String-Mounted Instrumentation (non-DOM)

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Kurt Woschnagg (L3 Detector Characterization)
University of California, Berkeley

Reviewed by: P. B. Price (UCB), Ryan Bay (UCB)

For review by:
Bob Morse (L2 Implementation)
Randy Iliff (L3 Systems Engineering)
Albrecht Karle (L2 Instrumentation)
Jim Baccus (Cables)
Doug Cowen (L2 Detector Commissioning & Verification)

Purpose

This document is intended to specify features of all string-mounted instrumentation other than the DOMs that are relevant for cable design, deployment planning, etc, in order to facilitate the integration of these devices into the system (and the budget). Since the integration concerns a number of WBS elements, this document is meant to make sure everyone is on the same page.

Scope

This document briefly describes the ancillary devices needed for calibration and deployment monitoring, i.e., all instrumentation that is deployed with the string except for the DOMs. For every device type, the following aspects are discussed: (1) the purpose
of the device; (2) a brief description of the device, e.g., its physical dimensions, mode of
to operation, whether it is to be built within the project or it is available off-the-shelf; (3)
[number] and placement on each string and within the entire array; (4) requirements on
the cable, e.g., number of wires needed, connectors down-hole and on the surface; (5)
communication, e.g., protocol, control, readout mode and rate, readout during and/or after
deployment (i.e., through slip ring or not); (6) power consumption and supply; (7)
deployment considerations; (8) cost estimates. Special arrangements, e.g., cable
configurations beyond the baseline design, for the strings to be deployed in the first
season (04/05) are discussed. The main features of the devices are summarized in Table
1, and cost estimates are summarized in Table 2, at the end of this document.

Introduction

Besides the 60 DOMs, each string will have a number of additional devices needed for
calibration and monitoring. Pressure sensors and thermistors will be attached to every
string and thus be part of the baseline configuration. In addition, some strings of the array
will have a dust logger (DL, 9 in total) or a standard candle (SC, 10 in total) laser
module. Some of the first strings will carry an acoustic televiewer (ATV) to measure the
dimensions of the hole during deployment. Disregarding the baseline instrumentation
(pressure sensors and thermistors), each string will have at most one additional
instrument (DL, SC or ATV) as there is no scientific reason to deploy several of them in
the same hole.

The design, integration, and operation of these devices relies on the coordination of
several areas within the WBS. The main ones, at level 3, are:

1.1.2 Systems Engineering
1.2.2 Drilling
1.2.3 Deployment
1.3.1 In-ice devices (Cable design)
1.3.4 Data Acquisition Software
1.5.3 Detector Characterization

Pressure sensors

Purpose

Every string will be equipped with at least two pressure sensors. These are needed for
two purposes. First, the progress of the string deployment is monitored by comparing the
pressure sensor readings with cable payout data to make sure that the string is moving
deeper at the same rate as it is released from the spool. A discrepancy would indicate a
problem down-hole such as the string being stuck. Secondly, during and at the end of
deployment the pressure reading is used to calibrate the absolute depth of the string.
**Description**

The main pressure sensor will be a unit from the Paroscientific 8000 series (a “Paro” in the following), specifically a 8CB4000 rated to 4000 m, mounted at the end of the string, below the deepest DOM. The Paro gives a temperature-corrected pressure reading (in mwe) and a temperature reading.

In addition, each string will have a second pressure sensor for reliability and cross-checks. It will be a KPSI 300DS pressure transducer (a “Keller” in the following). The Keller is rated up to 2000 psis and can be operated in standard voltage (0-5 V or 0-100 mV) or current loop (4-20 mA) outputs. The raw output is converted to a pressure reading with individual temperature-dependent calibration curves provided by the manufacturer.

Full spec sheets for both pressure sensors in docushare (see below).

**Configuration**

Driven to some extent by cost considerations, each string will have one Paro at the end, below the deepest DOM, and one Keller midway up the instrumented section at approximately 450 m from the Paro (so that its final depth is ~2000 m, the limit for the Keller pressure range). The four (or so) strings deployed in the 04/05 season will each have one additional Paro located TBD.

**Cable considerations**

Paro: RS-485 (half-duplex). This means it needs four wires, preferably one quad. Keller: 2-4 wires, depending on output mode (current[mA] or voltage[V, mV]). Both types of pressure sensors will have special connectors on short cables (that can be installed by Paro and KPSI, as for AMANDA) that mate with SeaCon connectors at the breakouts. Surface connectors TBD.

**Deployment considerations**

The pressure sensors are either attached at SeaCon when the breakouts are made, before spooling and shipping, or at deployment time. For the Keller, we need to take an initial air pressure reading at the point just before it reaches the water in the borehole; the current/voltage offset is used by the deployment monitoring DAQ to convert to an absolute depth reading.

**Communication/readout**

All pressure sensors are read out continuously during deployment. Need slip-ring connection for all (4 pins for Paro, 2-4 pins for Keller).

**Power**

Paro: TBD; Keller: < 0.5 W.
Cost estimate
The capital equipment cost for each Paro is $7k, and for each Keller $800. The total cost for 85 Paros is $595k, and for 85 Kellers the cost is $68k. These estimates do not include labor costs, breakout costs, or connectors.

Thermistors

Purpose
Also part of the baseline string configuration are several thermistors. These are needed for two purposes: (1) to get a more accurate measurement of the temperature profile below 2200 m, and (2) to monitor the freeze-in rate. The first requires the thermistors to be located at the lowest 200-300 m of the cable, whereas for the second the thermistors have to be spaced evenly throughout the entire instrumented string section [at least, why not even higher? need input from BobM/drillers]. Temperature vs depth data taken some years ago in the AMANDA array were quite sparse at depths below 2000 m. Additional temperature vs depth data are required in order to provide input for modeling of shear rate of the ice and consequent shifts in locations of the deepest OM.

Description
We will use thermistor model no. 44031 made by Omega, Inc. It has a simple design: a small (few mm) active component with two spider-leg wires. The resistance varies with temperature. The thermistors come with a general resistance-to-temperature conversion table. Full spec sheet has been submitted to docushare (see below).

Configuration
The tentative plan is to have five thermistors on every string. TBD of the strings will have all five in the lowest TBD m (for temperature profile), and TBD strings will have the thermistors evenly spread along the entire instrumented section (for refreeze monitoring). It is also conceivable to put thermistors on the part of the cable that is above the shallowest DOM for TBD strings. [need input from drillers, Bob M]

Cable considerations
One twisted pair per thermistor, one breakout per thermistor. The thermistor is molded into a watertight [thing] at the end of a short cable from the breakout (standard procedure by SeaCon for AMANDA).

Deployment considerations
None. The thermistors are already attached to the cable at the time of deployment, and are (typically) only read out after deployment. Therefore no need for slip-ring connection.

Communication/readout
The thermistors are read out by measuring (with, e.g., a multimeter) their resistance, which is then translated into a temperature via a conversion chart supplied by the
manufacturer. The resistance in the relevant temperature range (-20°C to -40°C, after freeze-in) lies in the range 80-200 kΩ. The precision on the temperature reading is a few percent. Given this uncertainty, the loop resistance in the cable (~300 Ω), which introduces a correction below one percent, can be ignored [but can also easily be corrected for].

**Power**
No power required.

**Cost estimate**
Assuming five thermistors per string, with each thermistor costing less than ~$10 (depending on quantity purchased) the total cost for 400 thermistors is $4k. This estimate does not include labor costs, or cable-related cost for, e.g., breakouts and molding.

**Dust loggers (DL)**

**Purpose**
From measurements of optical properties in AMANDA [1] we know that embedded dust determines the amount of scattering and absorption of Cherenkov light in the ice below 1400 m. The dust concentration, and thus the optical properties, vary strongly with depth, and exhibit a layered structure that must be faithfully reproduced in the detector simulation. Analysis of in-situ data from AMANDA has provided optical properties (with a 10-m resolution) down to ~2100 m; at greater depths we expect the ice to be cleaner based on Antarctic ice core measurements that were matched to the AMANDA dust profile. A deeply penetrating radar survey at the South Pole shows that the vertical locations of the layers can vary by tens of meters over the IceCube range of 1 km. Dust loggers use an optical technique to rapidly get a measure of the variations in dust concentration in the surrounding ice as the string is lowered into the hole. Volcanic ash layers, typically 1 cm thick, were not resolvable with the previous AMANDA techniques, and the new dust loggers will be optimized to detect the ash layers, in order to obtain the best fit to muon trajectories.

**Description**
A dust logger is typically cylindrical, a few feet long and a few inches in diameter [all this TBD], and contains one or more light sources at one end and one or more PMTs or integrated photon counters at the other. Ideally, several opaque brushes extend radially from the logger to prevent light from reaching the PMTs through the water in the hole, and centralizing springs keep the logger centered in the hole. Light is injected from the logger horizontally into the bulk ice, and the PMTs measure the light that is reflected back by scattering on impurities.

**Configuration**
A dust logger should be deployed in the 04-05 season for evaluation purposes, and to get an immediate measurement of dust at the greatest depths to be instrumented (below 2100
m, where no in-situ data from AMANDA exists). There will be nine dust loggers deployed throughout the array: in six holes at (or near) the corners of the hexagonal string layout, and in three holes TBD within this layout (one of which is the hole close to the center of the AMANDA array, so that the DL data can be calibrated to the dust profile measured in AMANDA). Each DL will be attached below the end of the cable to avoid the light being obstructed by it.

**Cable considerations**
1 quad or 4-5 instrument wires. Down-hole and surface connectors TBD.

**Deployment considerations**
Device is mounted near the lowest breakout; possibly interspersed with bottom weights for centralization and symmetry. After minimal set-up and testing, deployment will not be affected, although a slower descent improves resolution.

**Communication/readout**
RS-485 (half-duplex) read out continuously during deployment. Real-time deployment pressure information is provided by the nearest convenient Paro or Keller sensor and integrated into the data stream. A slip-ring connection is needed for power and telemetry.

**Power**
375 VDC; 20 to 50 W, depending on light source, number of channels, etc.

**Cost estimate**
The first DL will cost $30k, and the following eight will cost $20k each. The total cost for nine units will be $190k. This estimate does not include labor costs, or costs for breakouts and connectors.

**Standard-candle lasers (SC)**

**Purpose**
Powerful pulsed in-situ light sources with known light output (intensity and pattern) are needed for energy calibration of cascade events, and will also be used for long-range geometry measurements (i.e., optical time-of-flight measurements beyond nearest-neighbor strings).

**Description**
Nitrogen laser (337 nm, with dye to vary wavelength if feasible) in pressure housing (glass sphere or metal cylinder with quartz window/s). Nanosecond pulsing at 20 Hz or less. In-line energy calibration. Variable attenuator. Optics to create cascade-like shape. The light output from a fully assembled SC module will be calibrated in the lab, so that intensity and light pattern will be known at the point of injection into the ice.

A separate document on the standard candles is currently being written.
Configuration
The calibration plan calls for 10 standard candles to be deployed at different locations on separate strings throughout the array. The locations in the array and on individual strings, as well as the directionality of the light output, will vary in order to cover as large a variety of cascade event signatures as possible.

Cable considerations
The number of wires needed depends on the design and functionality of the modules, both of which are TBD. Typically, 10-12 wires are needed for power, control, and readout of trigger pulse.

Deployment considerations
Although the SCs are not operated during deployment, they will be tested as soon as they are attached to the cable, before they are lowered into the borehole. The basic functionalities will be tested. [communication, on/off, attenuator, etc.]

Communication/readout
The SCs will not be operated during deployment as they are intended for calibrations of the frozen-in-place array. No need for a slip-ring connection.

Power
The power consumption of one laser unit is TBD.

Cost estimate
The first SC laser module will cost $50k, and the following nine will cost $40k each. The total cost for ten units will be $410k. This estimate does not include labor costs, or the cost for building and operating a calibration setup for the SCs.

Acoustic televiewer (ATV)

Purpose
Two ATVs will be clamped to the drill hose in order to monitor hole size during drilling. They will be discussed elsewhere. This section deals only with the disposable ATV, which will be frozen into the ice together with a string. The circumference and inclination of the hole will be logged acoustically during deployment. Data on hole size obtained ~30 to ~40 hours after drill extraction will serve as input for the modeling of power (i.e., fuel) consumption for the drilling. The goal is to minimize fuel consumption so that the hole refreezes to a size of ~45 cm when the string has reached the desired depth. The first string in 04-05 will have a disposable ATV.

Description
ALT, a Luxembourg firm, makes ATVs for geophysical logging. An ATV is 4 cm in diameter and ~1.4 m in length. A transducer sends a collimated beam along the cylinder axis where it reflects off of a rotating concave mirror and exits the instrument. The sweep
rate is typically ~10 revolutions per second. Due to the acoustic impedance mismatch of water and ice, a strong reflected beam is returned to the instrument and recorded by the transducer. An image of the borehole wall as a function of depth is displayed and stored in memory. Software corrects the image for a displacement of the instrument from the center of the borehole. If the ATV can be maintained near the center of the borehole, the hole dimensions should be continuously determined to within a few mm.

**Configuration**

There will be one ATV below the end of the string (so the signal is not obstructed by the cable) on one or more of the early strings (i.e., the strings deployed in the 04-05 season). The tentative plan is to center the ATV inside a skeleton cylinder of diameter ~33 cm, consisting of five thin vertical struts, outside of which there will be calipers to center the ATV in the borehole.

**Cable considerations**

The ATV uses 4 wires (2 for power, 2 for readout and control [to be confirmed]). The mechanical and electrical connection is made via a GO 4-pin cable head (a world-wide standard for logging tools [ALT claim]). Surface connectors TBD.

**Deployment considerations**

Need expert from ALT on location. [Pre-attached or not? Test before it goes down?]

**Communication/readout**

The ATV will take data continuously during deployment. A slip-ring connection (4 pins) is needed.

**Power**

TBD

**Cost estimate**

Each ATV unit costs $90k. A total of four units will cost $360k. This estimate does not include labor costs.

**Summary**

Table 1. Summary of string-mounted instrumentation (non-DOM) and main features.

<table>
<thead>
<tr>
<th>Device</th>
<th>Quantity</th>
<th>Location</th>
<th>Cable req.</th>
<th>Slip ring</th>
<th>Comms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paro</td>
<td>1/S</td>
<td>bottom</td>
<td>1 quad</td>
<td>Y (4 pins)</td>
<td></td>
</tr>
<tr>
<td>Keller</td>
<td>1/S</td>
<td>450 from end</td>
<td>2 swp</td>
<td>Y (4 pins)</td>
<td></td>
</tr>
<tr>
<td>Thermistor</td>
<td>TBD/S</td>
<td>throughout</td>
<td>1 swp</td>
<td>N</td>
<td>Resistance</td>
</tr>
<tr>
<td>Dust logger</td>
<td>10/A</td>
<td>bottom</td>
<td>TBD</td>
<td>Y (TBD)</td>
<td></td>
</tr>
<tr>
<td>Standard candle</td>
<td>10/A</td>
<td>varying</td>
<td>TBD</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Acoustic televiewer</td>
<td>=2/A²</td>
<td>bottom</td>
<td>TBD</td>
<td>Y (TBD)</td>
<td></td>
</tr>
</tbody>
</table>

¹S=string, A=array (full 80 strings)
The estimate of 2 in the entire array assumes no unforeseen problems.

Table 2. Summary of cost estimates for string-mounted (non-DOM) instrumentation. Costs for labor, connectors, breakouts, calibration and testing not included.

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost/unit [$k]</th>
<th>Total # units</th>
<th>Total cost [$k]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paro</td>
<td>7</td>
<td>85</td>
<td>595</td>
</tr>
<tr>
<td>Keller</td>
<td>0.8</td>
<td>85</td>
<td>68</td>
</tr>
<tr>
<td>Thermistor</td>
<td>0.01</td>
<td>400</td>
<td>4</td>
</tr>
<tr>
<td>Dust logger</td>
<td>20, 30(^1)</td>
<td>8+1(^1)</td>
<td>190</td>
</tr>
<tr>
<td>Standard candle</td>
<td>40, 50(^1)</td>
<td>9+1(^1)</td>
<td>410</td>
</tr>
<tr>
<td>ATV</td>
<td>90</td>
<td>2(^2)+2(^3)</td>
<td>360</td>
</tr>
</tbody>
</table>

\(^1\)prototype; \(^2\)tail logger (on drill); \(^3\)disposable (on string)

**Additional documentation**

Additional documentation on string-mounted instrumentation (some are listed below as clickable links in the electronic version of this Word document) can be found under docushare, in the work area for WBS 1.5.3 Detector Characterization:

[http://docushare.icecube.wisc.edu/docushare/dsweb/View/Collection-422](http://docushare.icecube.wisc.edu/docushare/dsweb/View/Collection-422)

In case of a conflict, figures in this document supercede those given in older documents.

*Presentations at review meetings:*

**String-mounted Instrumentation (other than DOMs)**
Summary of non-DOM string instrumentation (June 03 PDR)

**IceCube String-Mounted Devices**
Review of string-mounted non-DOM devices (Feb. 03 SRR)

*Available spec sheets:*

**Paroscientific pressure sensor (specs)**
Specs for Paroscientific pressure sensor

**Keller pressure sensor (specs)**
Specs for Keller pressure sensor

**Thermistor (specs)**
Specs for thermistor

[1] [http://amanda.berkeley.edu/kurt/ice2000](http://amanda.berkeley.edu/kurt/ice2000)