The data acquisition and transport design for NEMO phase 2

F. Simeone on behalf of the NEMO Collaboration
Underwater Cherenkov neutrino detectors

Look at upgoing muons: use the Earth as a filter
Only atmospheric and astrophysical neutrinos can cross the Earth

Golden channel: throughgoing muon from CC $\nu_\mu$ interaction

Cherenkov photons ($\sim 42^\circ$ in water)

Array of PMTs

A bullet at Mach = 2.5

Cable to shore

 neutrino telescope!
NEMO is an underwater neutrino telescope experiment

- Events reconstructed with Čerenkov photon detection
- Photo-Multipliers (PMT) are used as sensors
- Background rate (due to $^{40}$K) $\sim 70$kHz
- PMT Signal Bandwidth $<100$MHz
- PMT full hit length $\sim 70$ns
- Timing coherency on the apparatus scale for hit “time stamping”
Design Choices

- Optical Signal digitization: sampling 200MHz@8bit
  - Background bit rate per PMT is about 10Mbps
  - 4 OMs produce about 40Mbps per floor

- Acoustic Signal digitization: sampling 192Hz@24bit
  - bit rate per hydrophone is about 6Mbps
  - 2 hydrophones produce about 12Mbps per floor

- Communication Synchronous Protocol
  - Clock and bit stream on same transport medium
  - Compliant with DWDM standards
  - Reduced number of fibers
Each floor has a point to point communication link

Floor

TRANSCEIVER DWDM

RX

TX

DROP

ADD

Next Floor

Previous Floor

to shore

from shore

DWDM MUX
Floor Control Module Board

- Off-Shore - On-Shore link
  - Fiber optic interface (DWDM transceiver)
  - FEM Interface (proprietary protocol)
  - Acoustic Interface (AES3 standard protocol)
  - Slow Control Board (SPI standard protocol)

- Communication with other electronics:
  - Slow Control Board
  - Acoustic Board
  - Time Calibration Board

- Safe reconfiguration from remote
- Used on-shore for bidirectional data communication
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FCM part I

3 Differential Lines:
- Tx Clock line (5 MHz)
- Tx Data line (5 Mbps)
- Rx Data line (20 Mbps)

Electrical Interfaces for 4 Optical Modules

Spartan-3 FPGA
Manage the communication and the interfaces with the other boards

Electro-Optical Interface:
Ser-Des (up to 1.4 Gbps) + DWDM compliant Transceiver
FCM part II

Power Area: linear regulators to minimize noise.

Acoustic Board link (AE3 standard)

Slow Control board connector: electrical link with SPI interface

Time calibration connector: send trigger signal synchronous with the master clock.
Serial Peripheral Interface (5Mbit/s) & SCI Power Supply

SCI Auxiliary Power Supply

Sound Velocity 1
Sound Velocity 2
CTD
Acoustic Doppler Current Profiler
Instrumentation Power Supply

Temp. Sensor
Humidity Sensor

Tilt Sensor
Spare RS232
C-Star
Auxiliary Sensor
Auxiliary Sensor
Auxiliary Sensor
Front End Module Board

- Signal sampling: two 100 MHz 8bit-ADCs
- Analog conditioning:
  - quasi-logarithmic compander => 13 bit
  - on-board calibration circuit
  - ADCs pedestal adjustment
- PMT HV management
- Low Power: 0.3A @ 3.3V
- Safe reconfiguration from remote
Local sensors (temperature, humidity) and front-end setup

PMT electrical interface

Serial interface for test, debug and standalone operations

Local processor for start-up, debug and board monitoring

On-board power regulators

Flash EEPROM (remotely reprogrammable)
FEM Board: PMT signal

Analog conditioning and digital sampling of PMT signal

Spartan IIE FPGA:
L0 trigger, FIFO, data coding and line interface

FCM – FEM Interface
Xilinx Virtex5 development board:

- Embedded PowerPC
- Embedded uBlaze
- Receive and distribute underwater the GPS clock
- Manage the optical communication with the underwater floor
- Extract the acoustic signals and distribute them over a dedicated physical link
- Extract the PMT signals and distribute them over a gigabit ethernet
- Manage the point-to-point connection with the remote instruments
### Jitter Measurement

#### Jitter RMS [ps]

<table>
<thead>
<tr>
<th>Board</th>
<th>Jitter RMS [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>13</td>
</tr>
<tr>
<td>PLL</td>
<td>7.2</td>
</tr>
<tr>
<td>FantimeV1</td>
<td>8.2</td>
</tr>
<tr>
<td>eFcm</td>
<td>10</td>
</tr>
<tr>
<td>FCM</td>
<td>15</td>
</tr>
</tbody>
</table>

#### Diagram:

- **Gen**: 13 ps
- **PLL**: 7.2 ps
- **FanT**: 8.2 ps
- **eFcm**: 10 ps
- **FCM**: 15 ps
Link budget

Test bench: losses of passive components

<table>
<thead>
<tr>
<th>Component</th>
<th>Power levels [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Channel launched power</td>
<td>1.71</td>
</tr>
<tr>
<td>submarine cable output</td>
<td>-17.93</td>
</tr>
<tr>
<td>3 dB coupler</td>
<td>-20.93</td>
</tr>
<tr>
<td>Circulator</td>
<td>-21.25</td>
</tr>
<tr>
<td>Add &amp; Drop - Power Control</td>
<td>-22.8</td>
</tr>
<tr>
<td>Add &amp; Drop - Acoustic Positioning</td>
<td>-23.12</td>
</tr>
<tr>
<td>Add &amp; Drop - 1° and 3°</td>
<td>-24.34</td>
</tr>
<tr>
<td>Add &amp; Drop - 5° and 7°</td>
<td>-24.96</td>
</tr>
<tr>
<td>Add &amp; Drop - 11° to 15°</td>
<td>-25</td>
</tr>
<tr>
<td>Circulator</td>
<td>-26.55</td>
</tr>
<tr>
<td>Add &amp; Drop #8</td>
<td>-3.2</td>
</tr>
</tbody>
</table>

Cable Termination Assembly and VEOC losses

<table>
<thead>
<tr>
<th>Connector</th>
<th>Worst Case</th>
<th>Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>optical connector (ALCATEL CTA)</td>
<td>-0.75</td>
<td>-0.3</td>
</tr>
<tr>
<td>ROV mateable connector (ALCATEL CTA)</td>
<td>-0.75</td>
<td>-0.3</td>
</tr>
<tr>
<td>ROV mateable connector (DU)</td>
<td>-0.75</td>
<td>-0.3</td>
</tr>
<tr>
<td>Optical connector in VEOC</td>
<td>-0.75</td>
<td>-0.3</td>
</tr>
<tr>
<td>Add &amp; Drop #8</td>
<td>-3.2</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

Optical power at receiver input: -32.75 dB, Sistem Margin [dB]: 0.25 dB, 3.65 dB

38dB for a BER of 10^-12 at 800Mb/s

8.65dB margin without the raman amplifier
Floor integration
Floor vessel assembly
Conclusions

- The synchronous protocol simplifies the overall design
- Transmission exploits optical passive devices
- The transmission latency is fixed
- The FCM board implements a point to point synchronous link between boards and sensors using different protocols.
- Powerful mechanism of safe reconfiguration
- Usefulness of hit waveform for DAQ tuning
- Tower deployment foreseen by the end of the year
The Cosmic Ray Spectrum

More than 10 orders of magnitude

Spectrum: $E^{-2.7}$ at almost all energies

The CR sources are still unknown

(protons accelerated in Galactic SN Remnants)

Nuclei accelerated in Galactic SNR

Hadrons deflected by the Galactic magnetic fields

Hadrons absorbed by the interaction with CMBR

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Cosmic Ray, Gamma Ray and Neutrinos

Cosmic accelerator (SNR, AGN, GRB, etc)
- Progenitor outflow
- Interstellar material
- Ambient photon field

$p + p \rightarrow \pi^0 \rightarrow \gamma + \gamma$

$p + \gamma \rightarrow \pi^\pm$

$\mu^\pm + \nu_\mu (\bar{\nu}_\mu)$

$e^\pm + \nu_e (\bar{\nu}_e) + \bar{\nu}_\mu (\nu_\mu)$

Cosmic ray

Photons

$p, \text{He, ...}$

Neutrinos

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Absorption length of protons and gammas in the Universe

Cosmic Microwave and IR radiation
Dusts and Clouds

Protons’ Horizon

Photons’ Horizon

Dusts and Clouds

Cosmic Microwave and IR radiation

Protons

Gammas

Neutrinos

Neutrino astronomy can:

- probe the far and violent Universe

- disentangle between pure leptonic and hadronic acceleration models
Measures: Jitter

- Clock generator (80 MHz):
  - Jitter = 13 ps
• Dejittered clock from PLL (80 MHz):
  – Jitter = 7.2ps
Measures: Jitter

- **LVDS clock distributed by FanTime (80 MHz):**
  - Jitter = 8.2 ps
• eFcm Transmit Clock (40 MHz):
  – Jitter = 10.6 ps
  – Measured on ML507 SMA connector;
Measures: Jitter

- Off-Shore recovered clock (40 MHz):
  - Jitter = 15 ps