The Digital Optical Module – How IceCube will Acquire Data

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IceCube[1] will be a km-scale neutrino detector consisting of 4800 optical modules (OMs) on 80 strings of 60 OMs each. The DAQ technology will have the following desirable features: 1. the robustness of copper cable between the OMs and the surface. 2. digitization and time-stamping of signals that are unattenuated and undispersed. 3. calibration methods (particularly for timing) appropriate for a large number of OMs. The PMT anode waveform is digitized and time-stamped in the OM. The time calibration procedure is both accurate and automatic.

A system[2] having these features has been tested in AMANDA. A prototype digital system consisting of 40 OMs was deployed in Jan., 2000. The principal components of the Digital Optical Module (DOM) signal processing circuitry are: the analog transient waveform digitizer (ATWD), a low-power custom integrated circuit that captures the waveform in 128 samples at a rate of ∼500 Megasamples/s; an ADC operating at ∼30 MS/s covering several microseconds; a FPGA that provides state control, time stamps events, handles communications, etc.; a low-power 32-bit ARM CPU with a real-time operating system. A 16.8 MHz oscillator, made by Toyocom, is free-running, very stable ($\delta f/f \sim 5 \cdot 10^{-11}$ over $\sim 5s$) and provides clock signals to several components. Short (12 m) cables connecting adjacent modules enable a local time coincidence, which eliminates most of the ∼1 kHz of dark noise pulses.

A critical requirement is the ability to calibrate the DOM oscillator against a master clock at the surface. In essence, timing pulses sent in one direction at known time intervals can be used to determine relative frequency, and the round trip time of pulses sent in both directions can determine the offset. After receiving a timing pulse at the DOM and waiting for a short time, δt, measured on the DOM clock, a pulse is sent from the DOM to the surface. The shapes of the pulses sent down and up are identical and are analyzed in the same way to determine the time mark. In this case, the times up and down are the same and are therefore equal to half the roundtrip time minus $\delta t/2$. This calibration method is called Reciprocal Active Pulsing[3]. Performing clock calibrations automatically every 5-10 seconds consumes negligible bandwidth.

The rms resolution for timing pulses received at the DOM is 1.8 ns. The resolution for pulses sent upward is larger, viz., 2.8 ns, because of the larger ambient electrical noise in the DAQ electronics on the surface compared to that in a DOM. The systematic errors are estimated to be less than 5 ns.

IceCube will have two DOMs per twisted pair cable. Eight DOMs will communicate with a HUB on surface. All communications after a HUB will be via Ethernet. Each string of 60 DOMs will have a CPU that time-orders hits and forms "string triggers." Hits satisfying a global trigger will be built into events. A disk storage system will retain all events for several days (e.g., to search for Gamma-Ray Bursts) and an on-line cluster of CPU's will filter data for transmission via satellite to North America.

REFERENCES

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3. RAP - Absolute Time-Calibration of a Large Array based on a Digital Optical Module System, R.G. Stokstad, et al., Oct. 1998, LBNL-43200