An Electronically Steered Phased-Array for the Radio Detection of High-Energy Neutrinos

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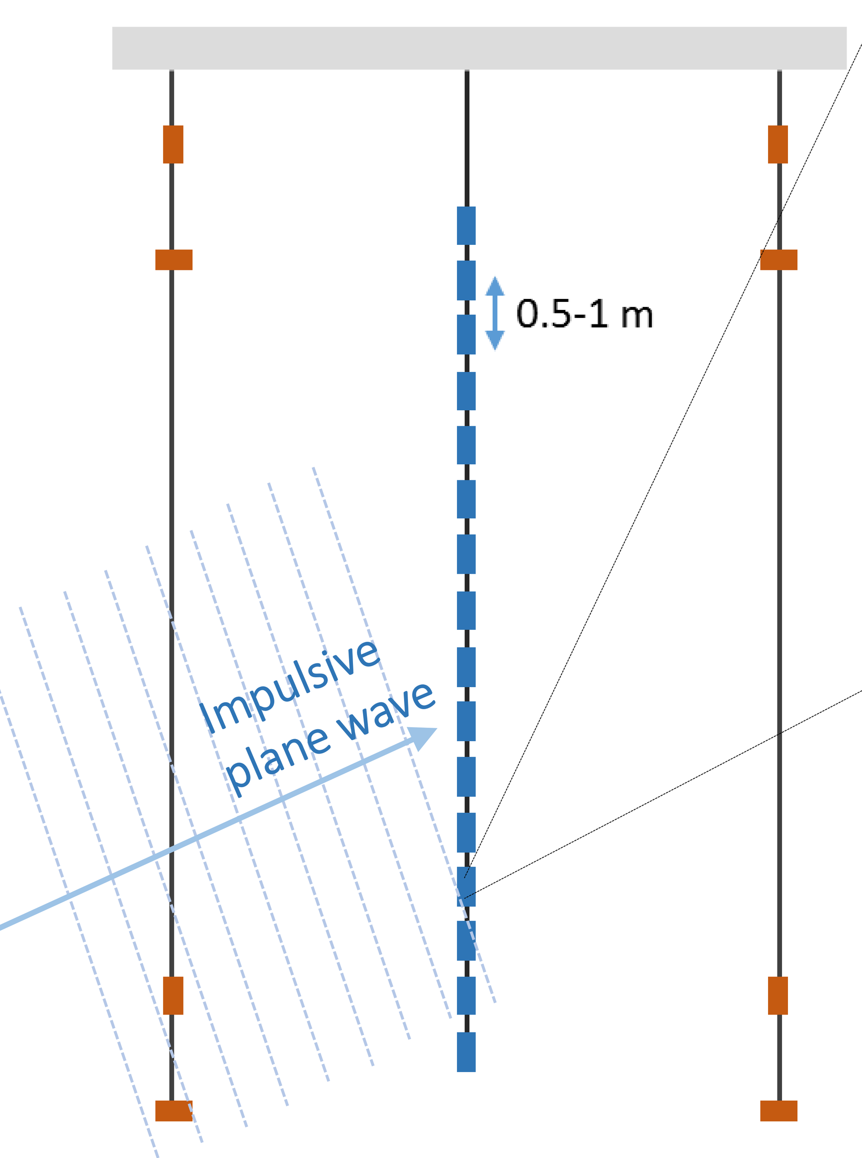
Abstract

Radio detector arrays such as RICE, ANITA, ARA, and ARIANNA target the discovery of cosmogenic neutrinos. These radio arrays exploit the Askaryan effect and the radio transparency of glacial ice, which together enables the economical instrumentation of necessarily large volumes of ice. We describe here the electronics design of a digitally-phased radio array that would both lower the energy threshold of existing radio detectors and provide a more efficient coverage of the instrumented volume of ice. A real-time trigger board digitizes 8 antennas each at 7-bit resolution and at a Nyquist sampling rate of 1.5 GHz. The digital correlation between antennas in the array is performed in an on-board field-programmable gate array (FPGA), which includes several gigabit serial-links to daisy chain trigger boards in order to phase larger arrays. The first implementation of this radio phased-array will be as a dynamic vertically-polarized trigger for a single station of the ARA detector located at the South Pole. We will characterize the electronics in-situ and use the 16-antenna phased array as an impulsive triggering device in this initial installation planned for 2017.

A Phased-Array for Broadband Transient Signals

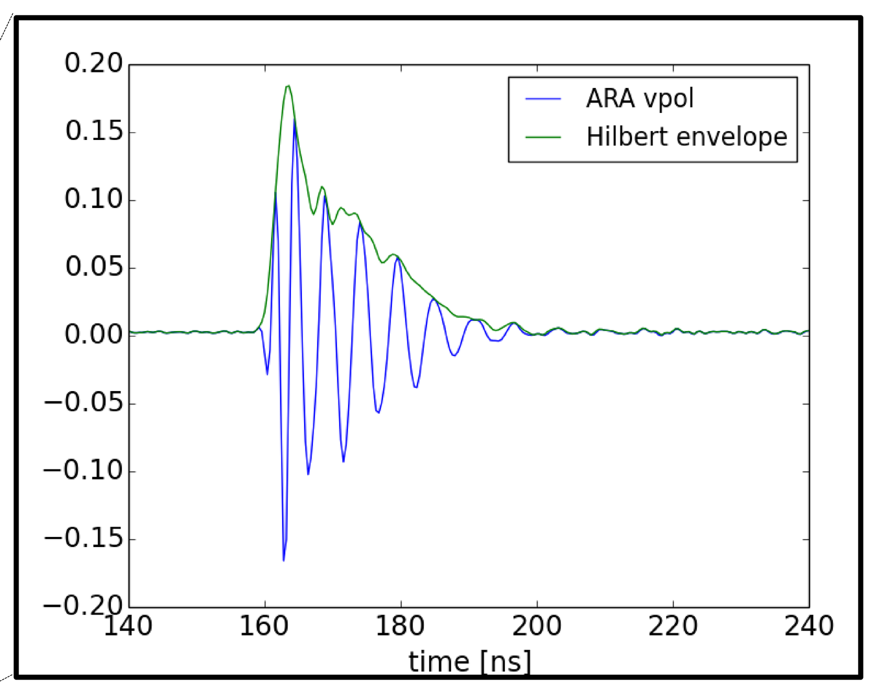
Searching for ~GHz bandwidth impulsive signals from Askaryan radiation induced by ultra high-energy neutrino interactions in the Antarctic ice



ARA station side-view (not to scale)

= Standard ARA pointing array (both pols)

= Phased array trigger (Vpol)



An effectively high-gain array of dipole antennas will be used as a directional trigger system. The noise is ideally uncorrelated between antennas as to boost the SNR by $\sqrt{N_{antenna}}$

Reduce the energy threshold for the radio detection technique of high energy neutrinos [1].

Implementation

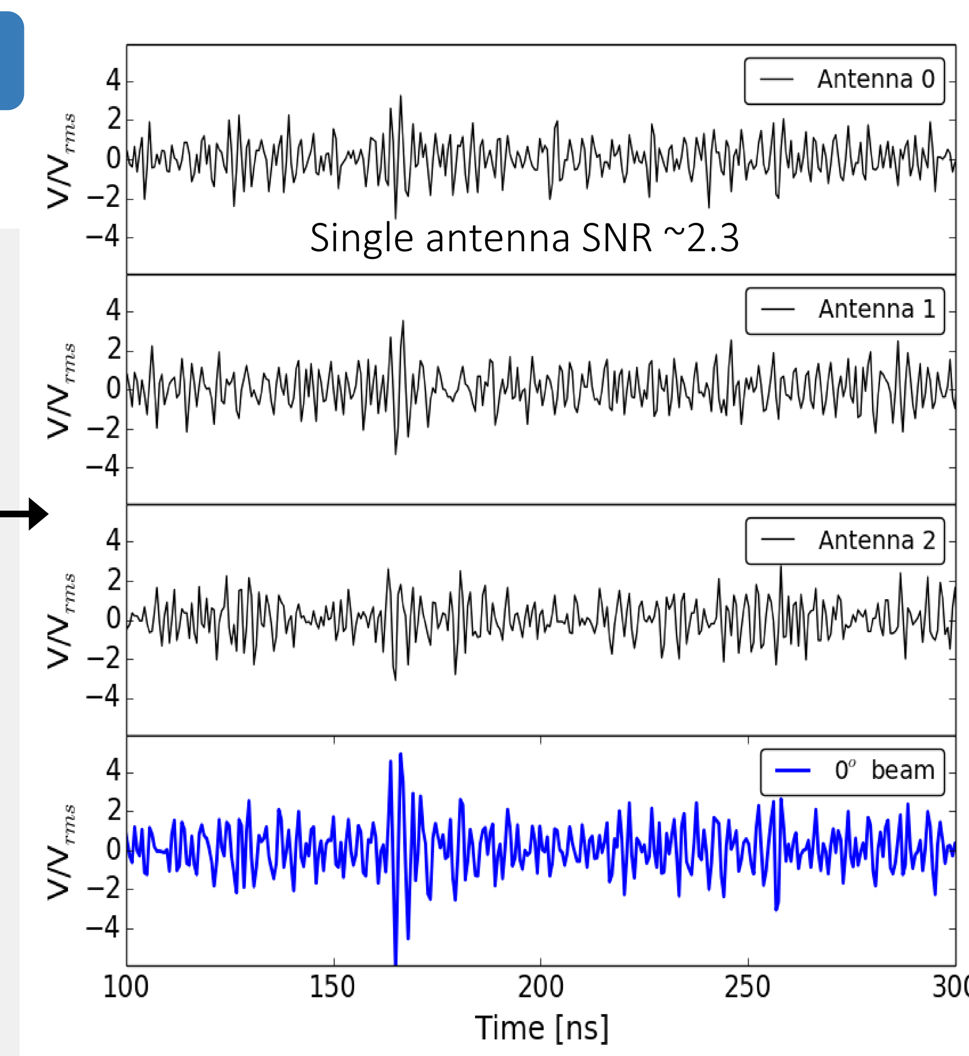
Waveforms from a 3-antenna array that was pulsed in an anechoic chamber are shown →

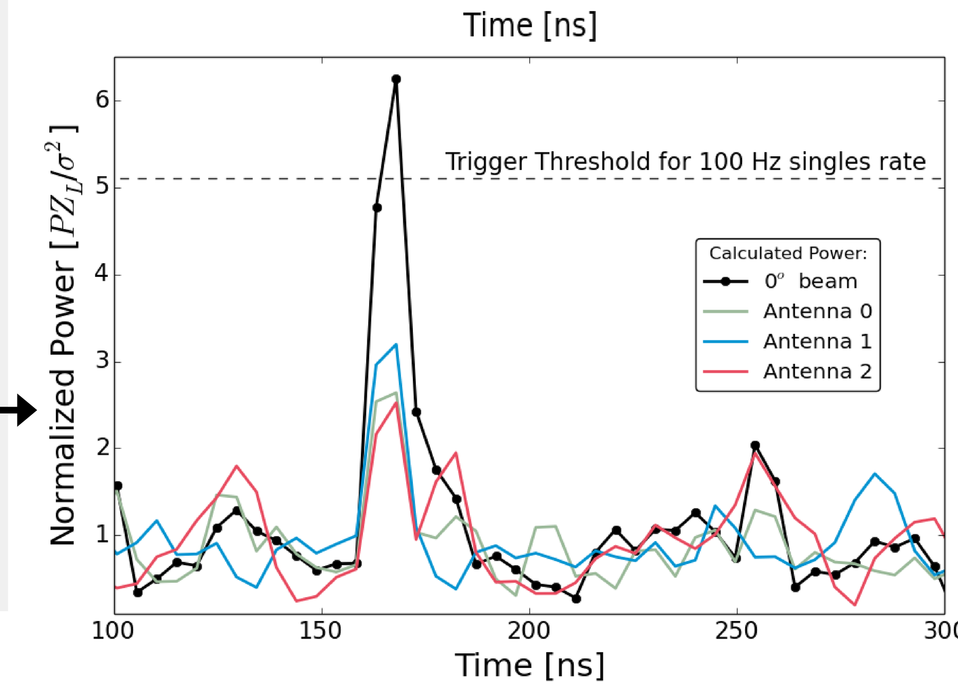
Interferometry is performed using coherent delay-and-sum beamforming:

$$\sin\theta_n = \frac{c\,n\,\Delta t}{d}$$

n = integer number of samples delayed for the beam centered at θ_n, d = antenna spacing, Δt is the sampling interval.

In each beam, the power is computed in 10.5 ns overlapping windows. →



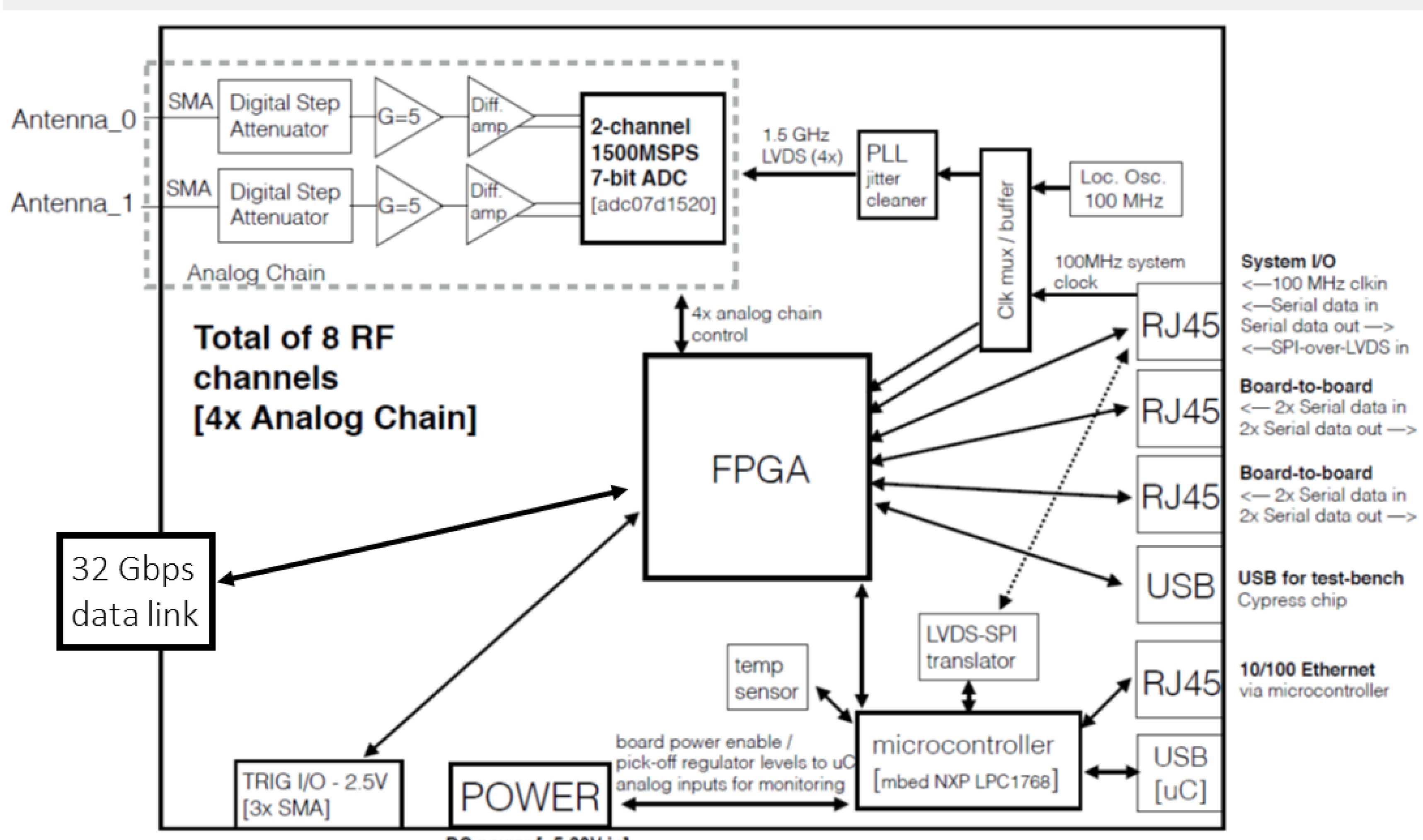


Planned 2017 deployment: Co-located **trigger** and **pointing** arrays with the Askaryan Radio Array (ARA) experiment [2]. The trigger array is the phased-array described here: a linear string of 16 Vpol antennas that are digitally correlated in surface electronics described below. The pointing array is the baseline ARA station design.

Hardware Design

Custom Trigger board: Dead-timeless digitization with beam-forming and triggering algorithms on the FPGA. Board is currently in fabrication.

- 1.5 Gigasample-per-second ADCs with 7-bit resolution
- High performance Altera Arria V FPGA for real-time computations
- 32 Gbps serial data link (copper or optical links): Allows real-time transfer of 3-bit data (out of 7-bits logged) to phase larger arrays of antennas
- On-board microcontroller with 10/100M Ethernet, USB, and boot-loader



References

[1] Vieregg, Bechtol, Romero-Wolf; JCAP 2 (2016)

[2] ARA Collaboration: Astroparticle Physics 35 (2012) 457; Phys Rev D 93 (2016), 082003.

[3] IceCube Collaboration: Astrophys. J. 809 (2015)

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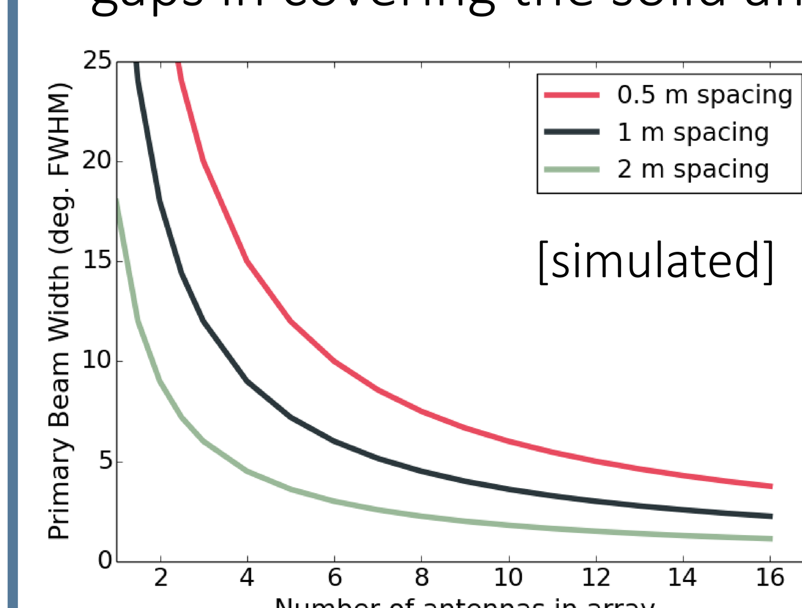
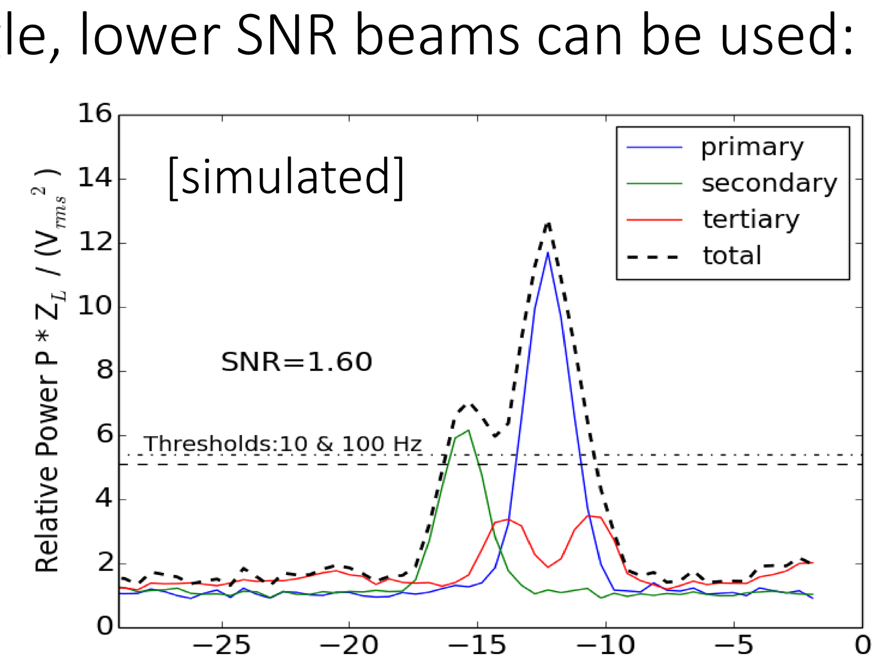
Efficiency and Coverage

The effective width of the primary beam (highest SNR beam) becomes narrower (more directional) as the number of antennas increases. The beam-centers of the primary beams are fixed by the antenna spacing and sampling rate. To avoid gaps in covering the solid angle, lower SNR beams can be used:





Alternatively, the data can be up-sampled in the firmware given enough FPGA resources and time. The trigger decision needs to be made within ~100 ns in order to freeze the analog buffers on the pointing array. If feasible, this improves the trigger efficiency of the array to a 50% point at a SNR of ~1.0: