NEMO-SMO acoustic array: a deep-sea test of a novel acoustic positioning system for a km3-scale underwater neutrino telescope

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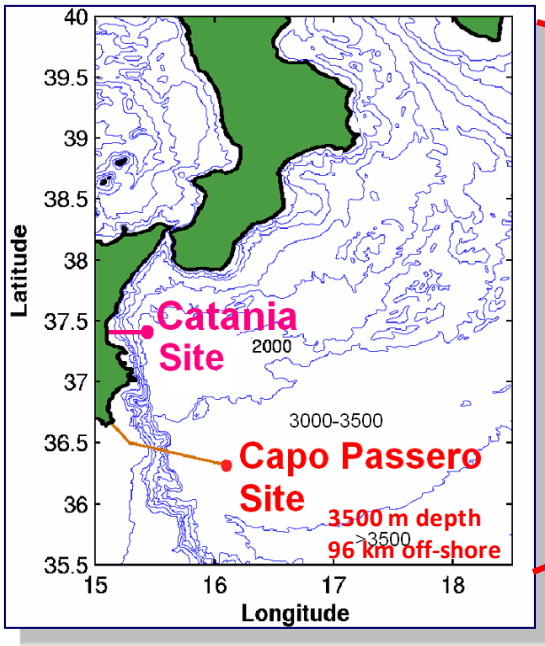
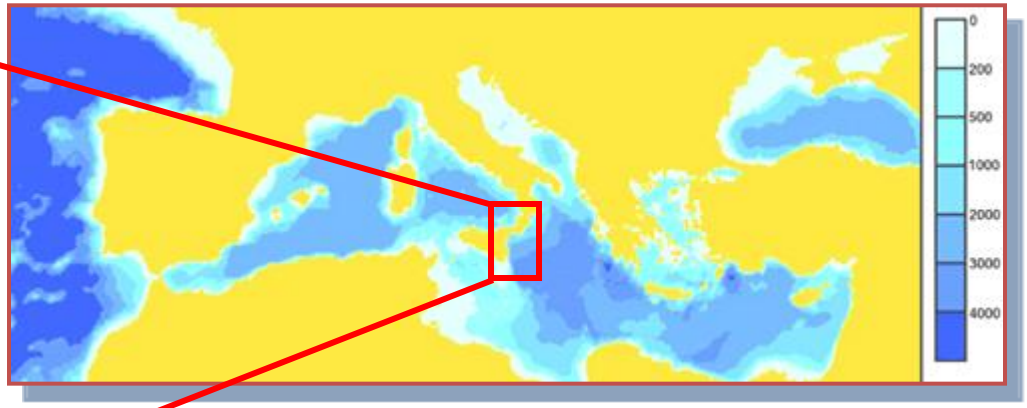
The Submarine Multidisciplinary Observatory Project

The SMO (Submarine Multidisciplinary Observatory) project aims at the construction, integration and joint operation of a submarine large bandwidth acoustic antenna at a depth of 3500 m, about 100 km off-shore South-East Sicily.

SMO goals:

- **Acoustic monitoring of the deep – sea environment**
- **Deep-sea test of a novel acoustic positioning system for a km3-scale underwater neutrino telescope**





ROMA TRE UNIVERSITÀ DEGLI STUDI

INFN Istituto Nazionale di Fisica Nucleare

SAPIENZA UNIVERSITÀ DI ROMA

NEMO – SMO tower

The SMO project consists of a 3D array of 18 acoustic sensors installed onboard the demonstrator NEMO – Phase II

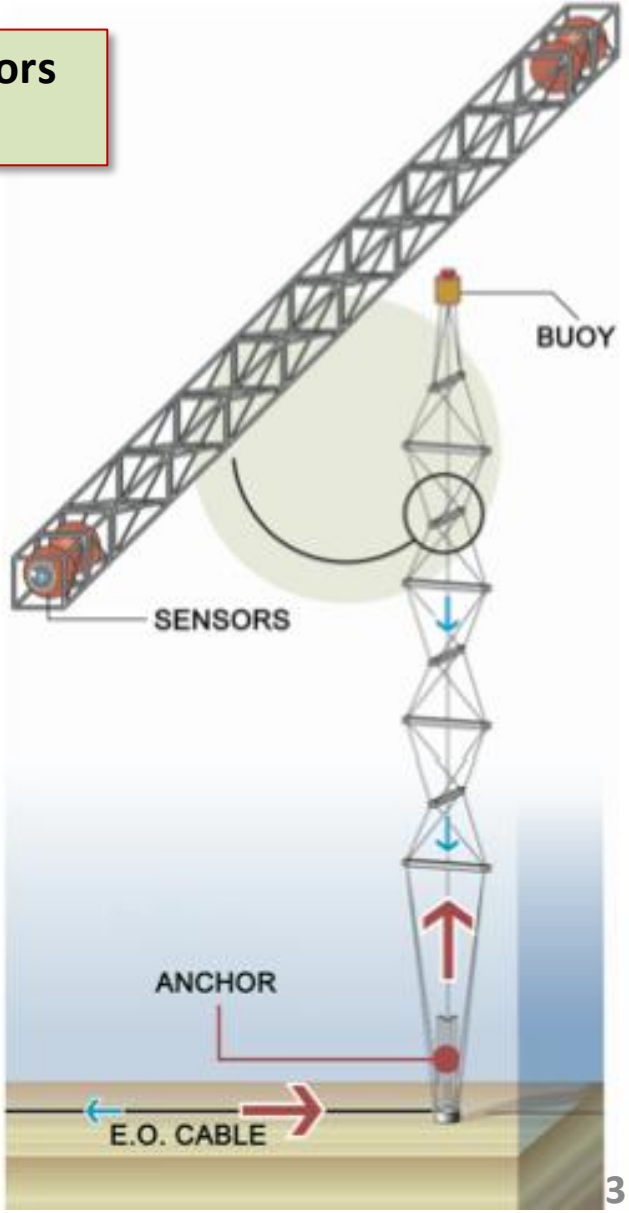
NEMO Phase II detector

8 floors plus a tower base
Floor length: 10 m
Distance between floors: 40 m

- **32 optical modules (4 OMs/storey)**
- **18 acoustic sensors (2 sensors/ storey + 2 sensors @ tower-base)**
- **4 autonomous acoustic beacons (for acoustic positioning)**
- **environmental sensors (compasses, CTD, Current-meter, C-Star)**

96 km

20 optical fibres
10 kV DC monopolar with sea return



Acoustic positioning system

The SMO acoustic array will provide the positioning of the NEMO Phase II detector

Requirements of neutrino telescope positioning system:

- ***relative positioning accuracy : < 10 cm (less than PMT diameter)***
- ***absolute positioning accuracy: < 1 m to optimize pointing resolution***

Key elements :

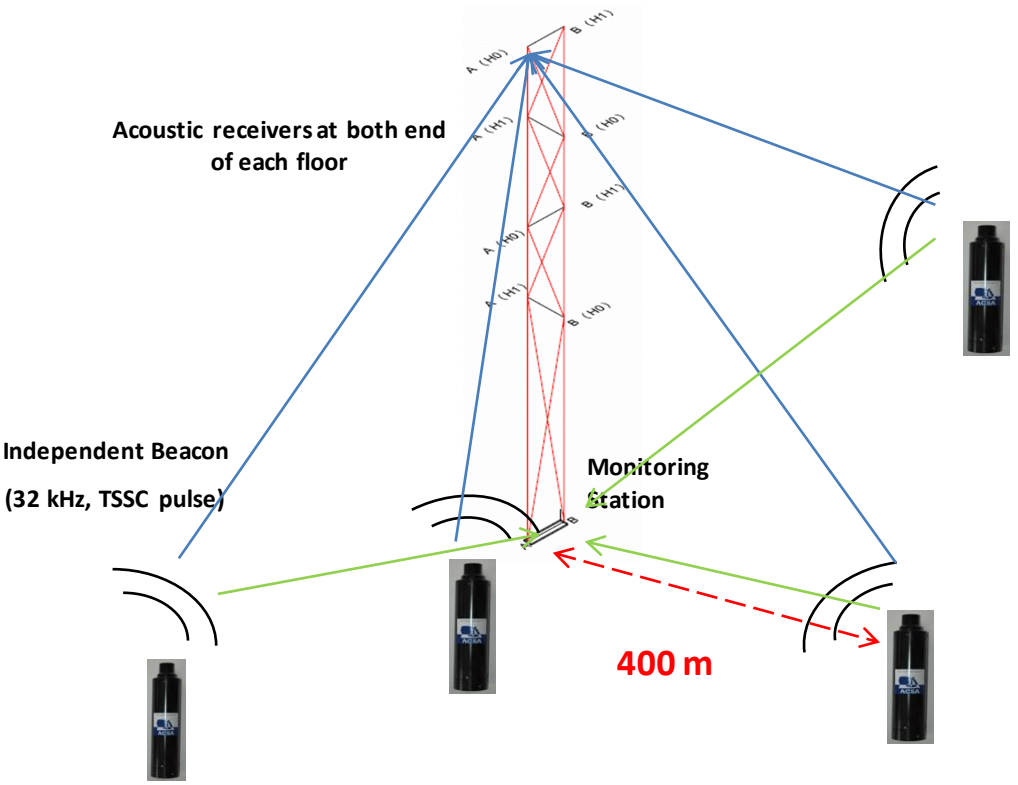
- ***Long Baseline of acoustic emitters anchored in known and fixed positions***
- ***Array of acoustic sensors (hydrophones) moving with the mechanical structures***

Measurament Technique:

1. ***TDoA (Time Difference of Arrival):***

   $T^{Emit}(Beacon) - T^{Receive}(Hydro)$

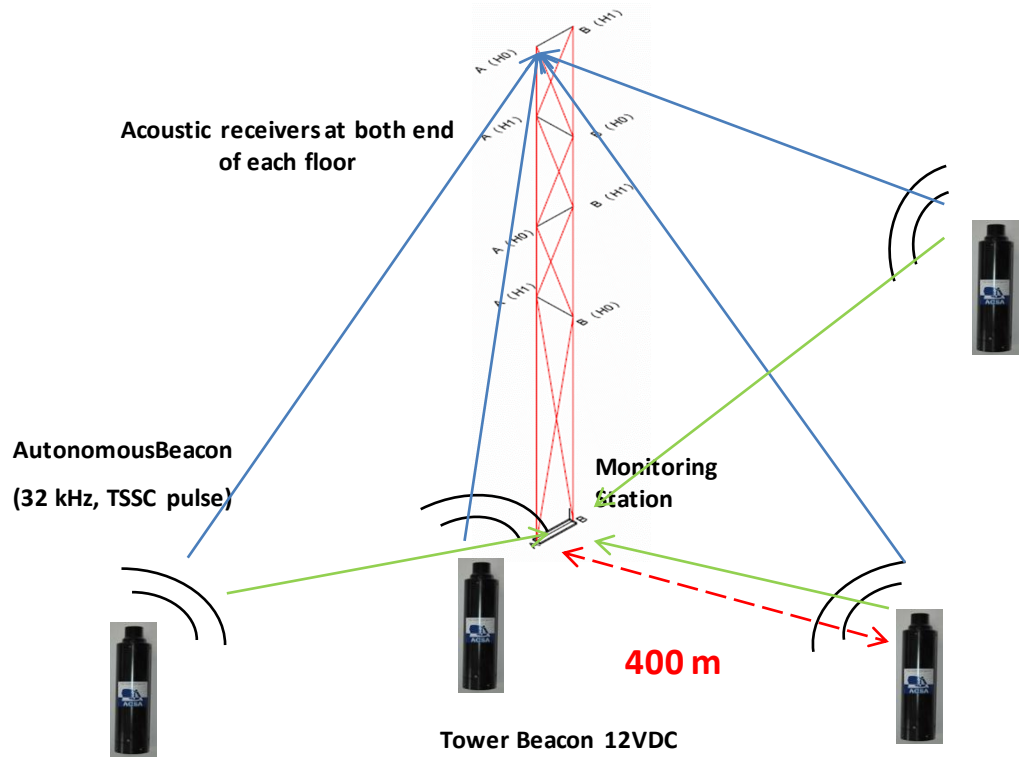
2. ***Geometrical Triangulation***



Acoustic Beacon

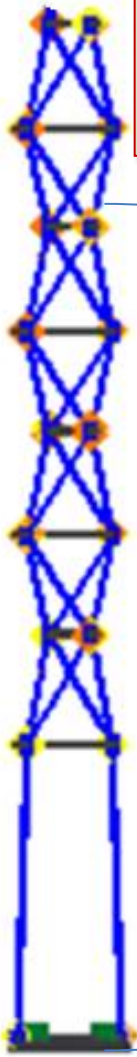
The positioning system is based on the measurements of beacon pulses time of arrival (TOA) at a given acoustic receiver

Each beacon transmits its TSSC (Time Spectral Spread Codes) sequence with a period of 6 sec, i.e. a pattern of 6 pseudo-random pulses (spaced by ~ 1 sec) that is different from the others.

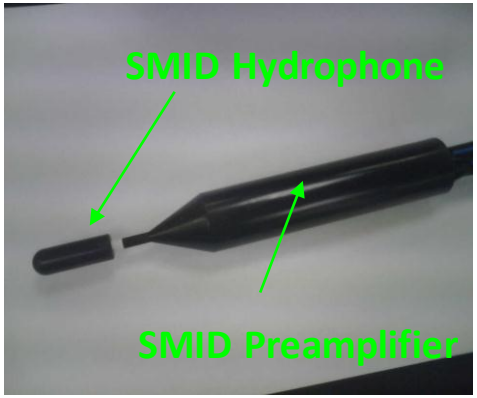


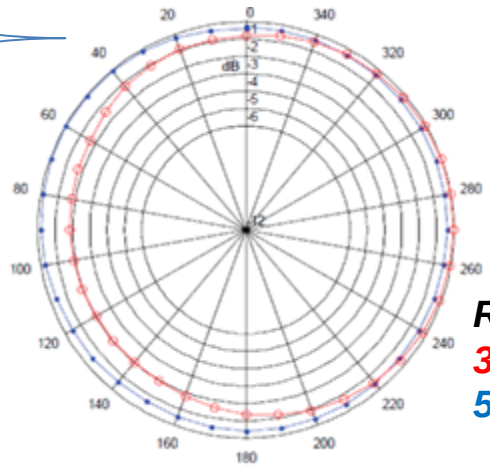
Beacon signal
Amplitude: 180 dB re µPa @1 m
Frequency : 32 kHz
Pulse length: 5 ms

Acoustic sensors

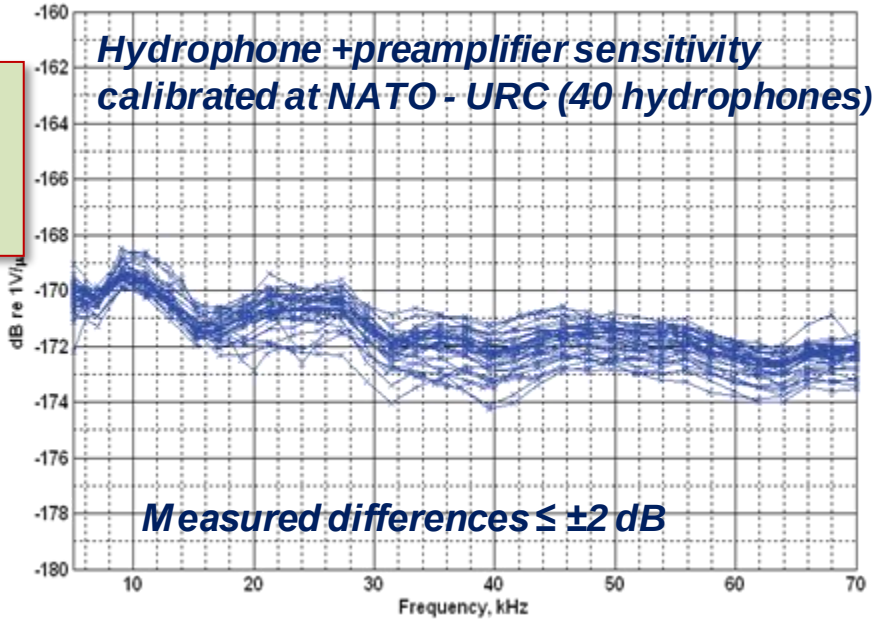


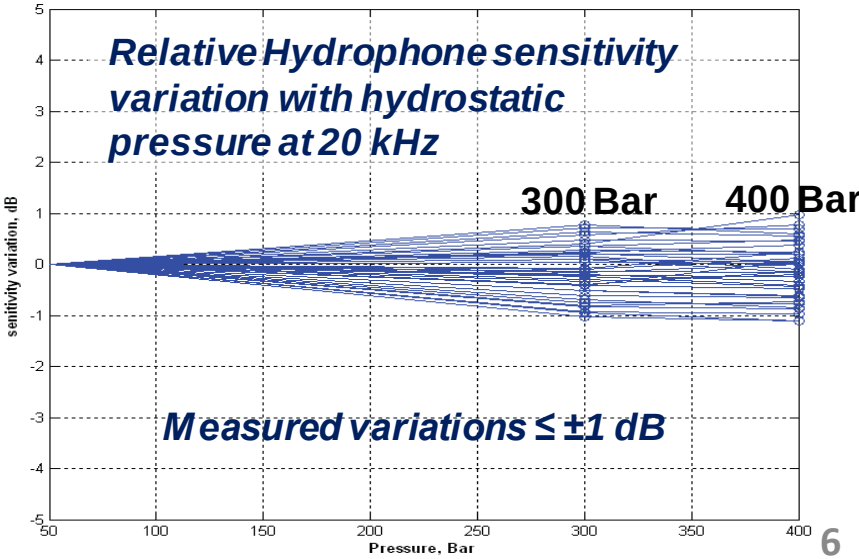
Floor #1 ÷Floor #6 +Tower-base
SMID Hydrophones
+ SMID preamplifiers (gain: +38 dB)





Radiation lobe
30 kHz
50 kHz

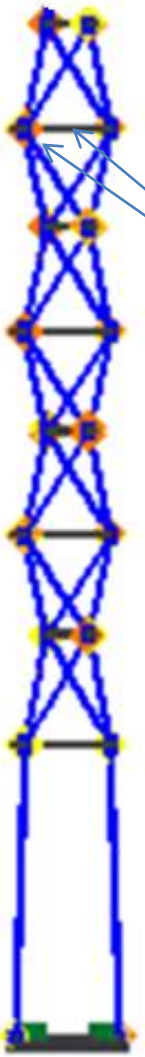




Acoustic sensors

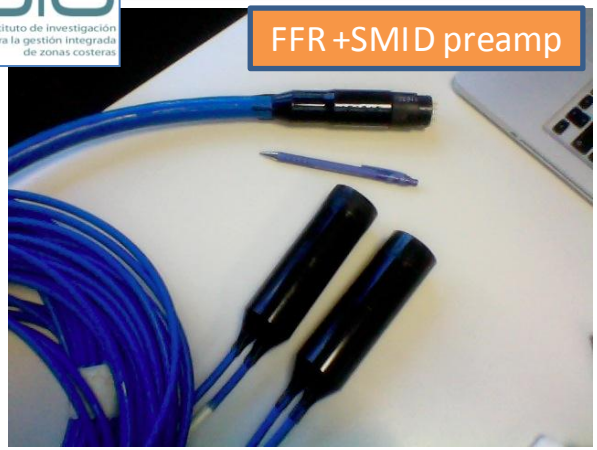
Floor #7

FFR(Free Flooded Rings)Hydrophones + SMID preamplifiers (gain :+38 dB)

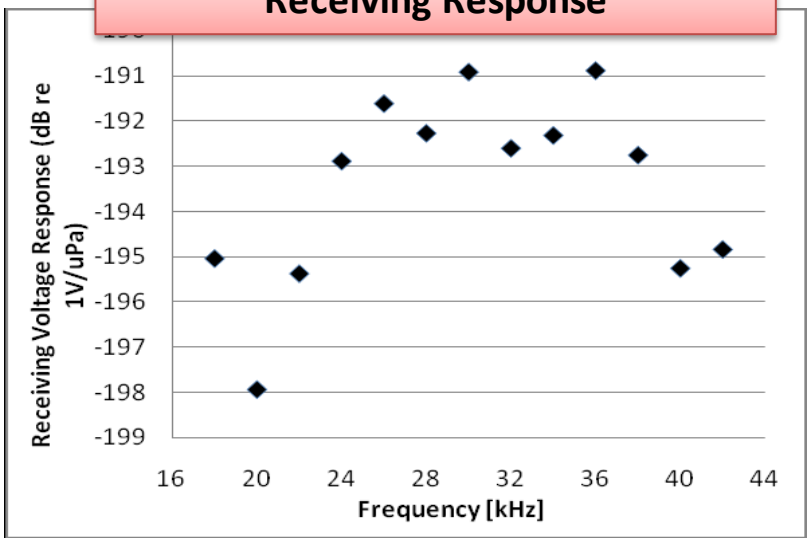


UNIVERSITAT POLITÈCNICA DE VALÈNCIA

IGIC Instituto de investigación para la gestión integrada de zonas costeras



Receiving Response

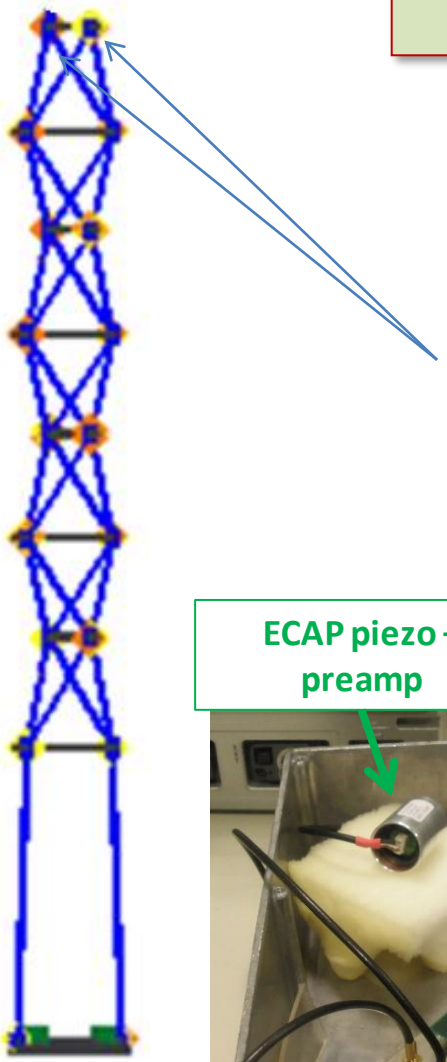


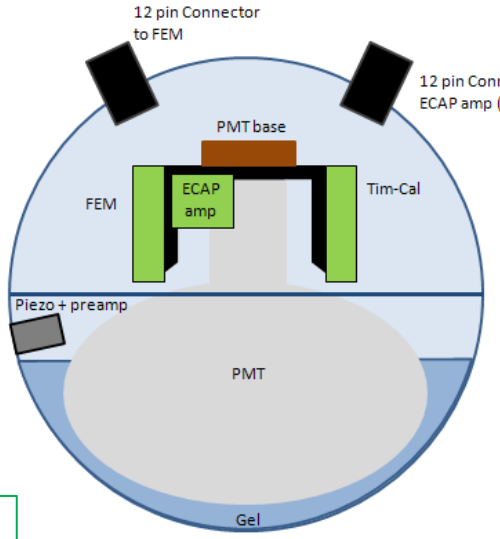
Fully compatibility with NEMO data acquisition chain

See G. Larosa presentation

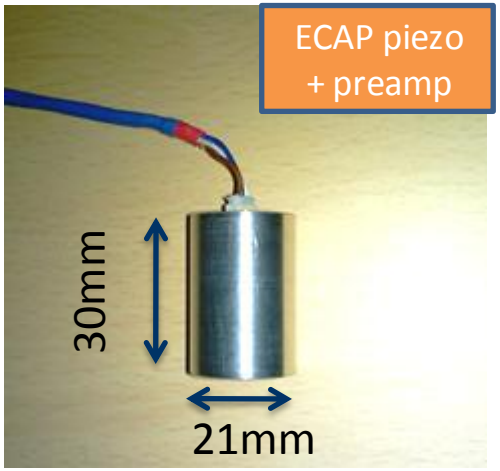
Acoustic sensors

Floor #8
ECAP Piezo sensors + ECAP preamplifiers

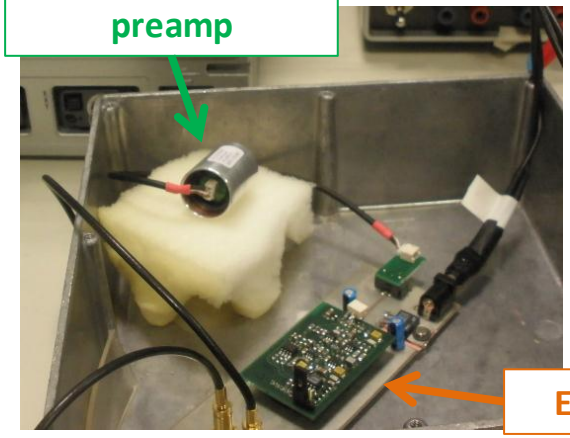




ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS



ECAP piezo + preamp

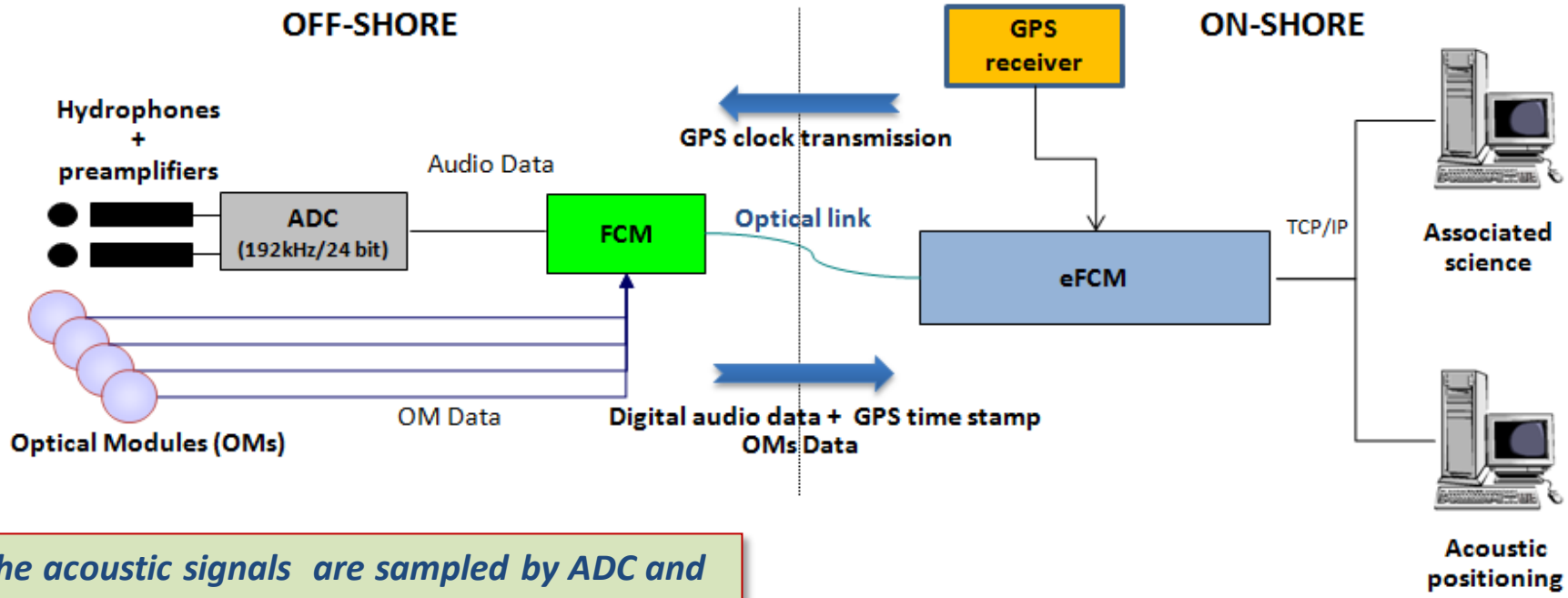


ECAP amp

See A. Enzenhöfer presentation

The hydrophone data acquisition chain

The hydrophones data acquisition chain is based on "all data to shore" philosophy, raw data are continuously transmitted to shore on a local internet network at the shore station.



The acoustic signals are sampled by ADC and "labeled" with GPS time by the Floor Control Module (FCM) off -shore

Optical and Acoustic array synchronous and phased with absolute GPS time

NEMO NEUTRINO MEDITERRANEAN OBSERVATORY

Data stream 32 bits @ 192 kHz → 12 Mbps (2 hydrophones)

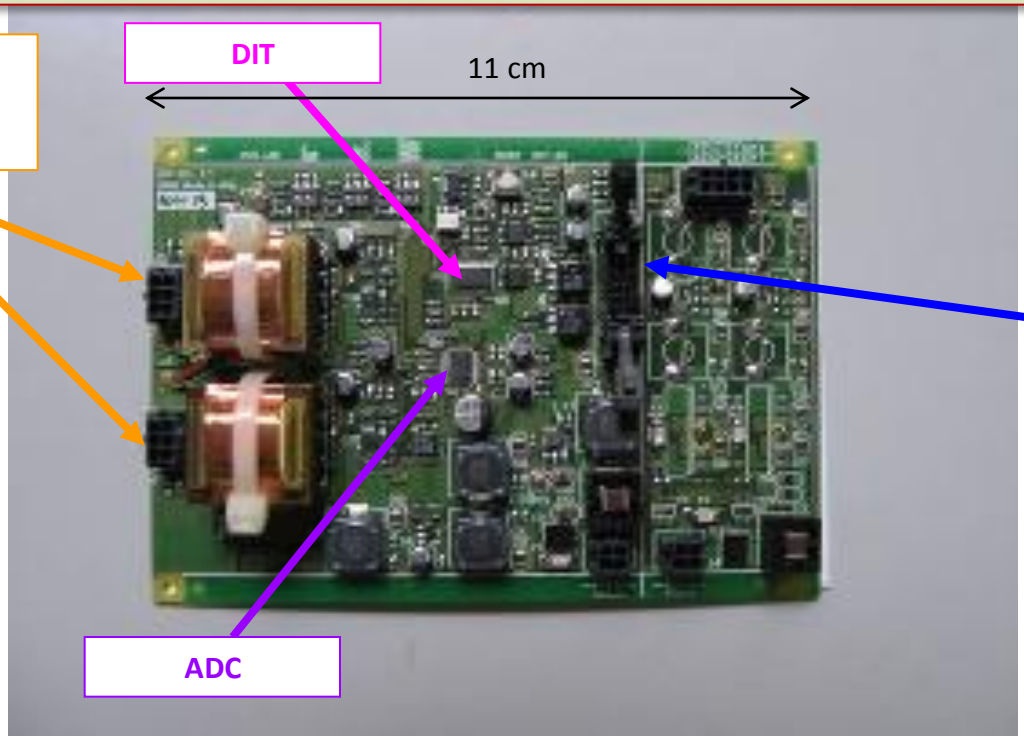
AcouBoard

The AcouBoard has been designed and realized by NEMO in collaboration with AGE Scientific (Lucca, Italy), by using professional audio technology components:

- *ADC 2 up to 4 channels (24 bit/192kHz, Max input 2 V_{RMS})*
- *EBU/AES-3 stereo compliant DIT (Digital Interface Transmitter)*
- *Power 160 mA @ 5.3 VDC*

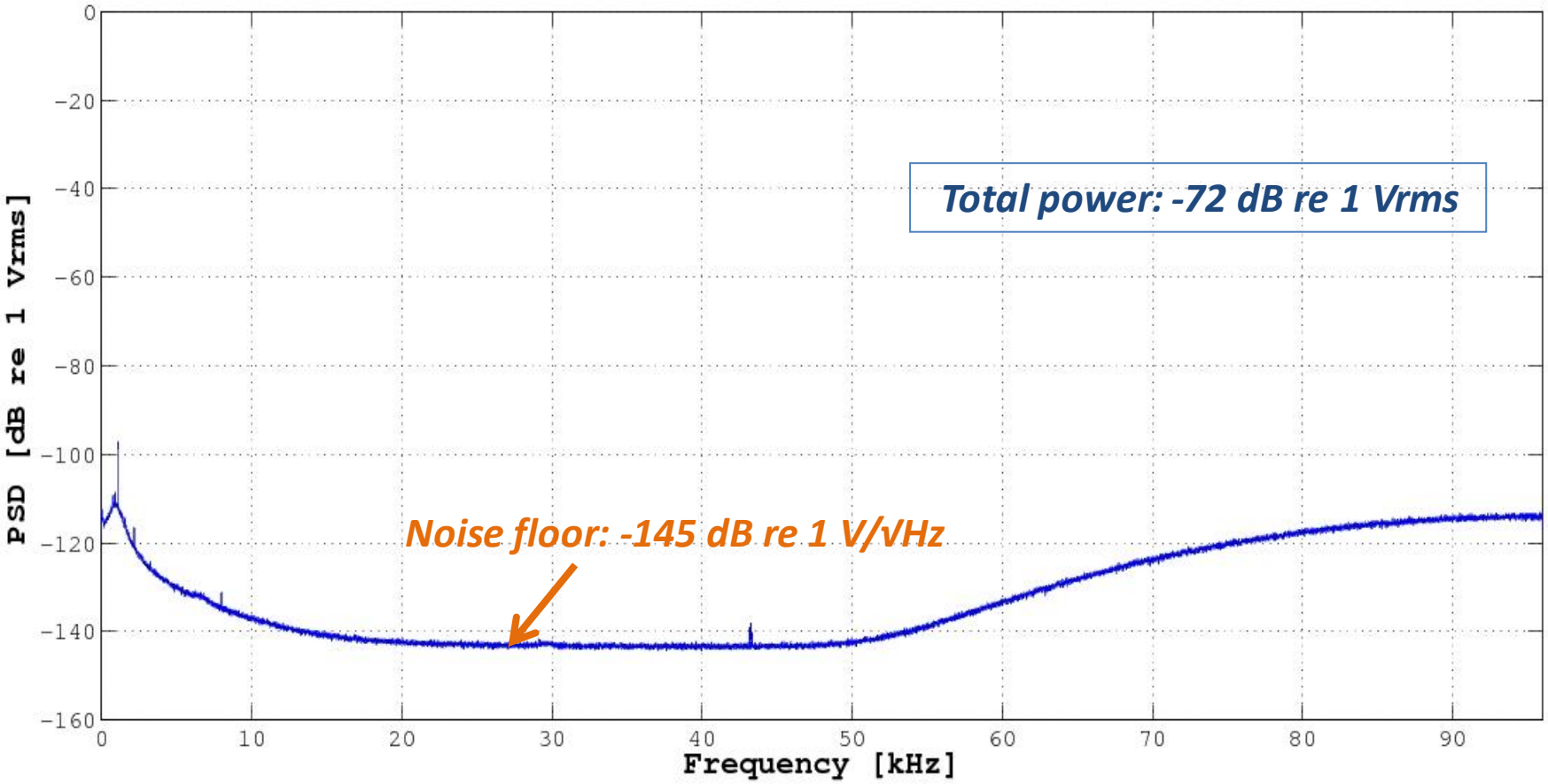
ADC and DIT are driven by a clock signal (24.576 MHz) , given by FCM off-shore.

The technology developed for the SMO data acquisition system will be employed for the acoustic mezzanine designed for the KM3NeT Pre-Production Module (PPM).



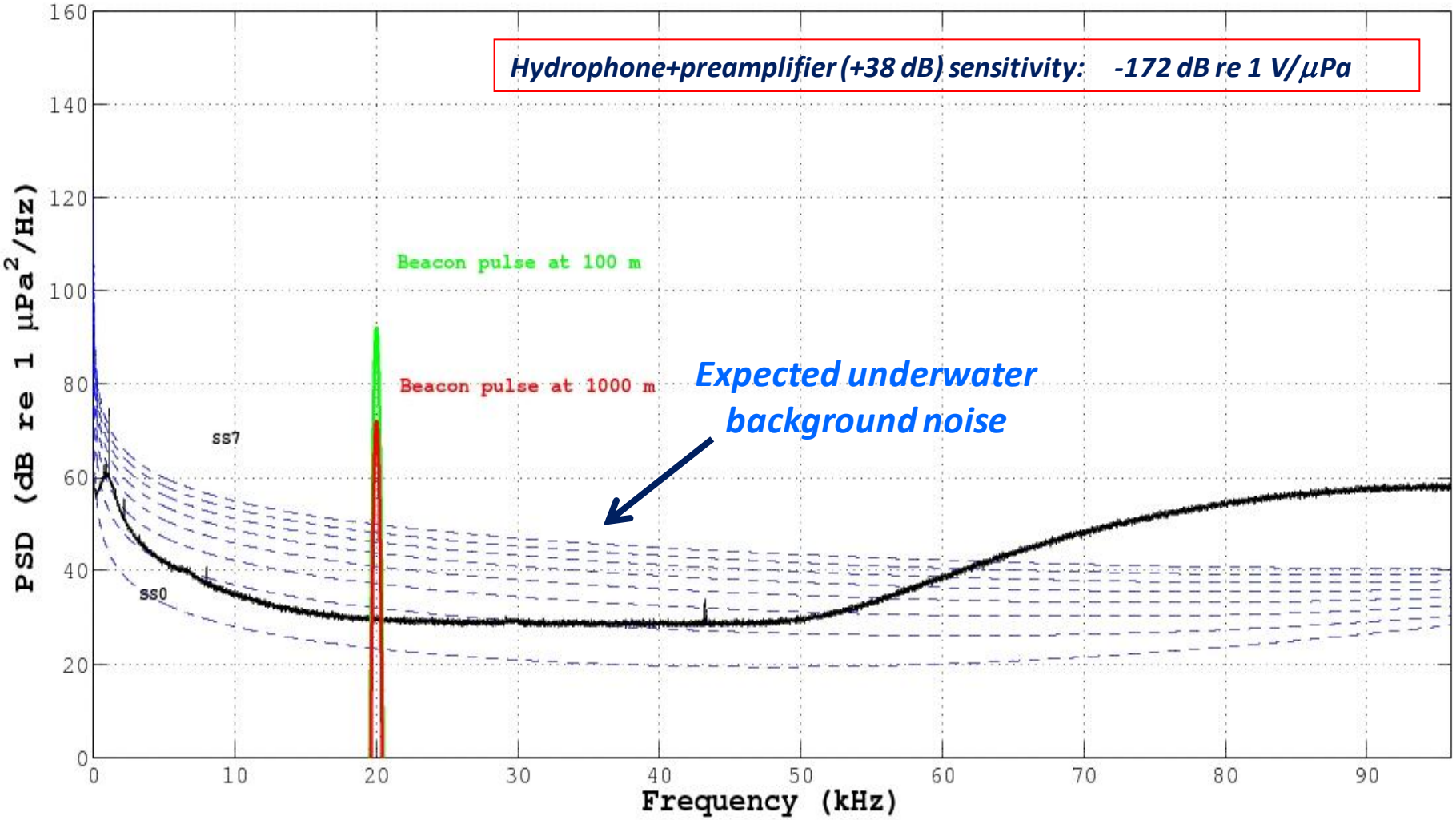
Intrinsic electronic noise

The intrinsic electronic noise of the whole NEMO-SMO data acquisition electronics has been measured at INFN –LNS. The measurement has consisted in to acquire the signals coming from the hydrophones' preamplifiers with shorted input through the whole acquisition chain.



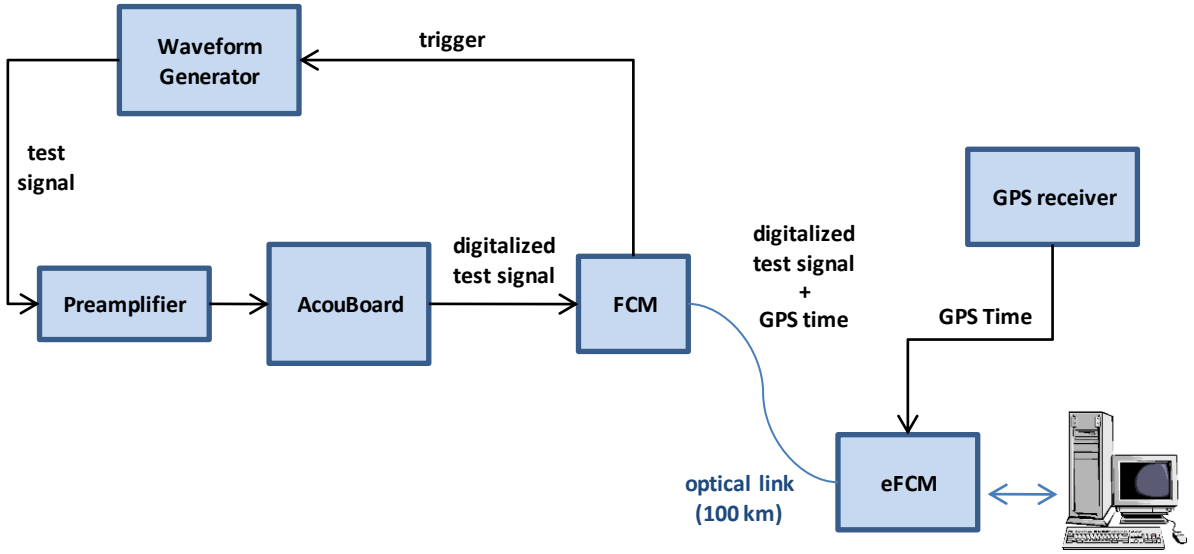
Acoustic system performances

Equivalent noise of the NEMO-SMO data acquisition electronics

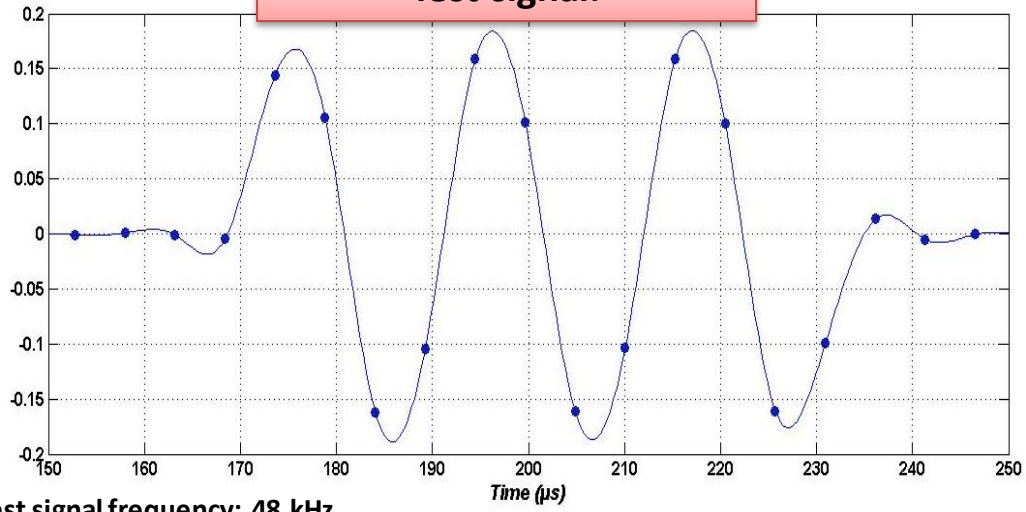


Underwater electronics latency measurement

The accuracy on the measurement of the arrival time of acoustic signals on the hydrophones depends on the latency time of the underwater electronics.



Test signal:

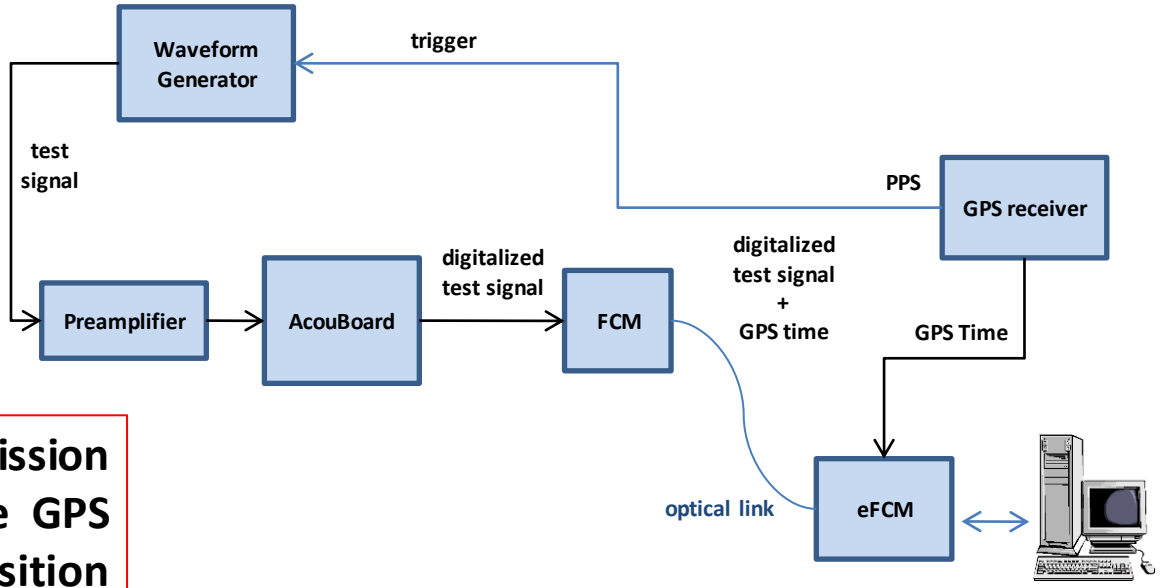


Test signal frequency: 48 kHz
Resampling frequency: 192 MHz

Latency time = 39.529μs ±0.005 μs

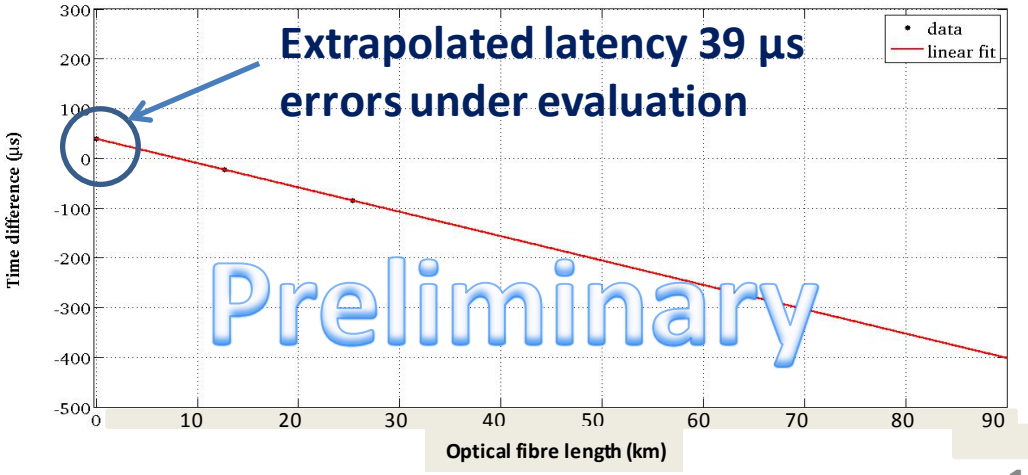
Time calibration

The GPS time is distributed off-shore through different optical link lengths. The time difference between the underwater time-stamping and the absolute GPS time was calculated.



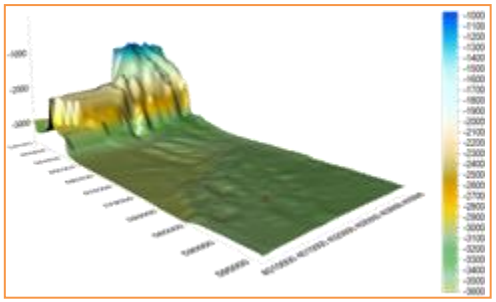
The differences between emission time of the test signal and the GPS time associated by the acquisition electronics to the corresponding audio samples has been measured for three different optical link lengths (±5 m) : 60m, 12710m and 25360m.

Preliminary results are compatible with results obtained with the previous method. Systematics and statistical errors are under evaluation.

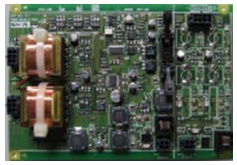


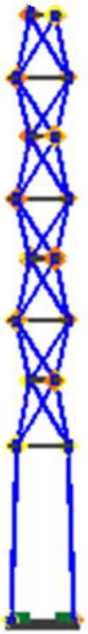
NEMO-SMO Data Transmission System

Deep-sea detector



Digitalization board





Floor Control Module

Sensor data acquistion
GPS time stamping
Data transmission
- fixed latency
- known optical walk

Underwater fibre

INFN Shore Laboratory

Trigger Storage

GPS receiver

eFCM

GPS clock transmission
Data parsing/distribution

10 Gbps link

INFN-LNS

Main Storage

GARR-X
(Italian Consortium for Research Network)

GRID ?

Conclusions

New technology:

New high pressure-calibrated hydrophones (in collaboration with SMID and NATO)

New front-end electronics

Synchronization with the detector master clock

Underwater GPS time stamping

All data to shore

Expected overall resolution for positioning few cm

HIGH ENERGY PHYSICS

Long term and real-time monitoring of high frequency acoustic background at different depths.

Input for simulations of large scale acoustic detection Capo Passero Site: strong candidate for the km3 Cherenkov neutrino telescope

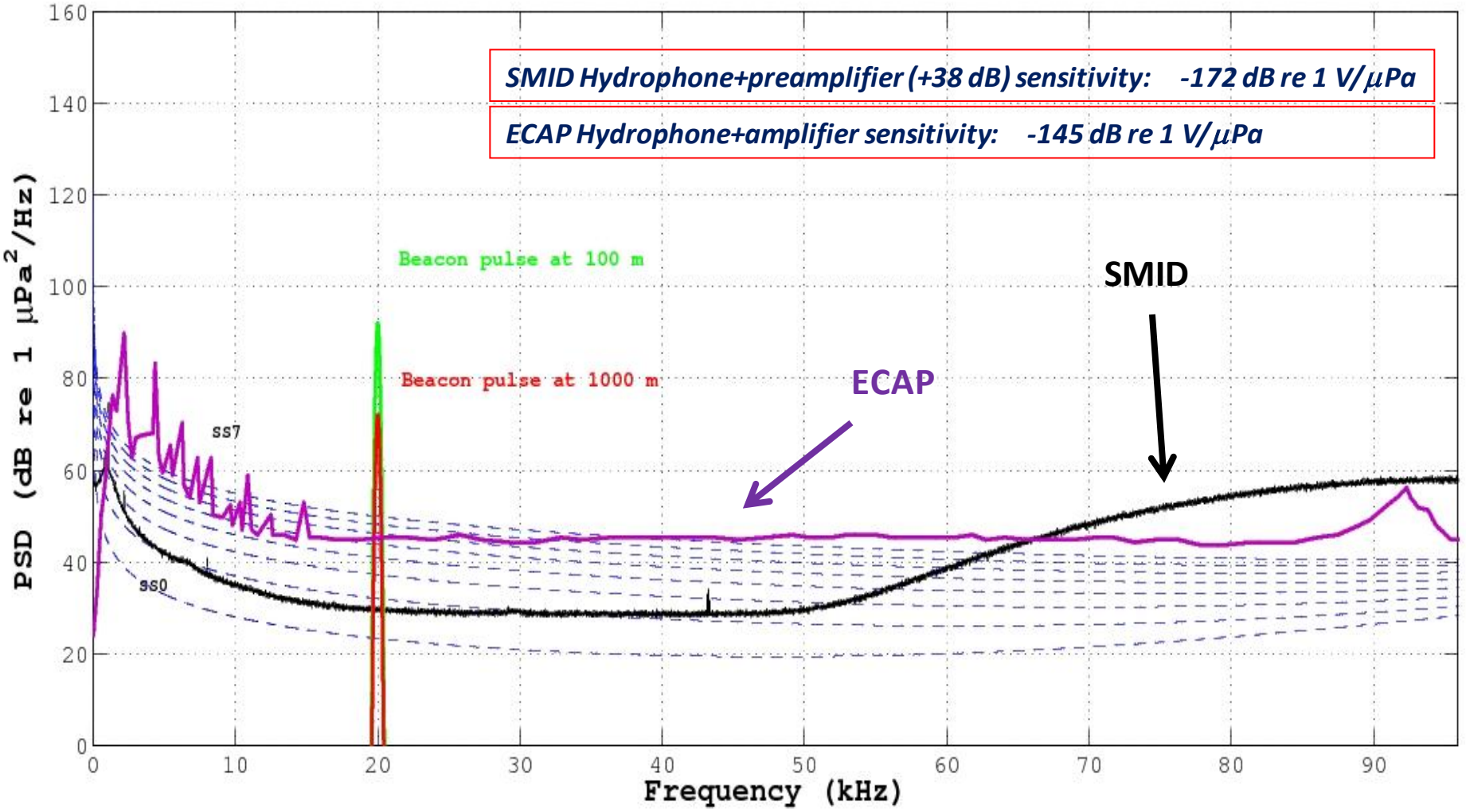
- ***Test of sensors and electronics for a future deep sea acoustic neutrino detector***
- ***Test of DSP techniques (matched filters) to improve source identification and localization***
- ***Detection of neutrino-like signals produced by calibrated sources***

THANK YOU

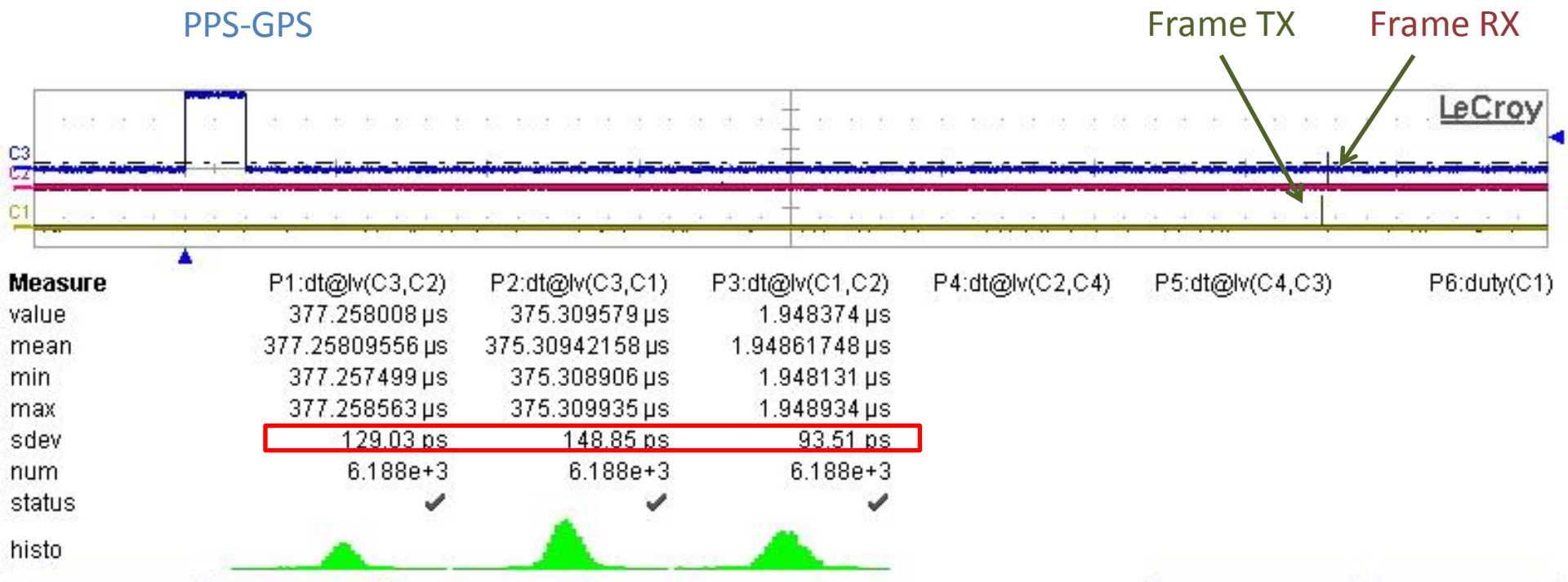
BACKUP

Acoustic system performances

Equivalent noise of the data acquisition electronics for SMID hydrophone + SMID preamplifier and ECAP piezoelectric + ECAP amplifier



Fixed latency between PPS and EFCM timing signals



The KM3NeT Pre-Production Module (PPM)

Acoustic System in the PPM - DOM

(INFN LNS / Roma 1)

All data to shore.

Positioning and multidisciplinary science

Stereo 192 kHz/24bit ADC

GPS synch&time stamp

Interfaced with Central Logic Board.

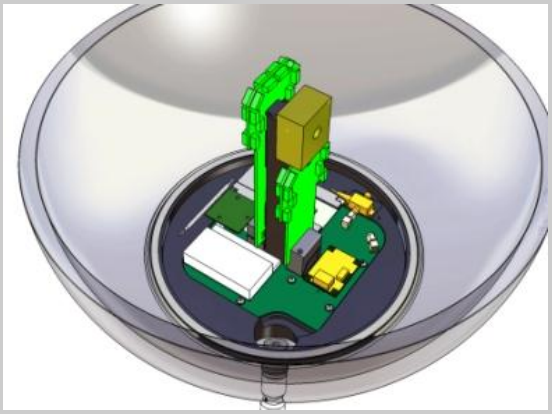
Sensor readout:

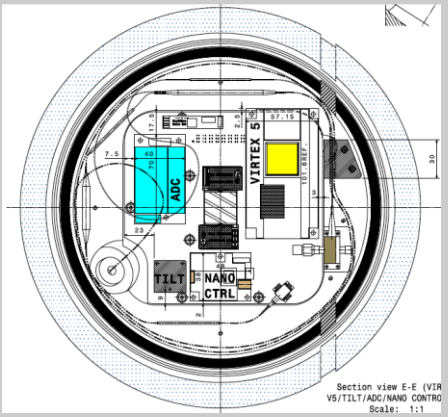
1 external hydrophone (INFN or UPV-FFR)

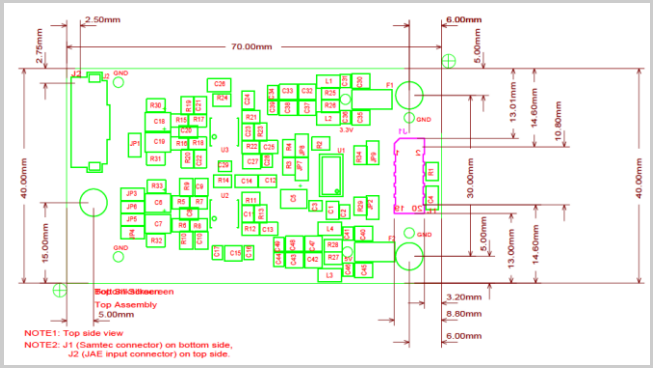
1internal piezo (ECAP)

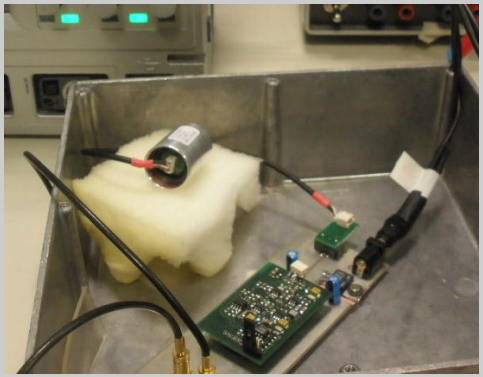
4 hydrophones ready

Boards under production

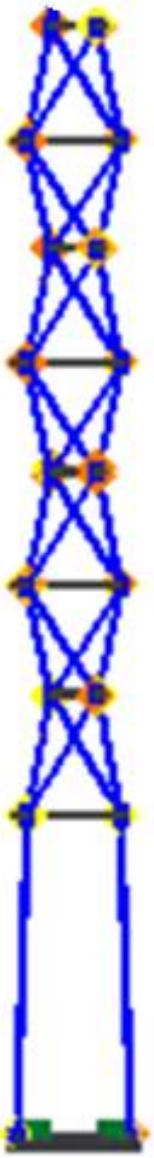








Environmental sensors



Floor #8
CTD (Conductive-Temperature-Depth)

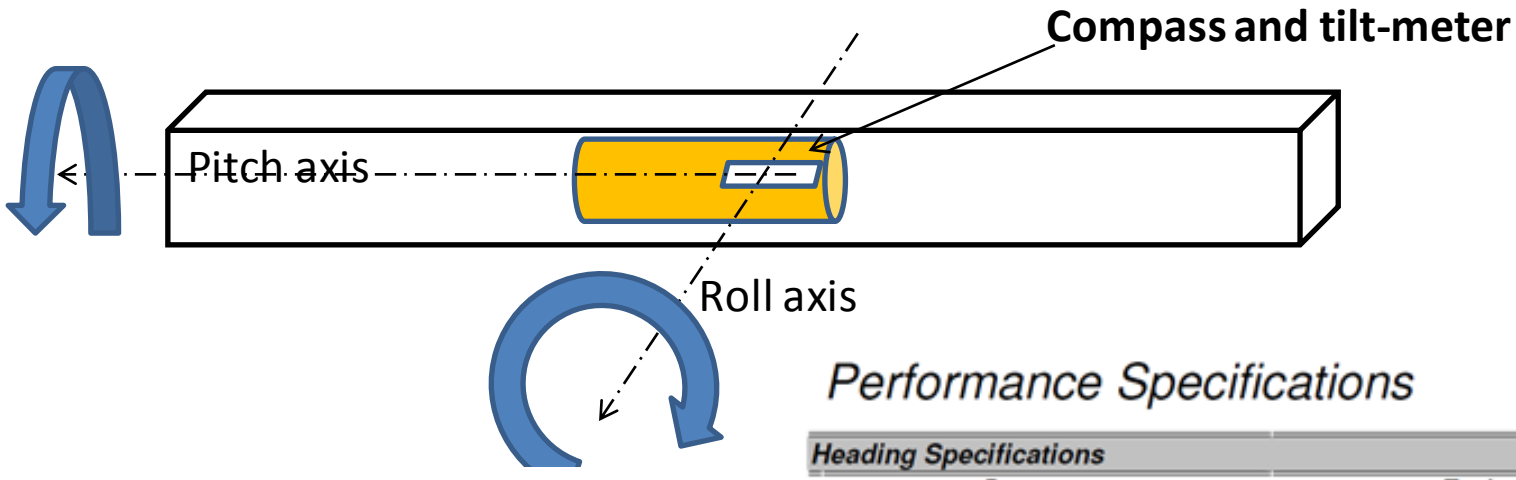
Floor #5
DCS (Doppler Current Sensor)

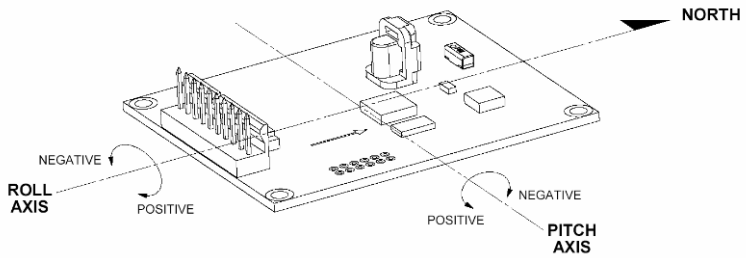
Floor #4
C-Star

Floor #1
CTD (Conductive-Temperature-Depth)

Compasses and tilt-meters

In order to measure inclination and orientation of each tower floor a compass and tiltmeter board was placed inside the electronics vessel of each floor.
These measurements, together with acoustic positioning, permit to estimate the tower position with the desired accuracy < *10 cm.*





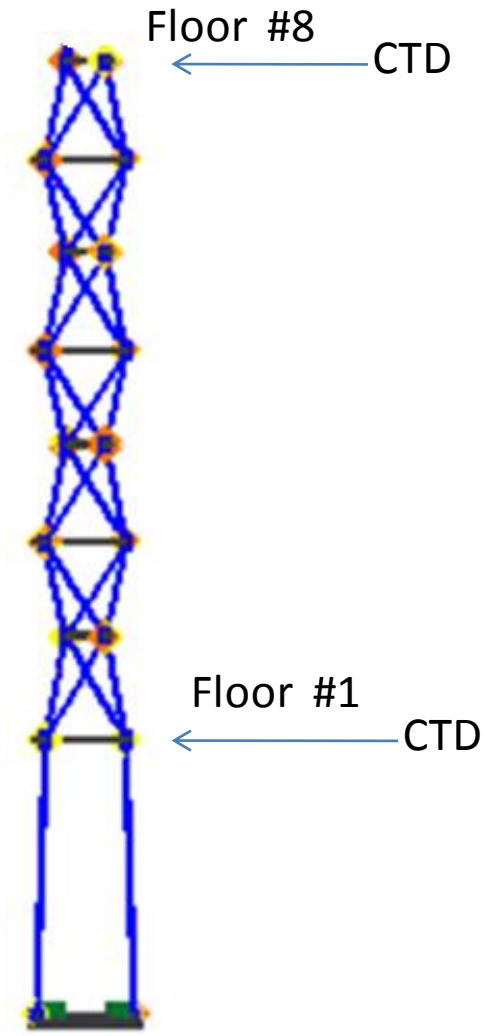
Compass and tilt-meter TCM 2.5

Performance Specifications

Heading Specifications		
Parameter	**Typical**	**Units**
Accuracy over tilt range	0.8°	Deg RMS
Resolution	0.1°	
Repeatability [1]	0.1°	
Max Dip Angle	85°	Deg
Tilt Specifications		
Pitch Accuracy	0.2°	Deg RMS
Roll Accuracy	0.2°	
Tilt Range	± 50°	Deg
Tilt Resolution	0.1°	
Tilt Repeatability [1]	0.1°	Deg RMS

Environmental sensors: CTD

A CTD (Conductivity-Temperature-Depth) probe will be installed on the 1st and on the 8th floor of the tower



The CTD used is a 37-SM MicroCAT CTD manufactured by Sea Bird

	Temperature (°C)	Conductivity (S/m)	Optional Pressure
Measurement Range	-5 to +35	0 to 7 (0 to 70 mS/cm)	0 to full scale range: 20 / 100 / 350 / 600 / 1000 / 2000 / 3500 / 7000 meters
Initial Accuracy	0.002	0.0003 (0.003 mS/cm)	0.1% of full scale range
Typical Stability (per month)	0.0002	0.0003 (0.003 mS/cm)	0.004% of full scale range
Resolution *	0.0001	0.00001 (0.0001 mS/cm)	0.002% of full scale range
Sensor Calibration	+1 to +32	0 to 6; physical calibration over the range 2.6 to 6 S/m, plus zero conductivity (air)	Ambient pressure to full scale range in 5 steps