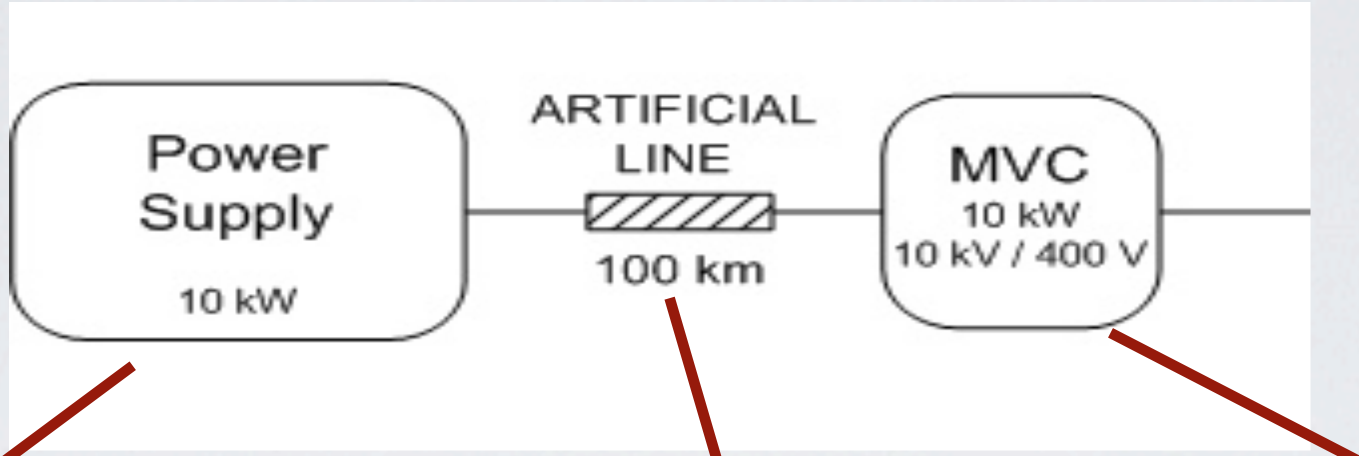


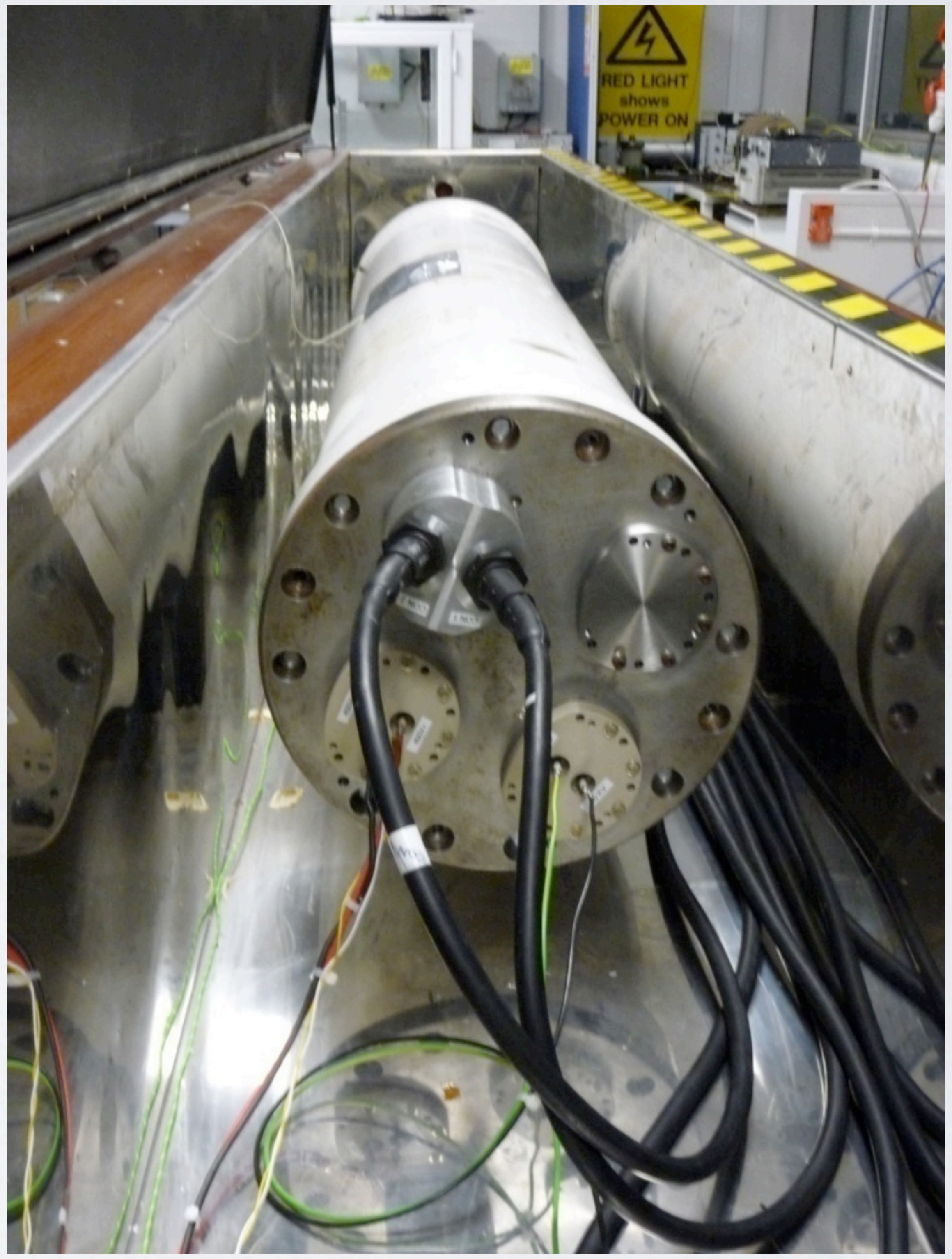
Complete MVC

MVC Qualification Tests Flowchart



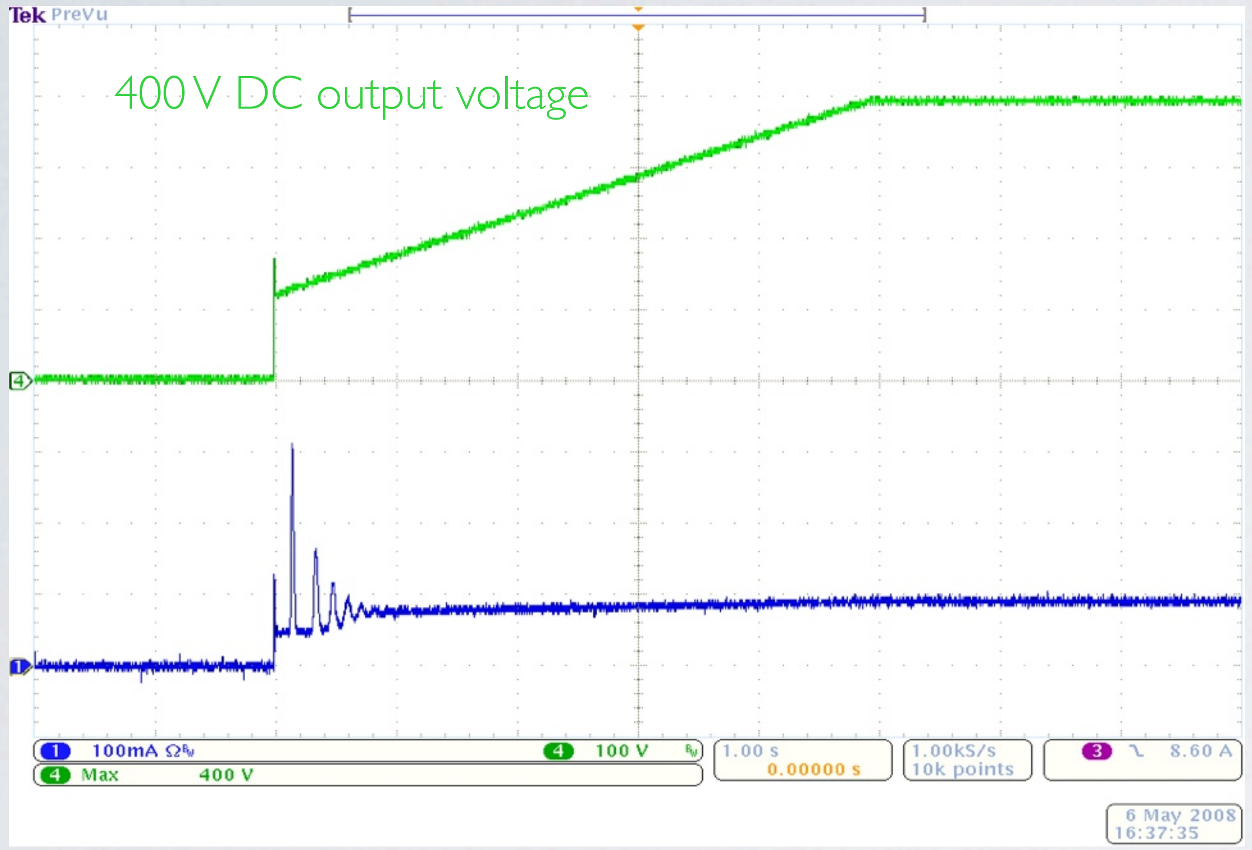
MVC Test layout



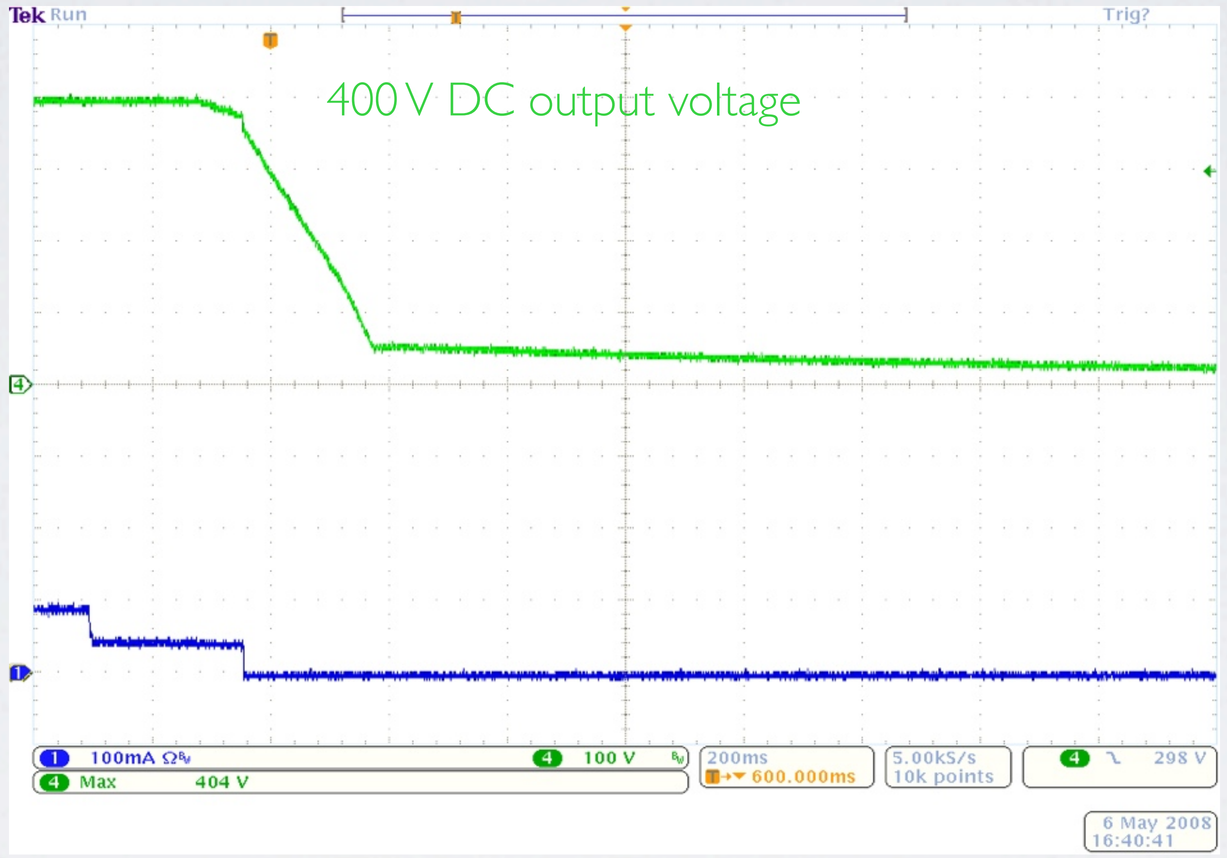


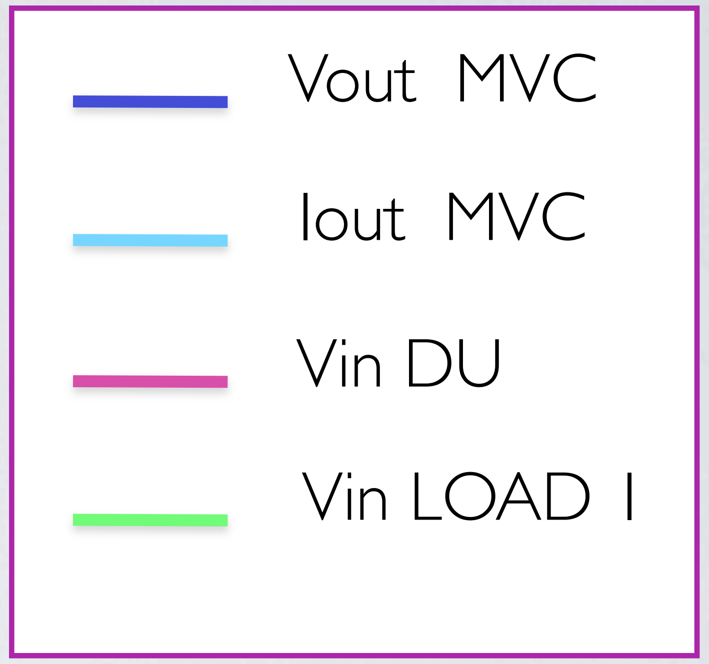
MVC Factory Test

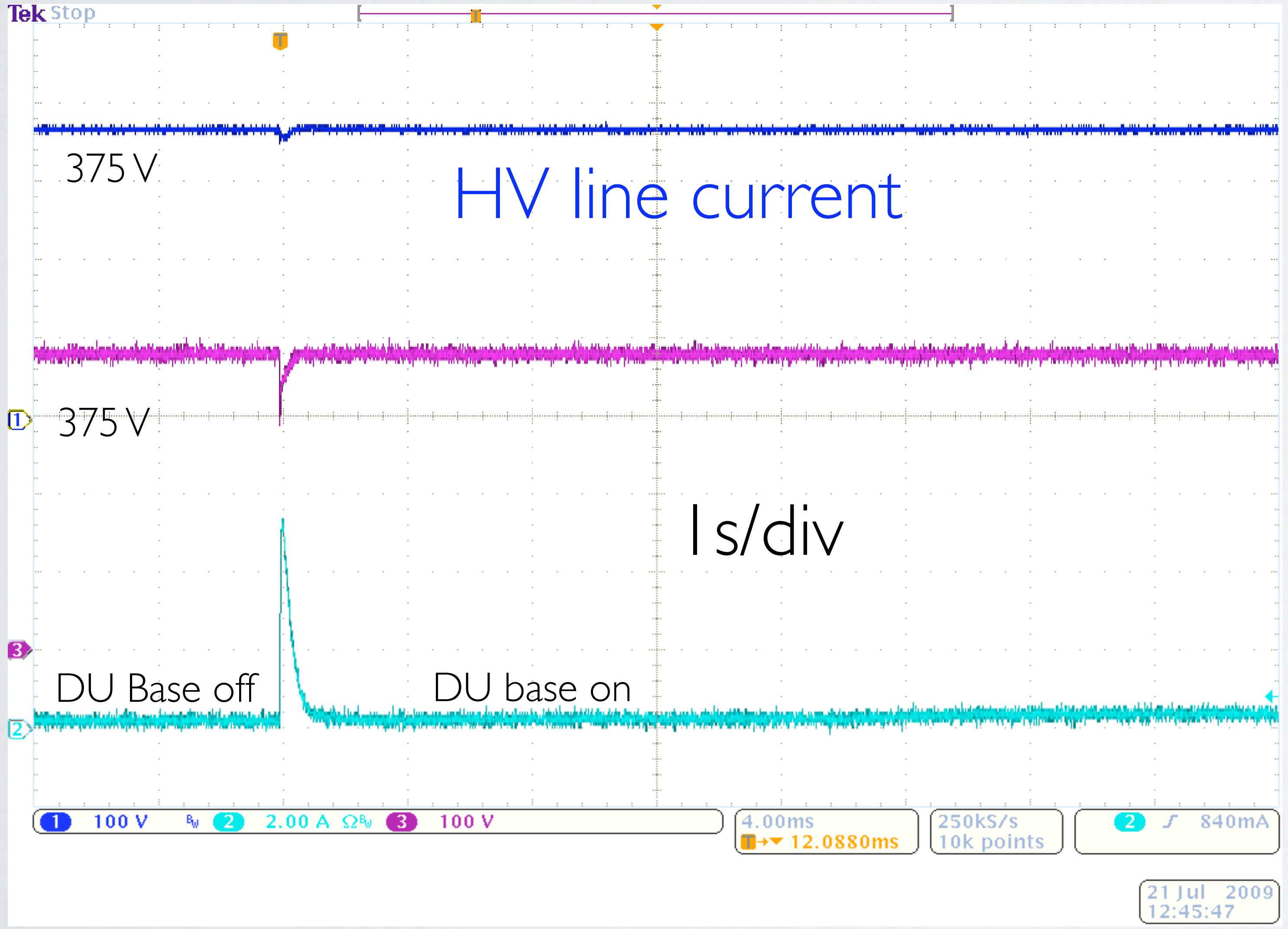
Start (when V input ≥ 5.7 kV)



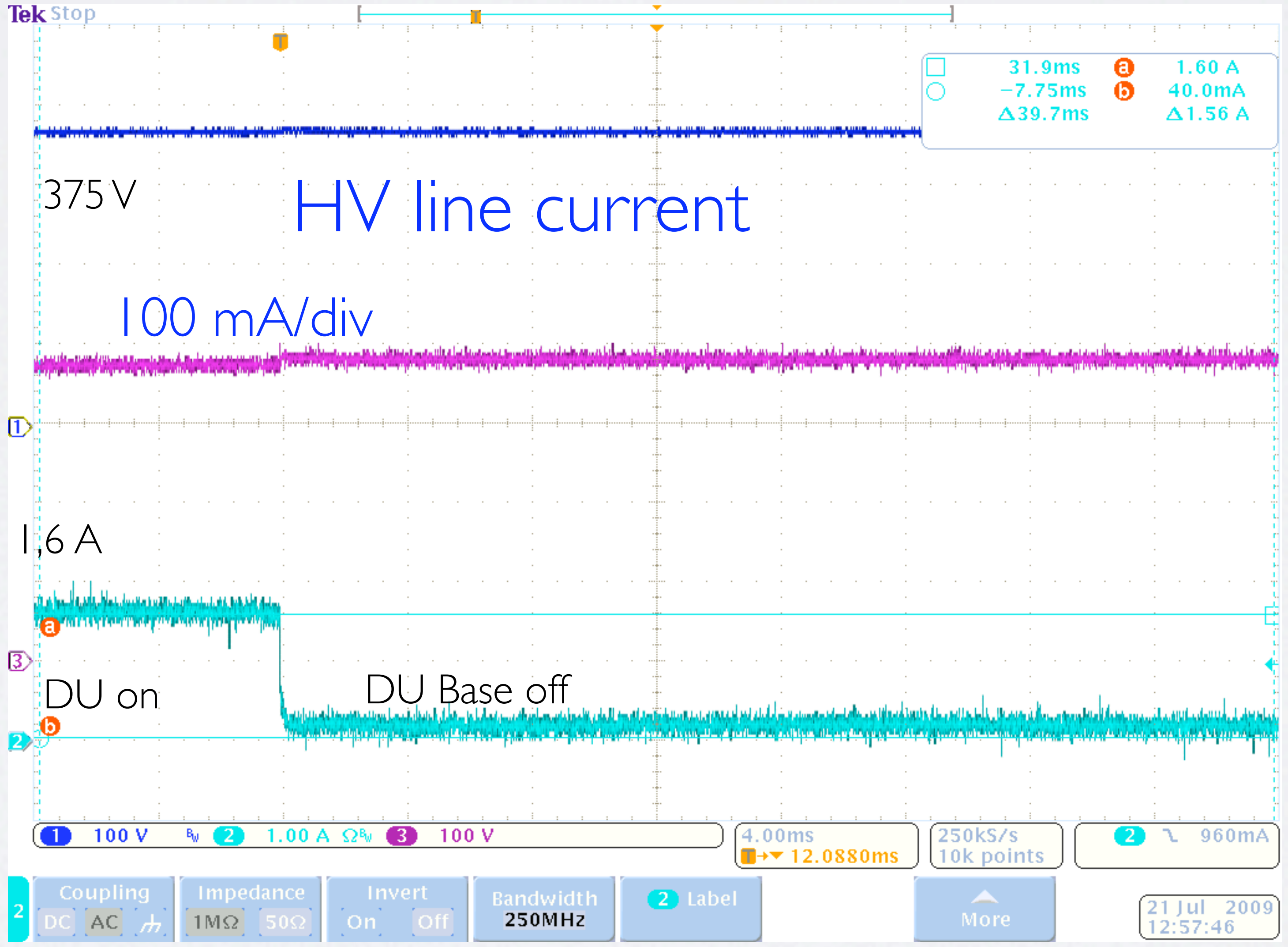
Stop (when V input <5.3kV)



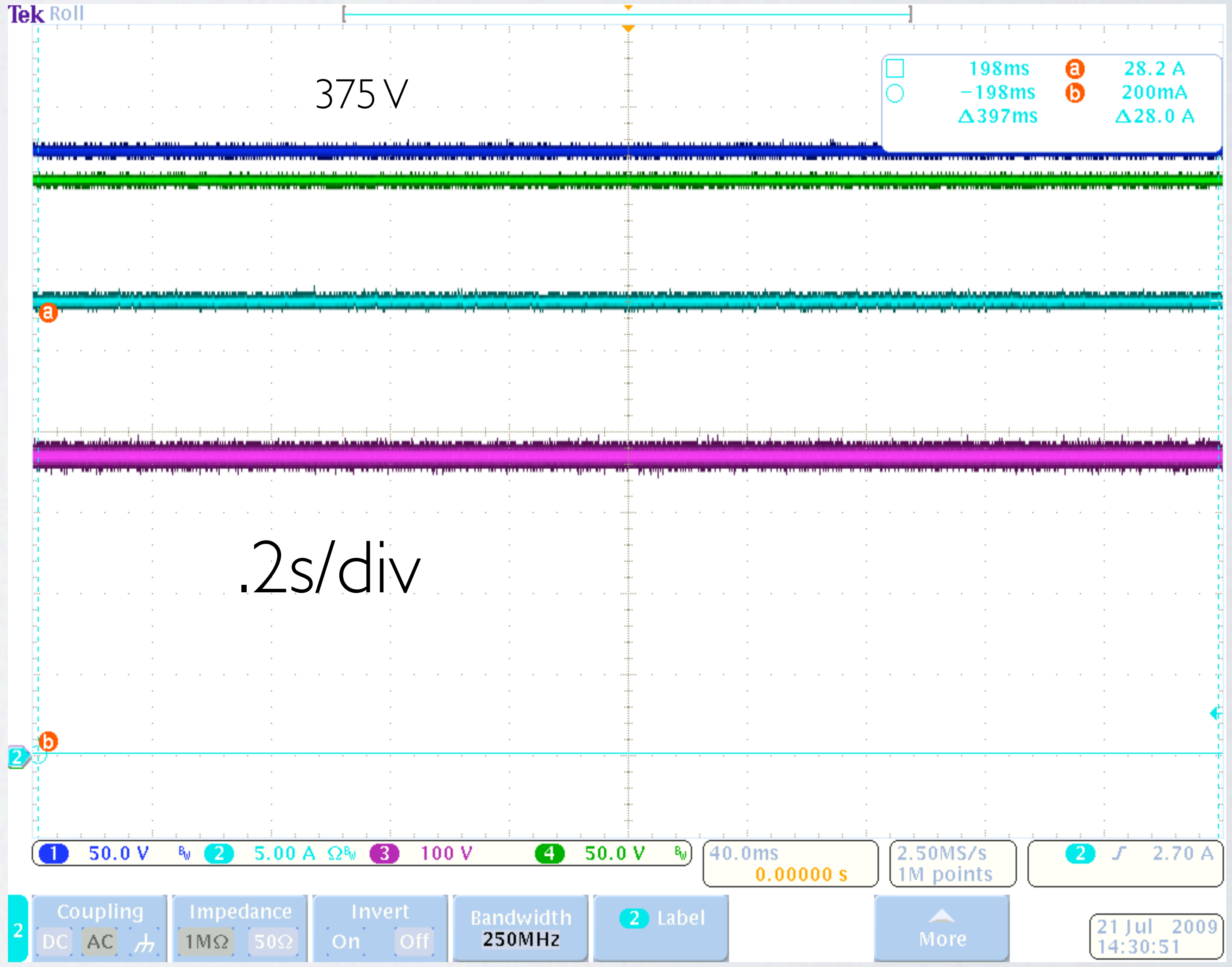




Switch DU 1 Base on (backbone on)



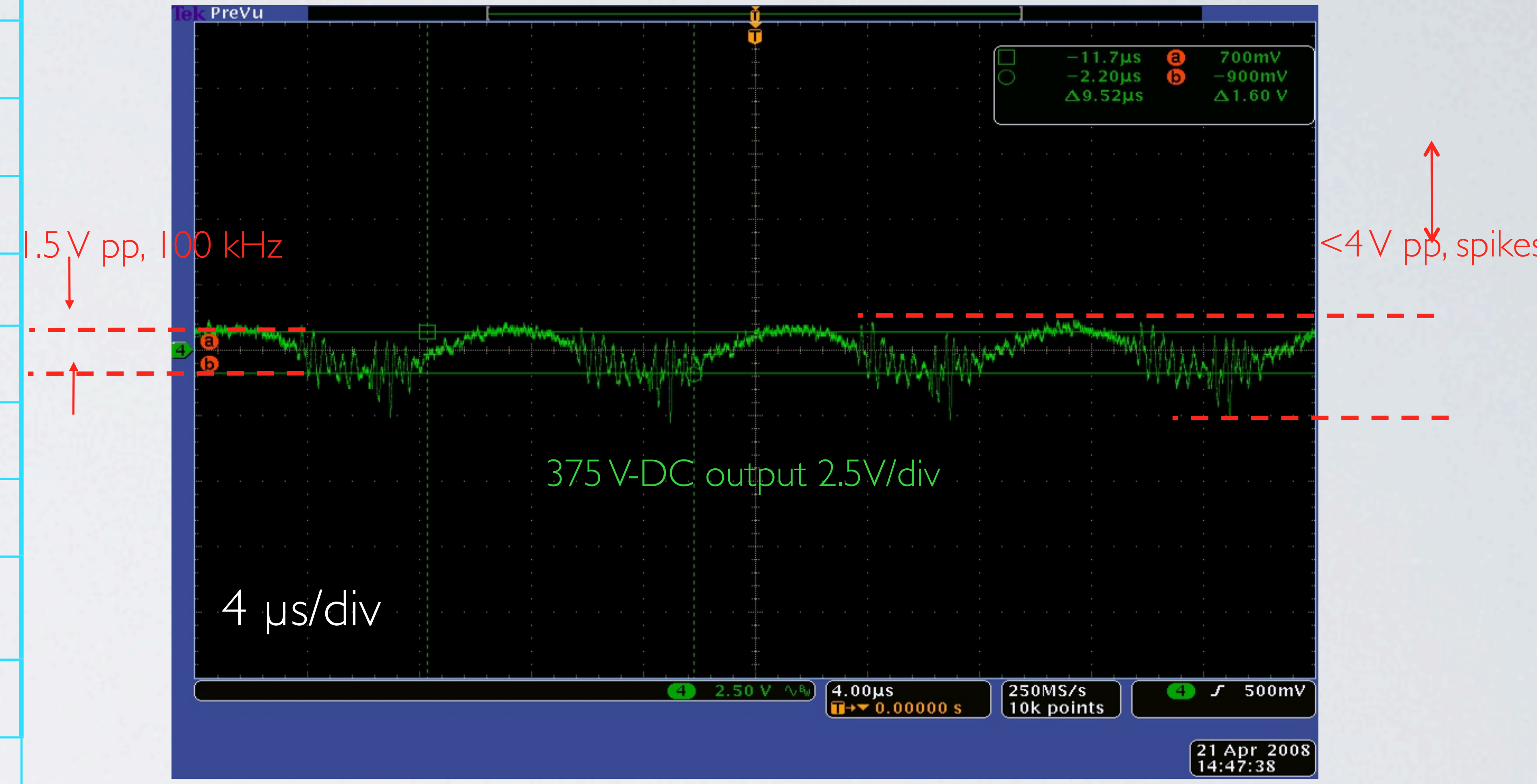
Switch on DU 1 - switches B0,…B16 – Switch off BT



Switch on 20 DUs (MVC output current = 28,2 A – 10,6 kW)

MVC Test Performance and Results

Input Voltage	-10 kV VDC
Max Steady State	-10kVdc max steady state; -5.7kV, -5.2kV hysteresis
Input ripple Current	Maximum 1.5mA at 50kHz
Input Surge Current	3A at turn on
Output Voltage	375 VDC
Output Ripple Voltage	1 Vrms. In any case 10 Vpp frequency range
Output Current	0 - 25 A
Output Voltage Overshoot	90% > 10% Step Load: overshoot ≤ 8.5% with 5 ms of settling time.
Output Voltage Undershoot	10% > 90% Step Load: undershoot ≤ 7.5% with 5 ms of settling time.
Output Regulation	± 1 % over load, line variations and temperature variations
Output short circuit protection	By fast blocking of power switches of each convert. **
Switching frequency	100 kHz ± 5 %
Efficiency	> 87 % at 10 kV 25 A load



** Short circuit protection

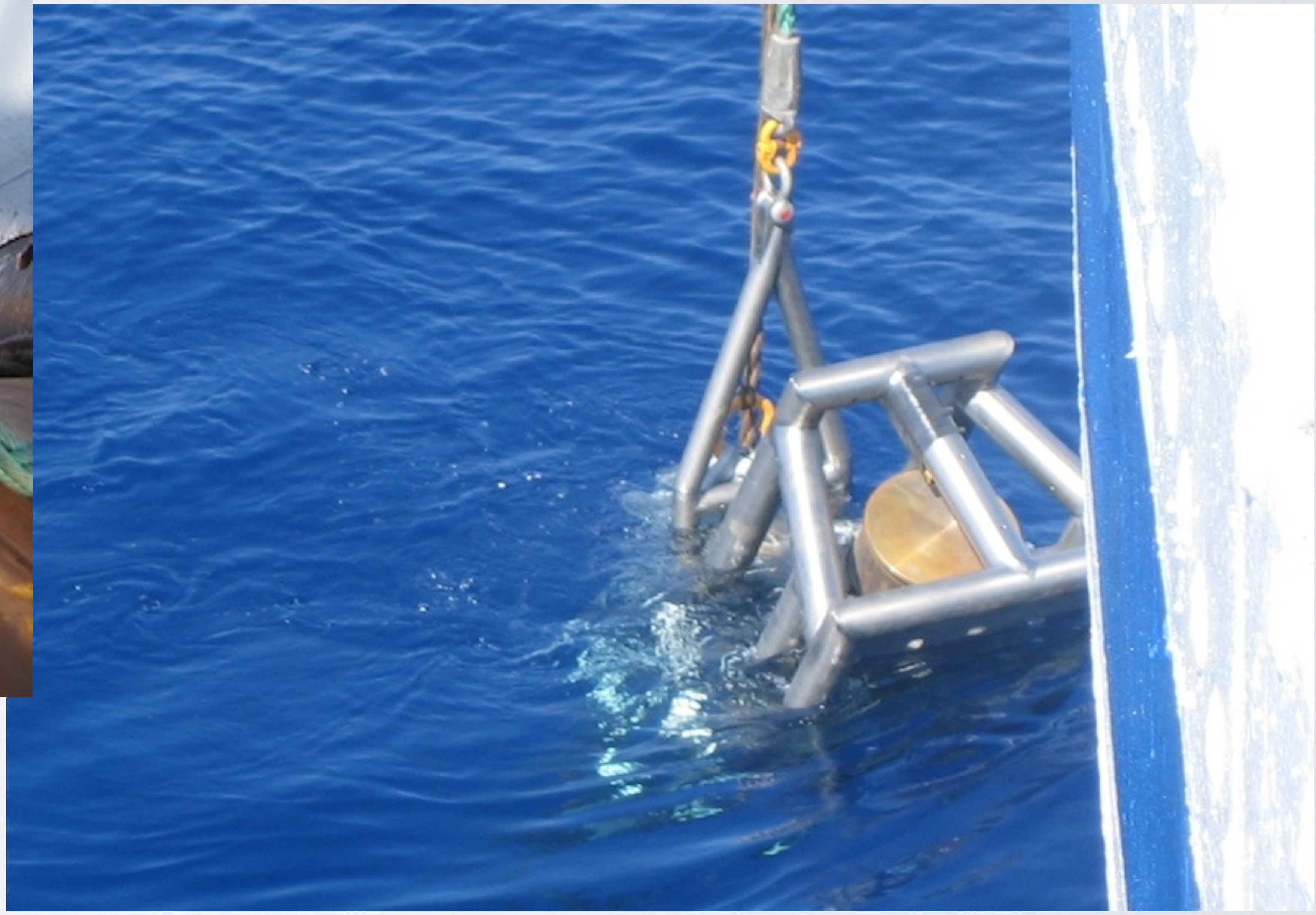
Threshold = 36 A

Delay time = 25 microseconds

Switch off time: the electronics instantaneously stops after these 25 µs.

The output filter capacitors (11.2 uF in parallel with a damping filter(90uF with 3 Ohm in series)) continue to discharge into the short circuit, but there will be no current into a straight short-circuit after 1ms.

Deployment Test MVC Frame

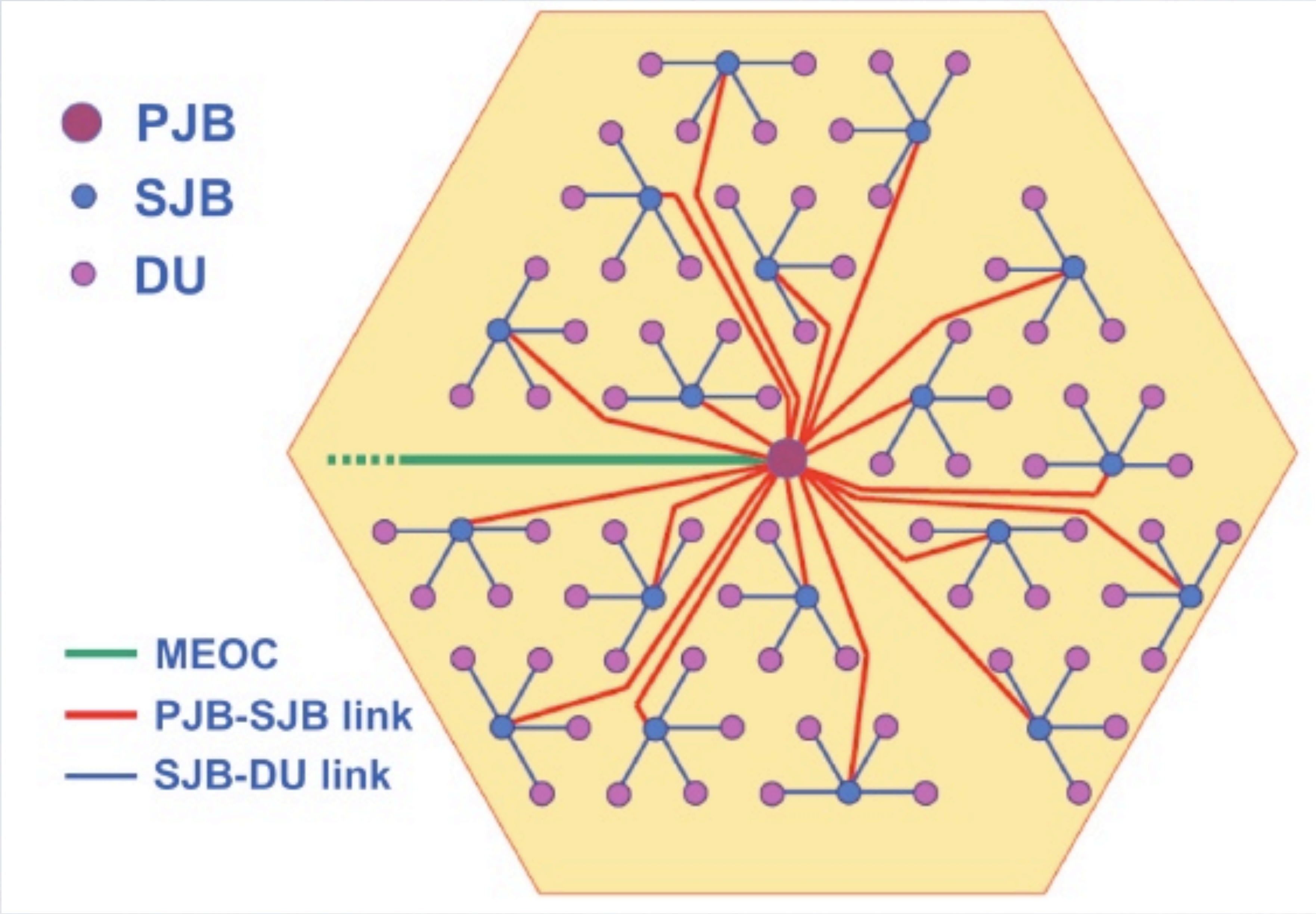


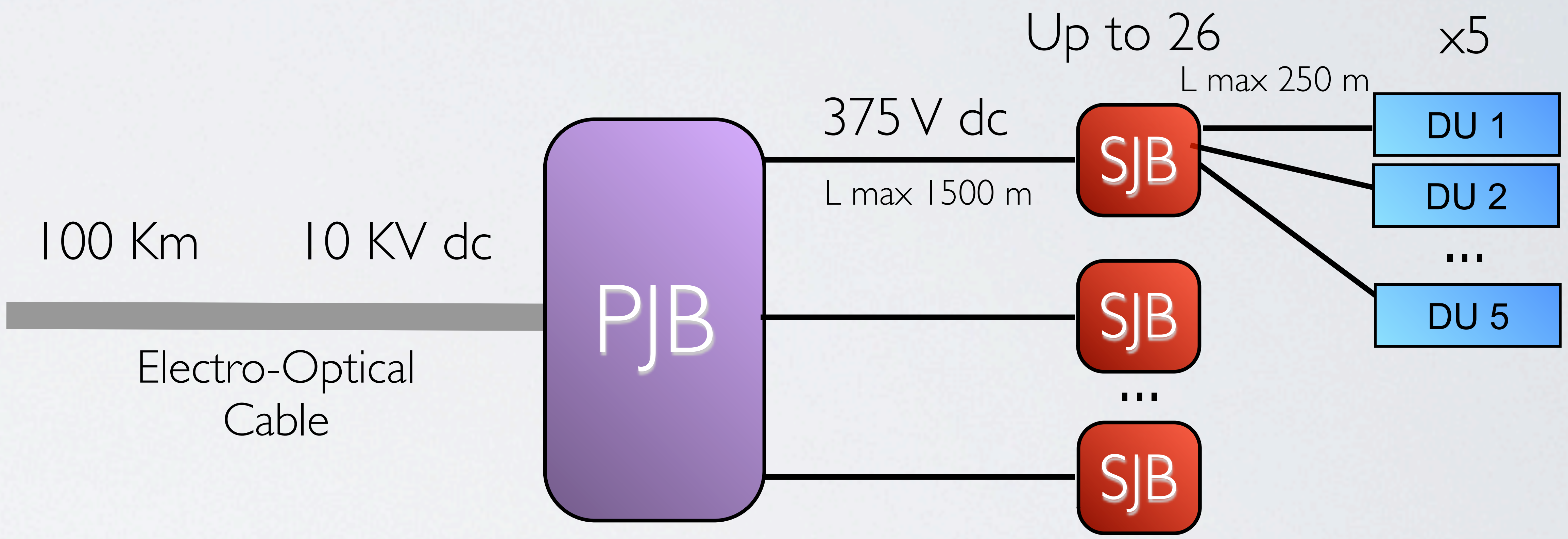
Dummy Load
Frame Test

MVC Frame Integration

Sea-floor Examples Neutrino Telescope Power Distribution

Star Distribution

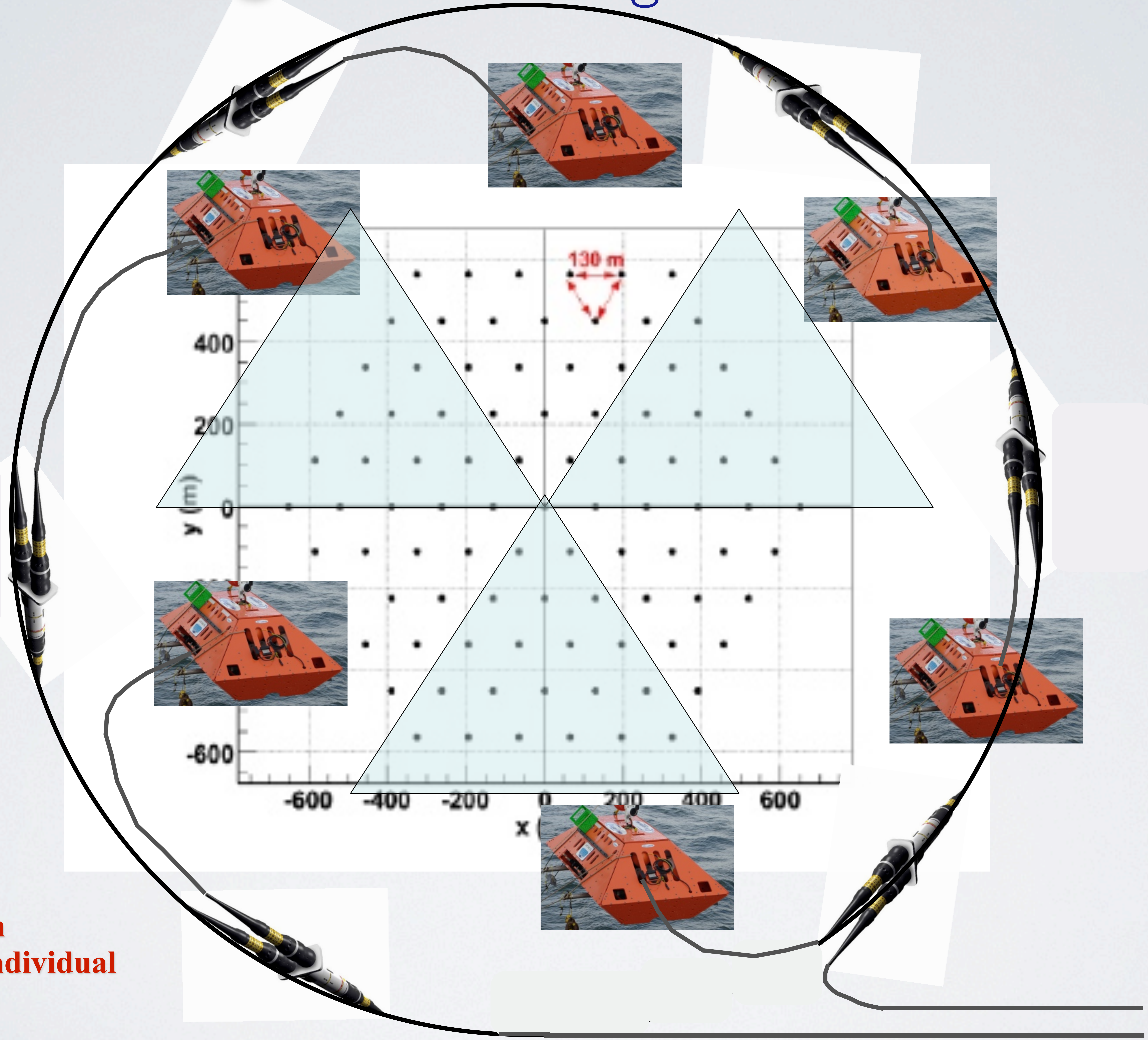




- 1 Primary Junction Box (PJB)
- Up to 26 Secondary Junction Boxes (SJB)
- 5 detection Unit (DU) per SJB
- 91 ÷ 127 DU
- 20 floors per DU

- PJB-SJB: DC radial distribution
- SJB-tower: DC radial distribution
- DU distribution: two emi-backbones with floors in parallel
- Max distance PJB-SJB: 1500m
- Max distance SJB-tower: 250 m
- DU backbone : 1050 m

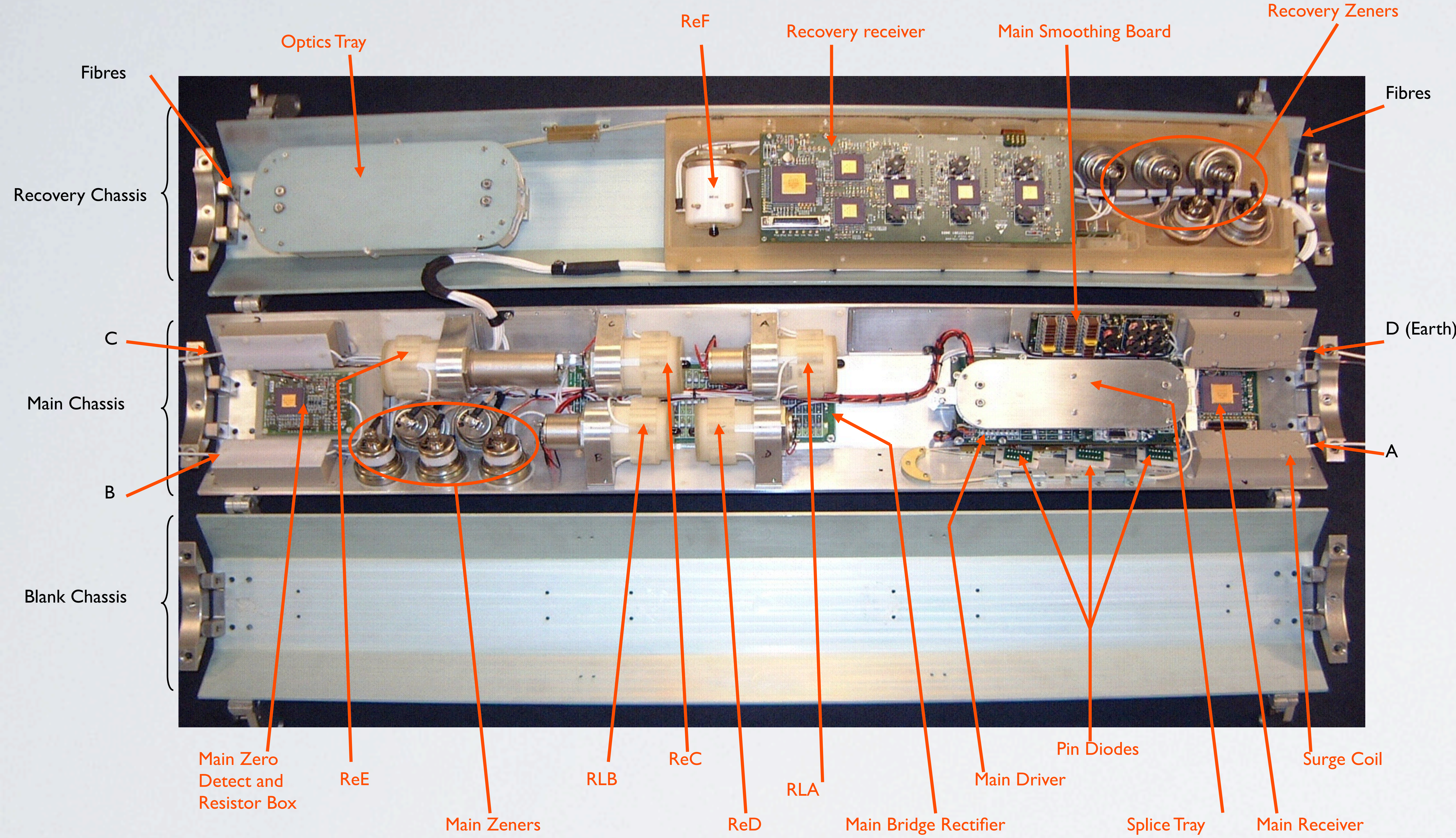
Sea-floor Ring Distribution

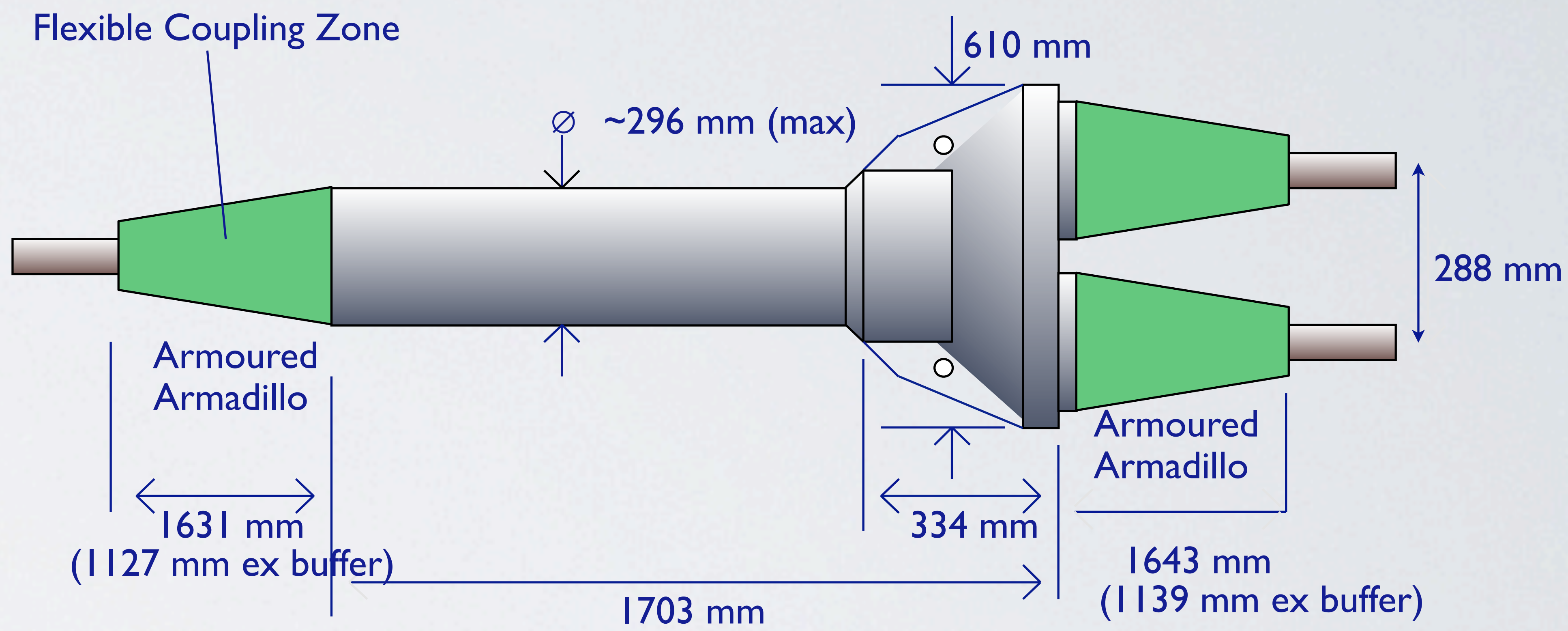


All spurs have a length ~ 2x water depth for individual JB retrieval

MEOC to shore

Active Brancing Unit

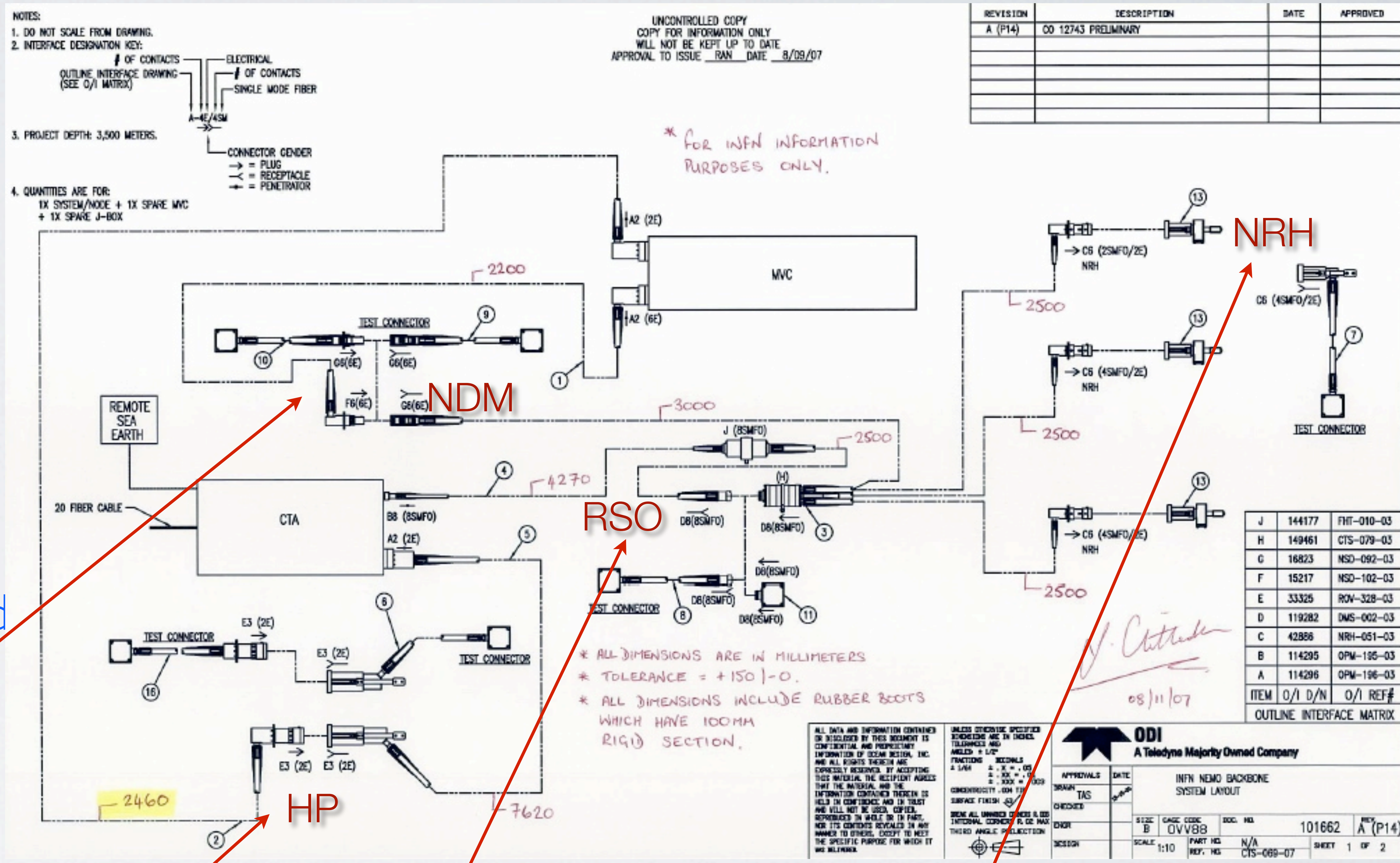




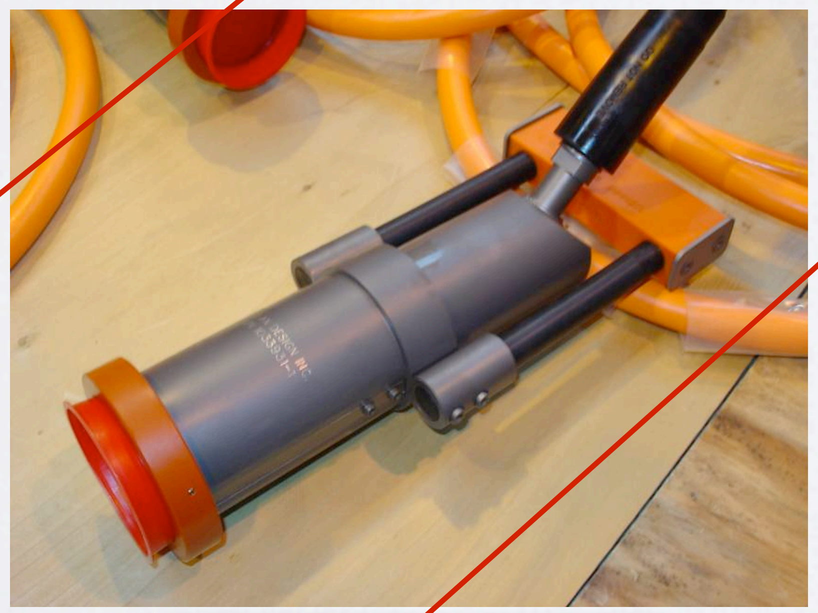
MVC Connection System an Example

Four types of ODI connectors are in use on MVC Frame

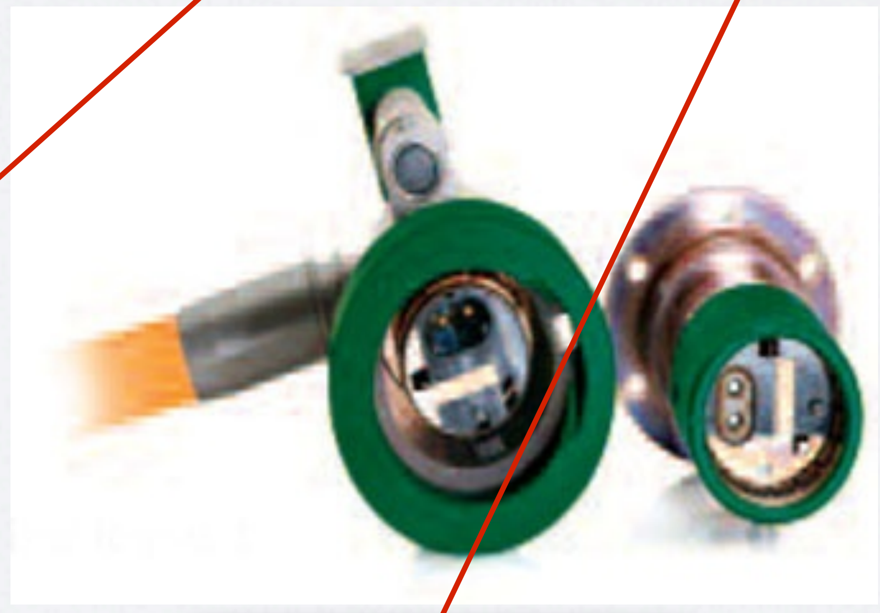
- NRH
  - Hybrid optical and electrical connectors at the output interface
- High Power
  - For the electrical connection between the CTA and MVC
- Nautilus Diver Mate
  - For the electrical connection between the MVC and Junction box
- Rolling seal optical
  - For the optical connection between the CTA and Junction box



Nautilus Diver mate



High power



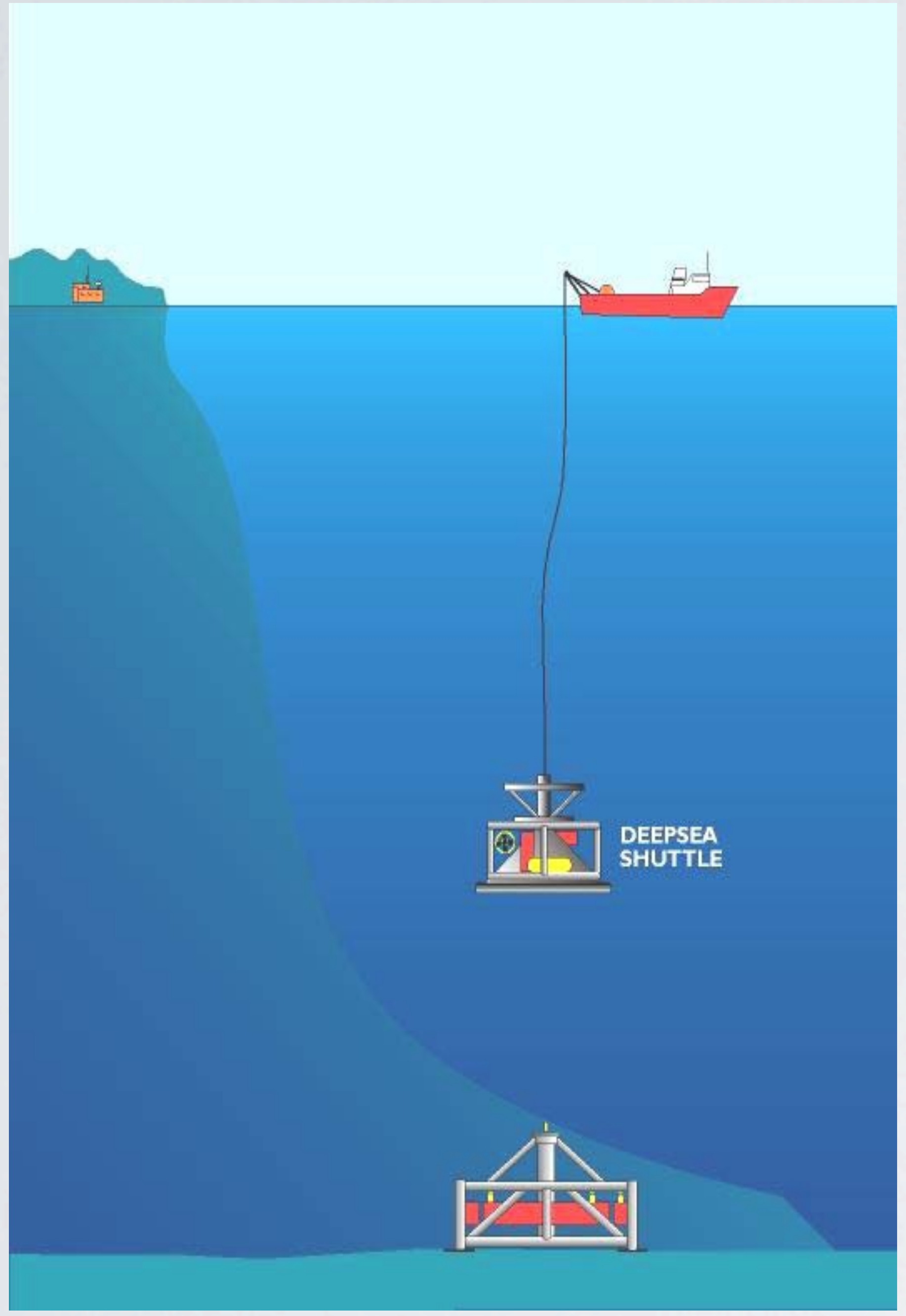
Rolling Seal

NRH

Connection Systems

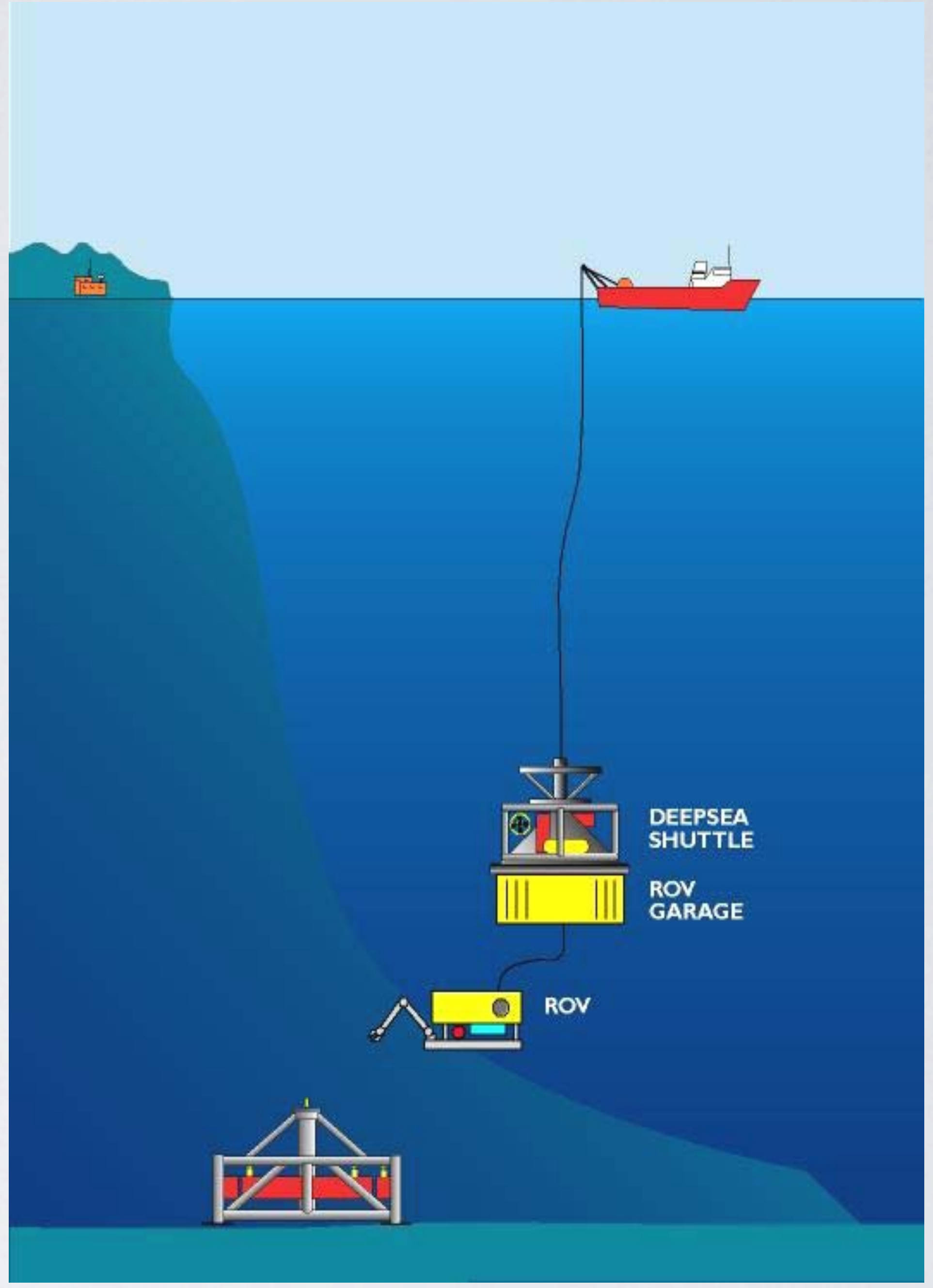
Remote Operated Vehicle

The INFN-INGV PEGASO Project



PEGASO in lifter configuration

SEAEYE - Cougar



PEGASO with DSS in supporting configuration for the ROV

- Maximum operating depth - 2000 metres upgraded to 4000 m
- 80 kg (176 lb) payload
- 100 kgf forward thrust (bollard pull)
- 76 kgf vertical thrust
- Four simultaneous video channels
- Fiber optic video transmission
- Optional fiber optic data transmission
- Seaeye SM6 brushless DC thrusters with velocity feedback control

Cable Maintenance, The MECMA Consortium

On 14 October 1999 the European Commission received notification, pursuant to Articles 2 and 4 of Council Regulation No 17, of an agreement between 27 participants related to submarine telecommunications cable maintenance and repair. (Case No IV/37.669 - Mediterranean Cable Maintenance Agreement) (1999/C 311/04)

The agreement provides for the performance of repair, maintenance and improvement services to the owners of undersea telecommunications cables (represented by the maintenance authorities) in the Mediterranean Sea, Black Sea and Red Sea by several operators of cableships.

The advantage to take part of the consortium is represented from the cableships operators that make available a certain number of cableships to the maintenance authorities, which are stationed at strategic locations and kept on permanent stand-by in order to be able to repair, as quickly as possible, any fault that may occur in any of the cables and to perform general maintenance services with reasonable costs.

The parties to the agreements notified are actually 44, mostly telecom companies now include IN2P3 for the Antares project and INFN for the NeMO project.

Conclusion

- Single conductor power of large deep sea structures possible using standard telecom cables

  Up to 50 km with 4kV A.C. (ANTARES)

  Around 100 km ; 10 kV D.C. (NEMO)

- ALCATEL Deep sea DC-DC convertor demonstred with dummy load tests at factory and now with 5 nodes deployed & powered in NEPTUNE deep sea oceanographic network (West Coast: Canada)

- ALCATEL Node to be used in NEMO and probably also for KM3NeT