A Digital Optical Module (DOM) Simulation for IceCube

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The IceCube experiment [1] will provide a cubic kilometer of instrumented ice volume at the South Pole for the detection and study of high energy astrophysical neutrinos. This instrumentation will be accomplished by deployment of 80 kilometer-length strings, each containing 60 digital optical modules (DOMs). Each DOM contains a photomultiplier tube (PMT) that detects the Cherenkov light generated in the ice by muons and electrons produced by neutrino interactions. Also included are main board electronics that process and capture the signal. Physics studies require realistic simulation; to this end a simulation of the DOM main board has been developed.

The DOM main board electronics apply a threshold trigger to the PMT analog signals and digitize the ones above threshold. Fast waveform sampling and capture (128 samples at 300 MHz) is provided by two analog transient waveform digitizers (ATWDs). Longer duration signals (up to 6.4 μs) are sampled at 40 MHz by a fast analog-to-digital converter (FADC). Each ATWD consists of three channels of differing gain providing a dynamic range over signals produced by 1 to $\sim$ 500 single photoelectrons (SPEs).

Additional features of the DOM main board that are simulated in a straight-forward fashion are the 70 ns delay line before the ATWDs, "ping-ponging" between the two ATWDs to minimize deadtime, and local coincidence bits that account for nearest-neighor DOM coincidences in an adjustable time window. The section of the DOM main board simulated is shown in the block diagram of Fig. 1.

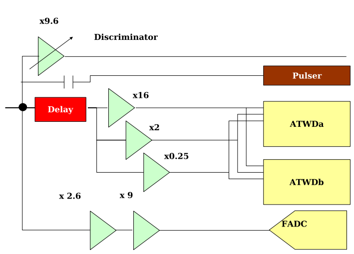

FIG. 1: Section of the DOM main board simulated.

Accurate modelling of the analog response of the DOM main board is achieved by analysis of data collected in the so-called Simple Test Framework (STF) by the IceCube group at LBNL. Various tests are conducted on the main boards to ensure proper functionality within specified standards. A particularly useful class of tests for determination of the analog response function of the DOM main board are the ATWD and FADC pulser tests. Pulses of known amplitudes and widths are injected at the point in the electronics where the PMT signal would be. Average waveforms are accumulated in the ATWD and FADC and the test passes if the measured pulse amplitudes and widths are within a certain range of deviation from the expected values.

The temperatures at which the STF tests were conducted were also measured and recorded with the most data available for -50° and 25° C. Differences between the measured and expected pulse amplitudes and widths at each temperature indicates a small temperature dependence in the ATWD response, *i.e.* for the lower temperature the measured pulse amplitude is closer to the expected amplitude. This behavior is not found in the FADC waveforms. The width of the pulse is independent of temperature and amplitude for both the ATWDs and FADC.

A log-normal function parameterizes the waveforms for both the ATWDs and FADCs quite well. In the simulation the narrow Gaussian PMT signal is convolved with the log-normal parameterization for each ATWD channel and for the FADC. Additional STF measurements of noise in the baseline have provided a simple Gaussian parameterization of the bin-to-bin noise that is easily implemented in the simulation.

A typical real SPE waveform generated by an LED flasher in a real DOM (with PMT) seen in the upper plot in Figure 2 can be compared with a typical simulated ATWD waveform seen in the lower plot. These waveforms indicate the overall agreement between the simulated and real waveform shapes as well as between the overall noise level in the baselines.

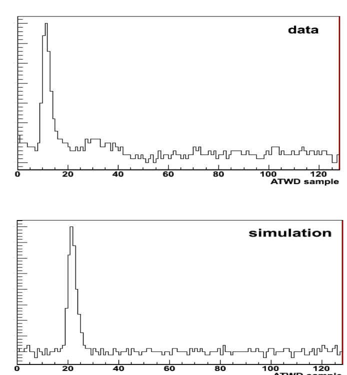

FIG. 2: Comparison of typical actual and simulated SPE waveforms.

[1] IceCube Preliminary Design Document, the IceCube Collaboration. `http://icecube.wisc.edu`