

Final Technical Report for Grant DE-FG02-06ER41429  
Advanced Detector Research Program  
“Development of a low-power, low-cost,  
front end electronics module for  
large scale distributed neutrino detectors”

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A number of concepts have been presented for distributed neutrino detectors formed of large numbers of autonomous detectors. Examples include the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA) [Barwick 2006], as well as proposed radio extensions to the IceCube detector at South Pole Station such as AURA and IceRay. [Besson 2008]. We have focused on key enabling technical developments required by this class of experiments.

The radio Cherenkov signal, generated by the Askaryan mechanism [Askaryan 1962, 1965], is impulsive and coherent up to above 1 GHz. In the frequency domain, the impulsive character of the emission results in simultaneous increase of the power detected in multiple frequency bands. This multiband triggering approach has proven fruitful, especially as anthropogenic interference often results from narrowband communications signals.

A typical distributed experiment of this type consists of a station responsible for the readout of a cluster of antennas either near the surface of the ice or deployed in boreholes. Each antenna is instrumented with a broadband low-noise amplifier, followed by an array of filters to facilitate multi-band coincidence trigger schemes at the antenna level. The power in each band is detected at the output of each band filter, using either square-law diode detectors or log-power detectors developed for the cellular telephone market. The use of multiple antennas per station allows a local coincidence among antennas to be used as the next stage of the trigger. Station triggers can then be combined into an array trigger by comparing timestamps of triggers among stations and identifying space-time clusters of station triggers. Data from each station is buffered and can be requested from the individual stations when a multi-station coincidence occurs. This approach has been successfully used in distributed experiments such as the Pierre Auger Observatory. [Abraham et al. 2004]

We identified the filters as being especially critical. The frequency range of interest,  $\sim 200$  MHz to  $\sim 1.2$  GHz, is a transitional region where the lumped circuit element approach taken at low frequencies begins to reach limitations due to component tolerances, component losses, and parasitic effects. Active circuits can help to mitigate against these effects at the cost of added power consumption that becomes prohibitive for distributed experiments across the band of interest. At higher frequency microstrip, stripline, and other microwave techniques come to the fore.

We have developed designs and design tools for passive filters extending the high frequency techniques to the frequency range of interest. Microstrip and stripline techniques are not usually attractive here because of the large physical dimensions of the resulting circuits, but in this application the tradeoff of size against power consumption favors this choice. These techniques are also intrinsically low-cost, as the filter is built into the circuit boards and the cost of components and their assembly onto the board is avoided.

The basic element of the filter tree is an impedance matched wideband diplexer. This consists of a pair of low pass and high pass filters with a shared cutoff frequency and complementary frequency responses. These are designing the lowpass filter as a high order  $LC$  filter, which can be implemented as a series of transmission line segments of varying width. This can be transformed in to a  $CL$  high pass filter with a complementary frequency response. When the two filters are coupled to a common input, the input impedances of the networks add in parallel to give a constant input impedance as a function of frequency, with power flowing into one leg or the other of the filter pair. These filters can be cascaded to divide the band into the frequency ranges of interest; the broadband impedance matching at the inputs makes coupling of successive stages straightforward. These circuits can be produced in quantity at low cost using standard PCB fabrication techniques. We have determined that to achieve best performance the circuits should be built on a low loss-tangent RF substrate. We are working in cooperation with our colleagues in condensed matter who also have a need for this capability to purchase the equipment for in-house fabrication of prototype quantities of these circuits. We plan to continue the work on these filters using internal funds, and produce and characterize the performance of prototypes.

We also participated in deployment of a prototype detector station near McMurdo Station, Antarctica in collaboration with colleagues at UCLA and UC-Irvine. The prototype station includes a single-board computer, GPS receiver, ADC board, and Iridium satellite modem powered by an omnidirectional solar array. We operated this station in the austral summer of 2006-2007, and used the Iridium SMS mode to transmit the status of the station until the end of the daylight season. This served to demonstrate the operation of an autonomous station and provide data on the operation of a realistic solar power



The prototype station (aluminum enclosure) and its battery box (white case) being deployed on the Ross Ice Shelf.

system in the environment faced by proposed experiments in the Ross Ice Shelf region.

We have also obtained a high voltage pulser to be used for *in situ* characterization and calibration of the antenna-front end-trigger subsystem. The calibration system consists of an in-ice borehole antenna coupled to the fast high-voltage pulser. This pulse can be viewed using a prototype receiving antenna and associated front-end electronics for either surface or borehole deployments.



The omnidirectional solar array of the prototype station on the Ross Ice Shelf, Antarctica

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