SEA CON Technology Crucial To Antarctic Research Project

Sensors Relay Data from Deep in the South Pole Ice Cap Via Satellite to University of Wisconsin, Madison

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An ambitious scientific research project at the South Pole, appropriately called IceCube, has brought together academia and industry to study elusive subatomic particles from space.

IceCube involves sinking an array of sensors into the Antarctic ice cap to form a one-cubic-kilometer telescope looking toward the center of the Earth.

SEA CON® Brantner & Associates Inc. (El Cajon, California) is one of the project's partners, providing the connectors and cable terminations for IceCube.

The company overcame a number of special challenges to ensure that its technology, originally designed to operate in the ocean, could deliver the performance required in the low temperature and high hydrostatic pressure of one of the harshest possible operating scenarios—being permanently encased in ice more than one mile beneath the Antarctic ice cap.

Why Study Neutrinos?

The goal of the IceCube experiment is to detect high-energy neutrinos.

Neutrinos are tiny, point-like particles that have no electric charge, nor do they readily interact with matter. There might be 10 trillion neutrinos passing through the human body every second, but a person is unlikely to have even a single neutrino interact inside the body during a lifetime.

This property makes neutrinos useful to astronomers who wish to understand the physics of the highest energy sources of radiation in the universe. It also means that neutrinos can be observed only through a very large detector.

IceCube encompasses one billion tons of ice, but scientists expect to capture only a handful of neutrinos every year.

The neutrinos interact in the ice and then become particles called electrons and muons, which give off a bluish

IceCube staff at South Pole Station. Left to right Evan Davis, Jim Haugen, Tim Murray and Mike Kleist.

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light—the optical counterpart of a sonic boom—which is detected by the IceCube sensors.

Background and Project History

In 1993 and 1994, several astrophysicists at the University of California, Berkeley; the University of California, Irvine; and the University of Wisconsin (UW), Madison, sank photo tubes to a depth of one kilometer in the Antarctic ice to study neutrinos in a project called Antarctic Muon and Neutrino Detector Array (AMANDA)—funded by the National Science Foundation (NSF) and other governments and organizations internationally.

Between November 1996 and February 1997, 216 of the 330-millimeter-diameter digital optical modules (DOMs), containing photodetectors, were placed in six holes at a depth of two kilometers, with 36 DOMs per string. Scientists increased the earlier one-kilometer sampling depth to 1.5 to two kilometers, which improved results because bubbles that scatter light were not as prevalent below 1.5 kilometers. This effort was called AMANDA B, and the original project was retroactively referred to as AMANDA A.

Between 1997 and 2004, the AMANDA B project continued its neutrino research at the South Pole scientific station. The AMANDA telescope, still in place and functioning today, amounted to the proof of concept for the feasibility of IceCube. AMANDA covered a volume of 0.02 cubic kilometers.

In 2004, NSF awarded a multiyear contract to the Antarctic Astronomy and Astrophysics Institute at UW Madison to manage the IceCube project. In addition to its earlier participation in the AMANDA A and B projects, in which it drilled 19 holes at depths of up to two kilometers and deployed more than 600 optical sensors, UW Madison had established credentials for electrical and electronics engineering, astrophysics and related technical expertise.

The first sensor string was drilled and deployed at the South Pole Station in January 2005, and the sensor array is due for completion in 2011.

The telescope is located at the South Pole, since the ice, formed by the compression of incremental snow over thousands of years, is about as pure as any ice on Earth below the depth of 1.45 kilometers. In addition, at -50° C, South Pole ice is nearly the coldest on the planet, causing far less thermal noise than ice in warmer temperatures.

The first 50 meters of subsurface material is snow, followed by ice extending to a depth of one kilometer beneath the surface. In comparison, while there is a one-kilometer vertical separation (i.e., from 1.4 to 2.4 kilometers) between the top of the sensor string and the bottom, the Eiffel Tower is only 300 meters tall.

Why SEA CON Connectors?

UW Madison evaluated several manufacturers before selecting SEA CON as the IceCube connector manufacturer in 2004. SEA CON brings 40 years of connector experience to the project, along with a history of participating in AMANDA A and B.

In addition, SEA CON offered several advantages. The company had a record of meeting demanding delivery schedules, a large selection of specialty connectors and a commitment to continuously improve the cable system and manufacturing processes, an open-door policy to customers and a staff of highly experienced employees, including production manager and IceCube project manager Kry Leap, who has more than 30 years of experience in the underwater connector industry. Most importantly, the company had experience in areas necessary to the project, such as assembly manufacture, including mating a penetrator assembly to a power/communications cable, which is the link between the sensor string and the outside world; overmolding, a method to create a seal between the cable and connector body; and cable breakouts, which are a method of reinstating a cable jacket following damage to or an intentional breach of the jacket.

IceCube System Details

When completed, the IceCube string configuration's 4,800 InIce DOMs will have 17 vertical meters of separation between each two sensors on a given string.

There will be up to 80 strings, each string separated by 125 meters from its nearest neighbor.

The strings are installed by drilling holes in the ice, using an enhanced hot water drill. When finished, the hole is approximately 2,500 meters deep and 60 centimeters in diameter.

Once the hole is ready, installers have approximately 24 hours to connect the DOMs to the surface-to-DOM cable and suspend them in position.

A five-meter-tall tower positions the cable over the hole and allows the installers to attach the DOMs to the surface-to-DOM cable. The cable is then lowered until a DOM connection point, consisting of two Yale Cordage (Saco, Maine) Yalegrips™ attached to the cable, is reached. Then the steel cables of the DOM harness are attached to the cable Yalegrips. The DOM penetrator assembly connectors are also mated to the SEA CON XSJJ connectors of the cable.

Once the string has been lowered into its final position, the string is left to freeze in place, and the IceCube sensors are ready to begin taking data. A DOM senses photons through its photomultiplier tube (PMT), and PMT data is digitized by the DOM electronics. This digital data is sent up through the SEA CON-manufactured DOM penetrator assembly, protected by a Teledyne Benthos (North Falmouth, Massachusetts) pressure sphere, and through a SEA CON glass-reinforced epoxy (GRE) XSJJ connection to the surface-to-DOM cable.

This cable, manufactured by Ericsson Network Technologies (Hudiksvall, Sweden), is 2,505 meters long and is comprised of 20 quads of conductors of nominally 145 ohms impedance. It has Kevlar outer and central-strength members, providing 55 kilonewtons of mechanical reinforcement.

Waterblocking around the quads prevents any water or ice from damaging the symmetry of the cable. A copper shield is used to provide electrical noise isolation.

The XSJJ connection is made possible by the SEA CON breakout design. Breakouts are installed by slicing open the cable, cutting the correct quads, terminating them to the XSJJ connectors, waterproofing and overmolding the connectors and then resealing the cable. Once data from the DOM is inside the surface-to-DOM cable, it travels up to the ice surface and on to the IceCube surface cable via military-specified (MS) round, metal shell connectors installed by SEA CON.

The surface and surface-to-DOM cables are mated in a stainless steel junction box. IceTop sensors are brought into the IceCube cable system

> *"IceCube's sensor strings will likely be in long-term cold storage for hundreds of years."*

via the surface junction box. The surface cable is also manufactured by Ericsson Network Technologies and has a similar construction to the surface-to-DOM cable, with the exception of the waterblock and Kevlar strength member. The data continues through the surface cable and into the IceCube Lab (ICL), where it meets another MS connection to short, patch cables, which are assembled by SEA CON.

By that time, the data has traveled anywhere from 2,650 to 3,300 meters of cable. The data is acquired in the ICL and transmitted to the IceCube headquarters in Madison, Wisconsin, via satellite at a rate of 30 gigabytes of data per day.

Special Considerations

Operating in the ice shafts imposes extraordinary stress in the form of both temperature and hydrostatic pressure on all elements of the sensor string—cables, connectors, penetrators and the Benthos pressure sphere. The SEA CON XSJJCCP7 and XSJJCCR7 connectors, used to mate the long penetrator assembly DOMs in the sensor array, and the XS77CCP9 and XS77CCR9 connectors, used to mate the short penetrator assembly DOMs, are exposed to 6,000 pounds per square inch of pressure in the ice shaft by the time the holes refreeze and encase the strings in new ice.

The challenges to SEA CON included working with extremes of temperature, not only the low temperature once the ice had frozen, but also the higher temperature during filling on the drilled hole; working at high pressures resulting from the compression of the ice; developing a reliable, repeatable method to break into a multistranded cable and reinstating the integrity of the cable to a level that can withstand not only the operating environment but also the rigors of deployment; selecting the correct connector, critical due to the permanent installation restriction and no maintenance opportunities once installed; handling multiple 2,500-meter cable lengths to enable accurate and reliable completion of multiple breakouts distributed in close proximity to each other; and project management of a complex set of cable assemblies with critical delivery demands due to logistical constraints in transferring cable to the South Pole.

With the extensive range of connectors SEA CON has in its portfolio, minimal modifications were required to the connectors selected for the IceCube program; however, developing a reliable cable breakout system for the surface-to-DOM cable benefited from many aspects of SEA CON's 40 years of experience in supplying cables and connectors for underwater, harsh-environment NSF applications.

Despite the many challenges, project workers have made steady progress toward having all 80 sensor strings installed by 2011.

Conclusions

Because the South Pole's extreme temperatures tend to keep frozen objects frozen into the foreseeable future, as well as the fact that the South Pole Station is so far inland, IceCube's sensor strings will likely be in long-term cold storage for hundreds of years.

IceCube is a tangible illustration of the success of instrumentation functioning unattended in a long-term deployment to gather and transmit valuable data from one of the harshest operating environments on Earth.

SEA CON's expertise in cable termination, overmolding and connector technology has enabled sensor strings to perform well, despite the project's demands that components work together in a location decidedly outside their intended operational setting.

IceCube is a dramatic example of productive collaboration between industry and the scientific community to reach a mutual goal.

Providing accessibility to the customer—maintaining real-time communications and jointly solving operational issues as they emerge—transcends the IceCube project and tends to lead to successful outcomes, regardless of the application.

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