Hardware Development for the Radio Neutrino Observatory in Greenland

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Introduction

The Radio Neutrino Observatory in Greenland (RNO-G) is a radio-based neutrino detector to be deployed to Greenland's Summit Station [1][2]. Using antennas deployed down boreholes in the ice coupled with surface antennas, the detector is designed to make the first observations of ultra-high energy neutrinos at energies above 100 PeV via the detection of Askaryan radiation and serve as a technology pathfinder for IceCube-Gen2.

Station Design & Layout

RNO-G will be deployed at Summit Station on 3 km of ice. 35 stations will be on a grid 1 km apart (Fig. 1). Each station is to operate autonomously, with a central data acquisition (DAQ) system serving three strings deployed down 5.75" diameter boreholes and surface antennas (Fig 3). The main down-hole string has 4 vertically–polarized (VPol) antennas for interferometric triggering. The remaining strings and antennas are used for reconstruction and calibration purposes. The surface detector is composed of LPDAs antennas, as used in ARIANNA[3].

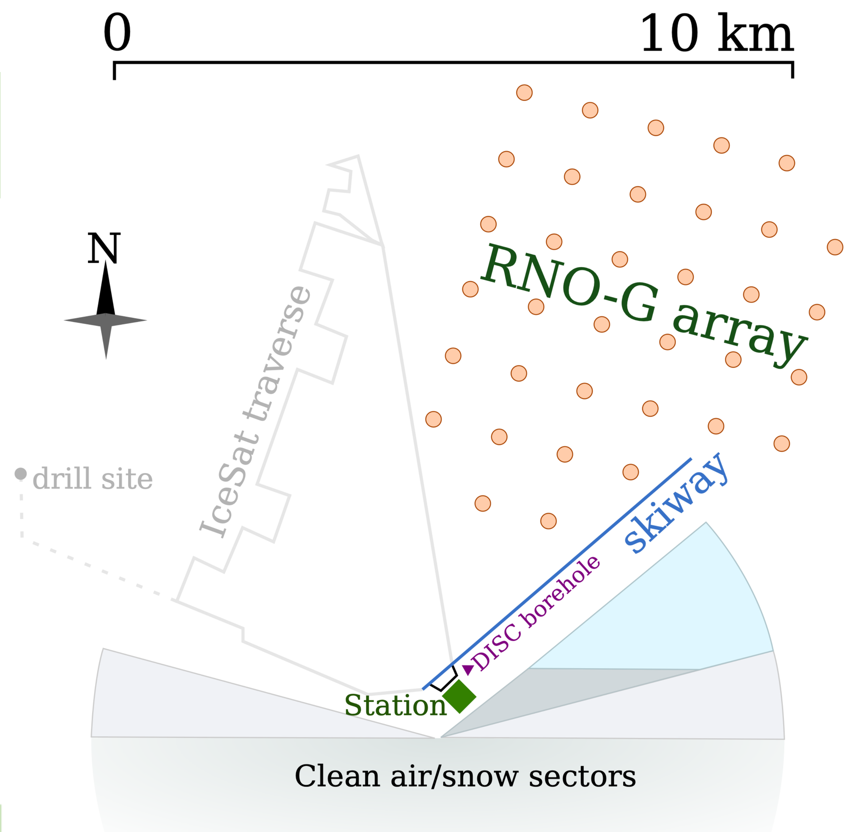

Fig. 1: Deployment map at Summit Station including obstacles and station infrastructure

RF Chain

The radio-frequency (RF) chain is composed of an custom developed front-end amplifier and Radio-Frequency-over-Fiber (RFoF) transmitter co-located with each antenna, a surface RFoF receiver and amplification board, and a digitizer. The chain is optimized for noise figure, ~1.6 FdB, and power, ~140 mW per channel.

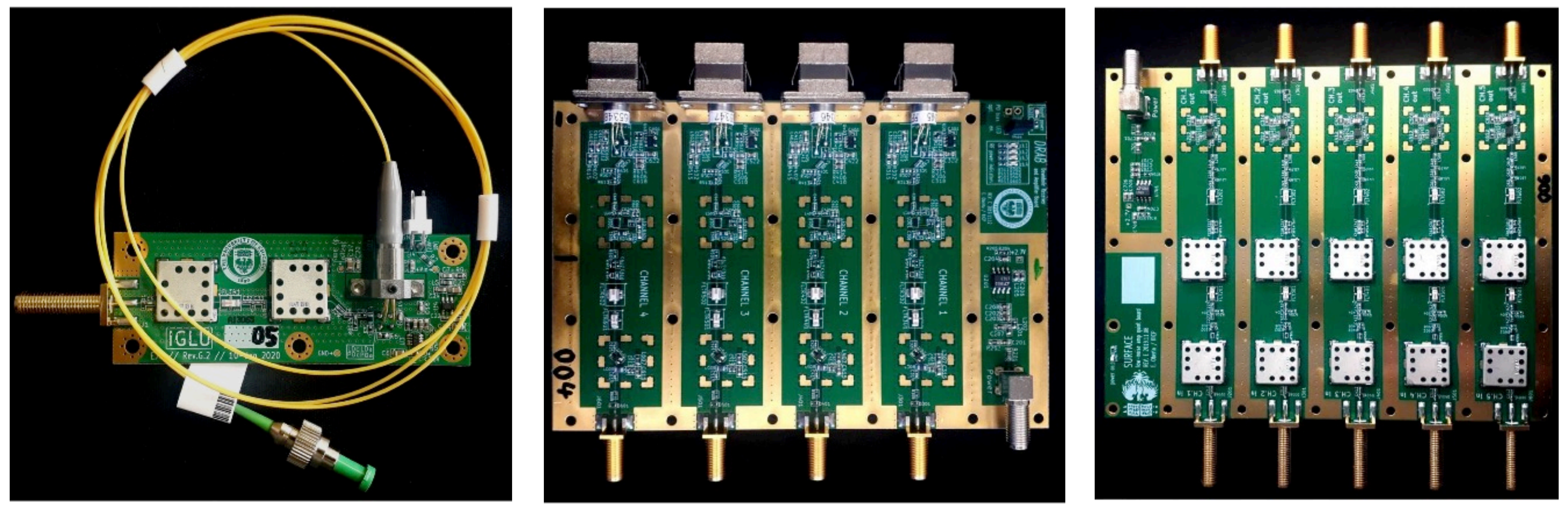

Fig. 2: Left: The front-end amplifier and RFoF transmitter. Center: The down-hole RFoF receiver and amplifier Right: Surface amplifiers.

Trigger

Triggering takes three forms: combinatoric triggering from the surface detector, low power combinatoric trigger from all down-hole antenna, and an interferometric trigger. The interferometric trigger will use 4 VPol antennas: signals are band-passed from 250-500 MHz before being injected into an FPGA for beam forming. Such a trigger will be used during the Summer season and the low-power combinatoric trigger from all channels will be used in the shoulder seasons. Simulations have shown that the interferometric trigger achieves a single antenna voltage threshold of 2σ [4] .

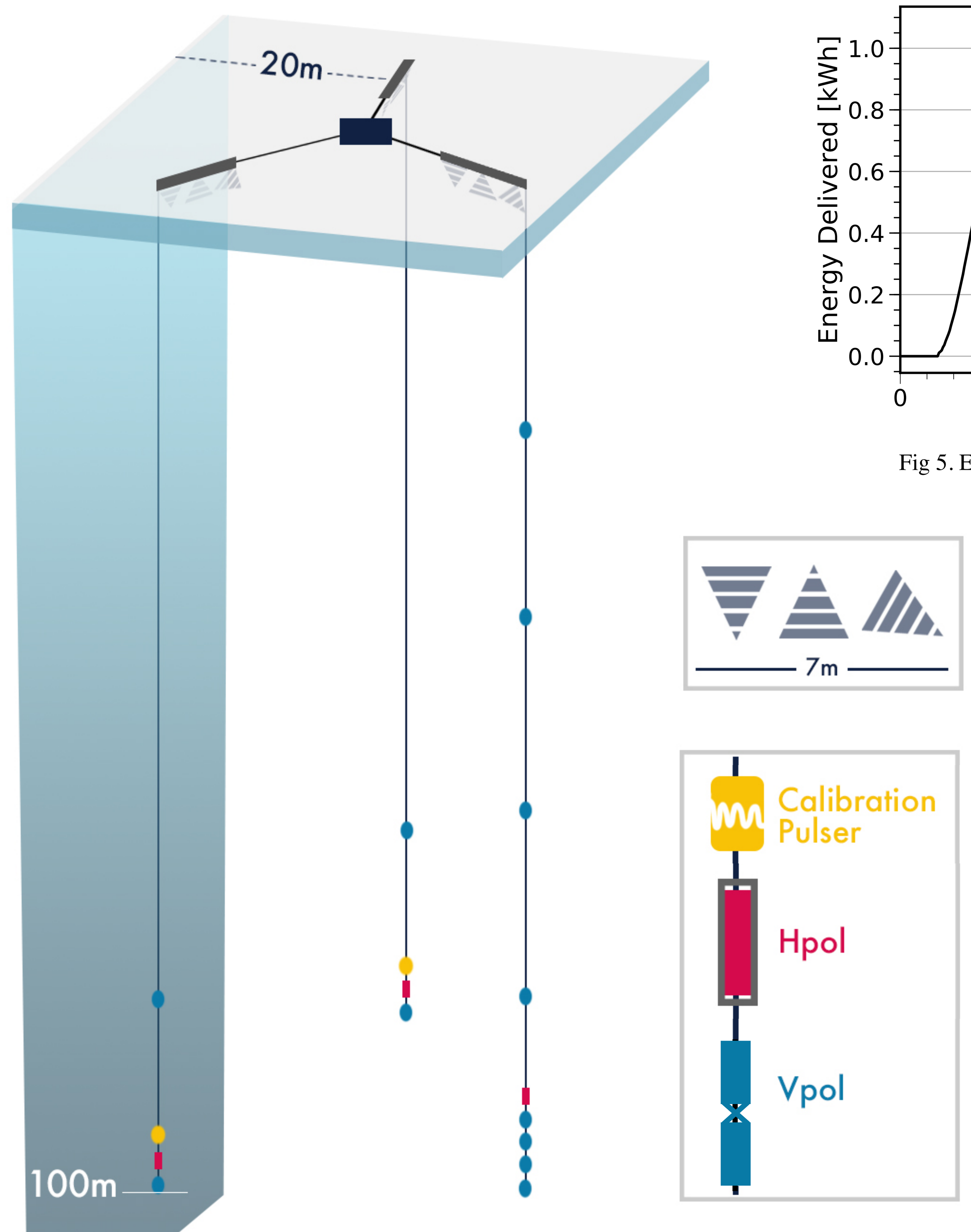

Fig. 3: Single station design, including deep & surface antennas and the DAQ box.

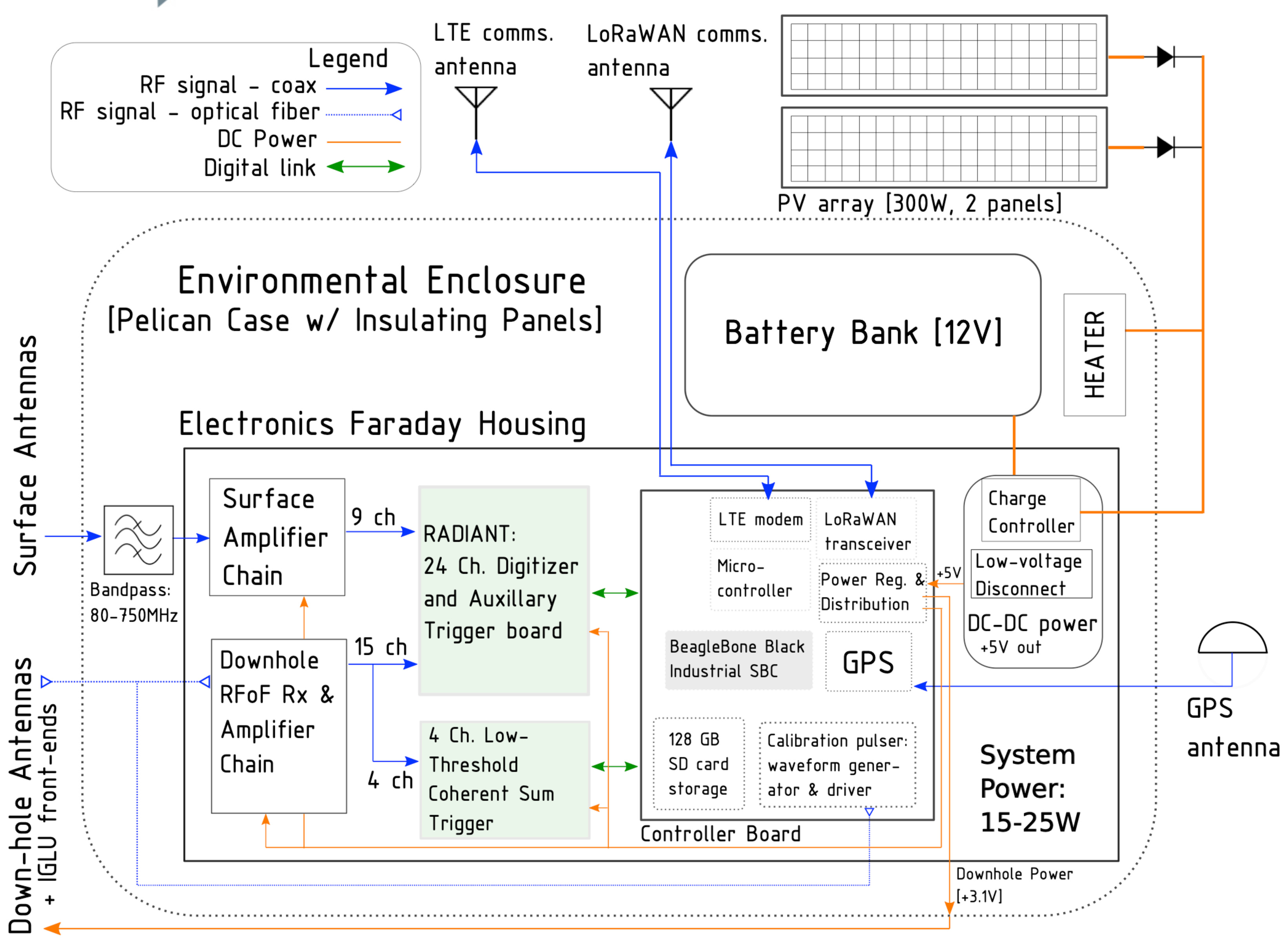

Fig. 4: Surface stations electronics diagram, including power, comms., calibration pulser, and DAQ.

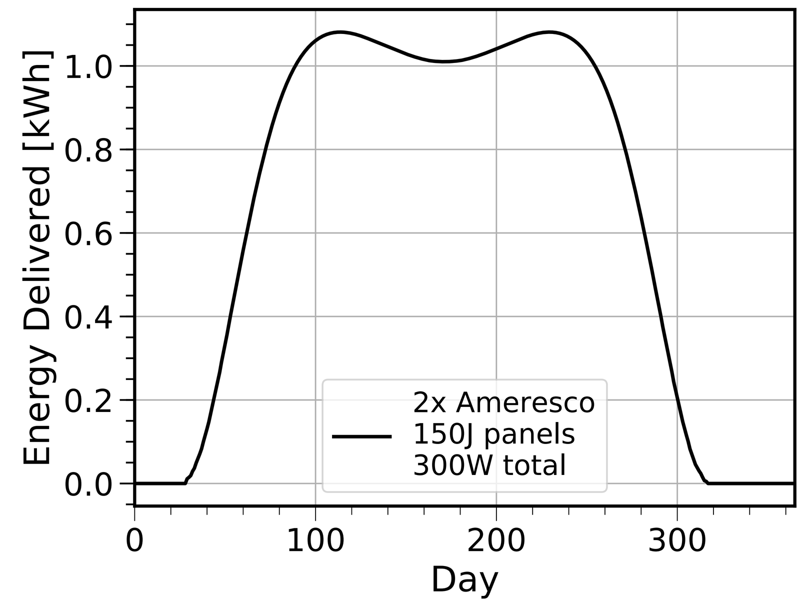

Fig 5. Expected delivered power from solar panels.

Power Systems

Each station will be powered by two 150 W solar panels with a battery bank system. Through power optimization, stations will have a ~70% up-time. Wind power will be used in future deployment to further increase detector up-time.

DAQ & Comms

The DAQ will be located in a weather-proof case at the surface. The case will contain the central controller board powered by a BeagleBone Black SBC, a 24-channel digitizer board using LAB4D switched-capacitor array sampling ASICs [5], and calibration pulsers. Data are saved on an SD card in the case, transmitted over LTE to a basestation at Summit Station camp and finally transmitted over VSAT. Slow control is performed via ultra-low power LoRaWAN, allowing for the station to operate in limited-power modes during the shoulder seasons. A station consumes 15-25 W.

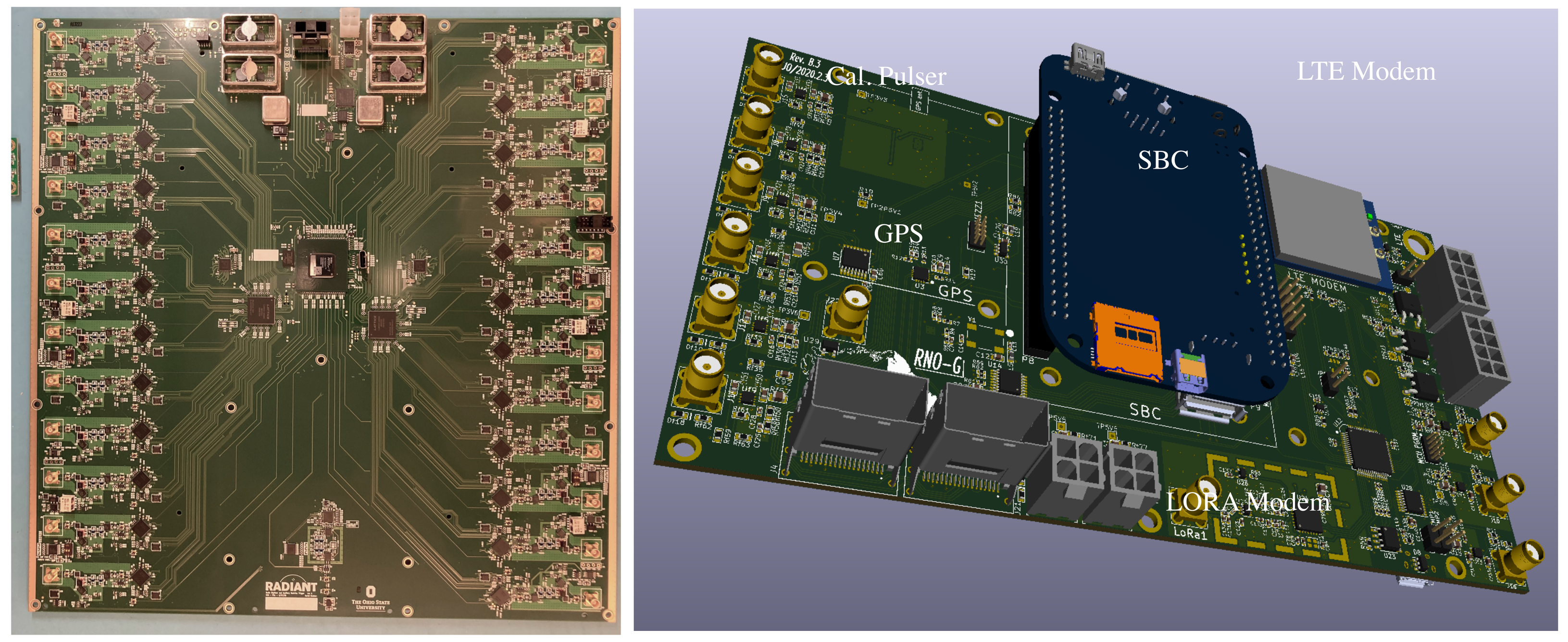

Fig. 6: Left: 24 channel RADIANT digitizer board. Right: Controller board with SBC in place.

Deep Antennas

Two types of deep antennas are deployed: VPol and HPol. The VPol is a fat-dipole with an in-ice bandwidth of 150-600 MHz. The HPol antenna is a tri-slot, ferrite-less cylindrical antenna, a design optimized for azimuthal symmetry, ease to model and ease to build. Simulations have shown the combination of these two types of antennas meets the science requirements of the experiment for polarization reconstruction.

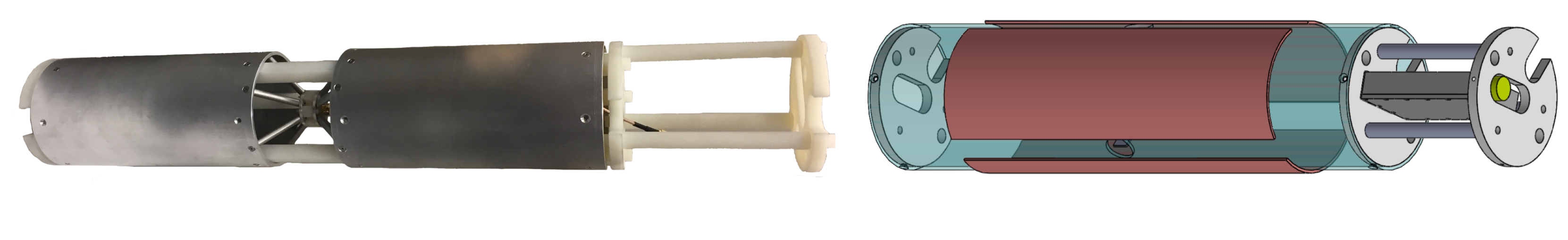

Fig. 7: Left: VPol antenna Right: HPol antenna.

Deployment & Future

First deployment in Summer 2021 will include base station infrastructure and at least 5 stations. The drill technology allows for a hole to be drilled per day, allowing for a three day schedule per station, making station deployment scalable. 12 and 18 stations will be deployed in Summer 2022 and 2023 respectively, along with station upgrades.

References:
[1] J. A. Aguilar et al., *The Next-Generation Radio Neutrino Observatory -- Multi-Messenger Neutrino Astrophysics at Extreme Energies*, Decadal Survey on Astronomy and Astrophysics (Astro2020)
[2] C. Deaconu et al., *RNO - The Radio Neutrino Observatory*, Lake Louise Winter Institute (2019)
[3] S.W. Barwick et al., *Time-domain response of the ARIANNA detector*, Astropart. Phys. (2014)
[4] P. Allison et. al. *Design and Performance of an Interferometric Trigger Array for Radio Detection of High Energy Neutrinos*, Nuclear Instruments and Methods A Vol 930 (2019)
[5] J. Robert et. at., *LAB4D: A Low Power, Multi-GSa/s, Transient Digitizer with Sampling Timebase Trimming Capabilities*, Nuclear Instruments and Methods in Physics Research A Vol 925 (2019)