Retrofitted Digital Optical Modules for the Radio Detection of Neutrinos in Ice

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Abstract. The Askaryan Underice Radio Array (AURA) is a proposed next-generation radio neutrino detector for the South Pole, which succeeds the existing Radio Ice Cherenkov Experiment (RICE). In the 2006/7 IceCube deployment season, AURA will co-deploy new radio antennas. I describe the Digital Optical Module (DRM), which will incorporate triggering and data-handling in-ice, using both IceCube and radio technology.

1. Introduction

The RICE experiment [1] consists of 18 radio receivers deployed in a 200 m $\times$ 200 m $\times$ 200 m cube from 100 to 300 m in depth. Twelve RICE receivers are co-deployed in holes drilled for the Antarctic Muon and Neutrino Detector Array (AMANDA) [3], the rest are in dedicated RICE holes. The object of the experiment is to see coherent radio pulses from extremely high energy neutrino showers in South Pole ice [2], which is transparent at radio frequencies [5]. The presence of AMANDA and IceCube and the forthcoming South Pole Acoustic Test Setup [6] also offer the possibility of coincident detection of EHE neutrinos by more than one method. Because radio emission from showers dominates at neutrino energies above 1 PeV, where predicted fluxes are very low, it is necessary to expand the radio instrumentation into a larger volume. The ongoing deployment of IceCube offers an immediate opportunity for expansion.

2. Digital Radio Module

The IceCube digital optical module (DOM) is a pressure vessel containing a photomultiplier tube, a mainboard with digitizing electronics, and a separate board with flashing LEDs for optical calibration. In the Digital Radio Module (DRM), the photomultiplier tube and the flasher board are removed from the pressure vessel and replaced by the radio trigger, digitizing and data-handling electronics. The radio electronics are connected to the IceCube mainboard via the flasher board connection. Each DRM is attached to 4 external RICE dipoles, spaced vertically 13 m apart with 2 above and 2 below the DRM. The DRM is attached to the IceCube cable as shown in Figure 1. There is a spare breakout on each IceCube cable at 1400 m depth, where the DRM can be deployed, so the data from the DRM would flow over the IceCube cable. Some DRMs may also be deployed at a shallower depth comparable to the depth of the first RICE array (~200 m), in which case the DRM would be attached to a separate cable parallel to the IceCube cable.

The layout of the DRM triggering, digitizing and data-handling electronics is shown in Figure 2 and described in the following sections.
2.1. Trigger and Digitization

The DRM trigger adopts the strategy of triggering on multiple frequency bands, as the coherent radio signal is broad-band. This trigger scheme was developed for the ANITA experiment [9] and the AURA trigger electronics use ANITA hardware and firmware. The antenna signals are split into two paths, one to the ReadOut Board UHF Sampling and Trigger (ROBUST) and one to the SURF High Occupancy RF Trigger (SHORT) board. On the SHORT board, each antenna signal is split into four frequency bands (200-400, 400-650, 650-880, and 880-1200 MHz). Each band is sent through a tunnel diode and then a discriminator.

The in-ice trigger consists of 3 levels:

- **L0 (SHORT):** An antenna band crosses the discriminator threshold.
- **L1 (ROBUST):** A coincidence forms between multiple bands from 1 antenna.
- **L2 (ROBUST):** A coincidence forms between multiple antennas in 1 DRM.

The discriminator thresholds, coincidence time windows and multiplicity requirements are programmable and will be determined based on the actual noise conditions in the ice.

When a signal satisfies the trigger, it is digitized by the Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC [7] on the ROBUST card.
LABRADOR was developed for the ANITA experiment [8] and consists of 9 digitizing channels of 260 samples per channel at 12 bits per sample. Each antenna signal is digitized in two channels which are sampling at half the full sampling rate and interleaved, in order to increase the time coverage. The 9th channel will digitize the timing signal. The digitization time for a full event is 120 s. The data transfer rate up the IceCube cable is 90 kB/s, limiting the ROBUST trigger rate to 25 Hz, which corresponds to over 99 % livetime.

Digitized waveforms are then sent to the Trigger Reduction and Communications for Radio (TRACR) board. The ROBUST also sends the trigger signal to the IceCube mainboard.

2.2. Data Handling

The TRACR board contains a Xilinx Virtex2Pro FPGA which buffers the LABRADOR waveforms until the mainboard requests an event. The TRACR adds header information to the event including the timestamp, discriminator thresholds and active antenna channels. The total event size including all header information is 3.5 kB. The TRACR also stores monitoring information such as singles rates, livetime and temperatures, which are passed to the mainboard on request.

This year the waveforms are passed through with no additional processing. In the future, the
CPU cores of the Virtex2Pro may be utilized for filtering and compressing data.

2.3. Mainboard

The trigger signal to the mainboard is digitized in 3 ns bins by the onboard Analog Transient Waveform Digitizer (ATWD). Since the timestamp resolution is only 25 ns, the digitized trigger signal provides finer timing offline.

The mainboard includes a FORTH bootloader environment called Iceboot. Scripted commands in the Iceboot environment will be used to transfer the event and monitoring data to the surface. Iceboot also supports lossless compression of the event. The mainboard sends the digitized trigger signal with the event.

On the surface, the data from all DRMs will be routed to one computer will implement a majority trigger based on the number of DRMs hit within a time window.

3. Conclusion

The DRM takes advantage of tested IceCube, ANITA and RICE technologies to improve on the performance of the RICE receiver/trigger system. The anticipated co-deployment with IceCube in 2006/7 gives us an opportunity to test the new modules with no additional drilling cost, in preparation for an eventual larger in-ice radio array.

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