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ANITA: First Flight Overview and Detector Performance

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Abstract: The ANtarctic Impulsive Transient Antenna (ANITA) searches for ultra high energy neutrinos interacting in the Antarctic ice cap. It is a long duration balloon experiment composed of an array of broadband dual-polarized horn antennas that had its first science flight over Antarctica in December 2006 through January 2007. ANITA relies upon the Askaryan effect, in which a particle shower in a dense medium emits coherent Cherenkov radiation at radio wavelengths, for the detection of a neutrino induced shower. ANITA is designed to detect — or constrain flux models of — ultra high energy neutrinos created by the interaction of ultra high energy cosmic rays with the cosmic microwave background. In this paper we discuss the detector performance during the first ANITA flight.

Introduction

The existence of Ultra High Energy Cosmic Rays (UHECR) has been well established by their detection over the past 40 years by a variety of experiments. Nonetheless, their origins and composition remain a mystery. UHECR protons are not magnetically confined and may travel extragalactically. Yet, for protons with energies exceeding $5\text{x}10^{19}$ eV, interactions with the cosmic microwave background via photopion production limit their propagation to a mean free path of ~ 10 Mpc. This attenuates the UHECR spectrum by the GZK effect [1, 2]. The decay of resultant charged pions produces a flux of ultra high energy GZK neutrinos, the study of which may provide clues to the UHECR sources and composition.

In addition to the GZK process, hadronic cosmic ray accelerators or more exotic sources can produce ultra high energy (UHE) neutrinos. Unlike photons and charged particles, neutrinos may travel unimpeded and undeflected from their source to provide valuable information about the UHE universe.

At lower energies, neutrinos are detected via optical Cherenkov signals of their interaction products. Such a technique is not practical for the detection of UHE neutrinos due to the large instrumented volumes needed to detect their lower flux. Instead, we employ the Askaryan effect [3], where a particle shower in a dense medium creates a coherent Cherenkov pulse at radio frequencies. The Askaryan effect has been verified experimentally for different media including sand, rock salt and ice [4, 5, 6], and allows a large detector volume to be observed with limited numbers of antennas in these radio transparent media.

Instrument Description

The ANITA instrument is a long duration balloon (LDB) payload designed to detect RF pulses created by neutrino induced particle showers in the Antarctic ice cap. A diagram of the core RF subsystem, which consists of the receiving antennas, a front-end of filters and low-noise amplifiers, and triggering and digitizing electronics, is shown in Figure 1.

There are 32 dual-polarized quad-ridged horn antennas cylindrically arranged in two upper tiers of 8 antennas each, separated by ~ 3 m from a lower tier of 16 antennas. The antennas are placed such that two antennas, one from the bottom tier and one from a top tier, share the same azimuthal direction while adjacent antennas have overlapping beams. The separation between the tiers provides the timing baseline necessary for reconstructing the incident angle of the arriving pulse. The instrument operates over a range of $0.2 - 1.2$ GHz, and over these frequencies the antennas have a directivity gain of $9 - 11$ dBi which corresponds to a full-width-half-maximum beamwidth of $\sim 45°$. There are 8 additional vertically polarized antennas placed between the second and third tiers which provide broadband monitoring and are not involved in triggering.

The RF signal is processed through high- and low-pass filters and amplified ~ 75 dB to travel to the main electronics box where triggers are formed and the signal is digitized. After a second set of filters, the signal is split, with half going to the digitizer, and the other half to the trigger. The signal at the digitizer is continuously sampled at a rate of 2.6 GHz, but is only digitized upon triggering when sampling is halted and the samples held for readout.

Along the trigger path, the signal first passes through a $90°$ hybrid combiner which turns the linear horizontal and vertical polarization signals into left- and right-circularly polarized (LCP and RCP) signals. The signals are then split into four frequency bands centered about 270, 435, 650 and 990 MHz with an average fractional bandwidth ($\Delta\nu/\nu$) of 44%. The split, hybrid signal provides an advantage to triggering on the broadband, linearly polarized Askaryan pulse, which will have equal power in LCP and RCP and in multiple bands, unlike most thermal and some anthropogenic noise.

Triggering occurs in three levels: the first in a single antenna (L1), the second amongst 2 adjacent antennas (L2), and the third between upper and lower tier antenna clusters about the same azimuth (L3). For an L1 trigger, 3 of the 8 channels per antenna must be over threshold within 12 ns. Individual channel thresholds adjust to maintain a constant trigger rate in the presence of thermal noise. An L2 trigger requires that two L1 events occur in adjacent antennas within 20ns, and an L3 trigger requires L2 triggers in the upper and lower tiers within 30 ns. The thresholds are set to correspond to a trigger rate of $4 - 5$ Hz on thermal noise. ANITA has a trigger efficiency of $\sim 50\%$ at $5.4\sigma_V$ and is fully efficient near $7\sigma_V$, where σ_V is the Gaussian standard deviation above the thermal noise root-mean square voltage.

ANITA also has subsystems for providing timing and orientation. A Thales ADU5 differential GPS system provides not only timing and location, but also instrument attitude. Four sunsensors, two accelerometers and a magnetometer offer an independent orientation measurement.

Flight Overview

ANITA launched on Dec 15, 2006 from Williams Field, Antarctica and flew for 35 days before terminating on January 19, 2007. The instrument came to ground 360 km away from the South Pole at 84.58° S, 22.28° W and was subsequently re-

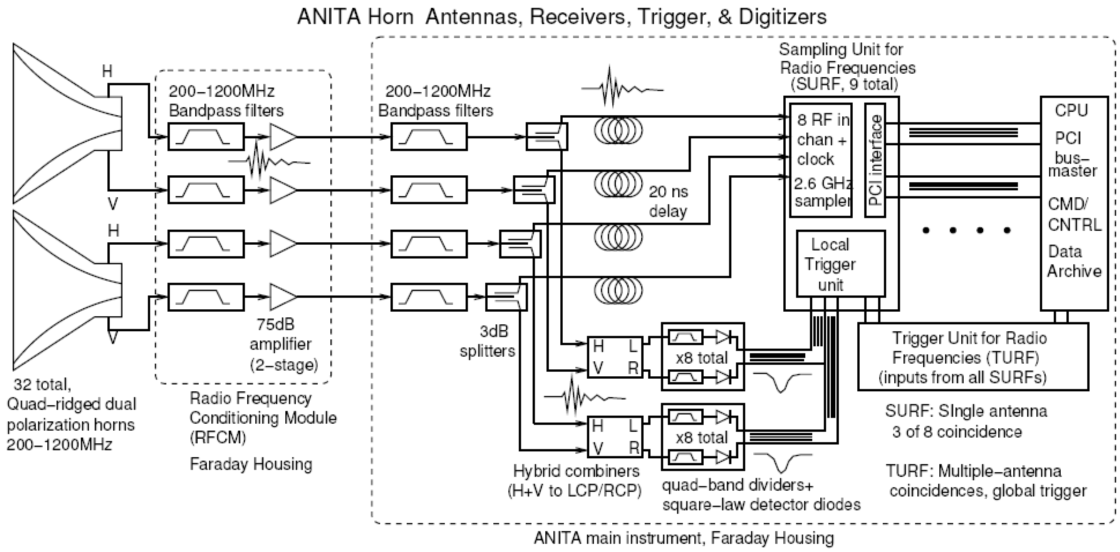

Figure 1: The primary ANITA RF subsystems.

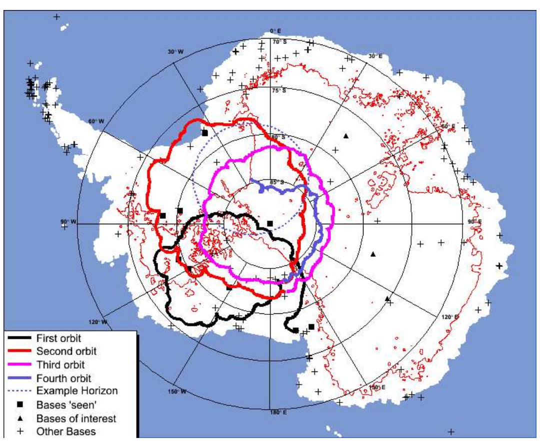

Figure 2: The ANITA '06-'07 flightpath, beginning at McMurdo traveling counter-clockwise for 3.5 orbits and terminating 360 km from the South Pole. The path data is taken from the Columbia Scientific Balloon Facility's Support Instrument Package GPS data. An example horizon of 600 km at float is indicated in dotted lines and the thin (red) contour line indicates where the ice is 2 km deep.

covered in full. The flightpath, shown in Figure 2, is an anomaly in the LDB program because of the off-pole centering of the south polar vortex, the annual wind pattern that allows balloons to orbit the continent. Although ANITA did not fly over east Antarctica where much of the deep, cold ice of Antarctica resides, Figure 3 shows that ANITA passed over ice of average depth greater than 1 km; the average ice depth within ANITA's horizon was $\sim$ 1.2 km. At float, ANITA was $\sim$ 36 km aloft, with an average distance to the horizon of 680 km, thus instrumenting $\sim$ 1.5x10^6 km^3 of ice for radio attenuation lengths on the order of 1 km [7]. The path and large horizon distance caused ANITA to spend substantial amounts of time in view of bases with high RF noise, including McMurdo, Admundsen-Scott South Pole Station, and the West Antarctic Ice Sheet (WAIS).

Instrument calibration was performed during the flight using ground and payload based transmitting antennas. Upon launch and during the first return to McMurdo, pulses were sent from surface horn antennas identical to those in flight, and from dipole antennas lowered into boreholes at both Williams Field in McMurdo and a field camp at Taylor Dome. Analysis of these pulses shows that ANITA has a pointing resolution in elevation and azimuth of $(\Delta\theta, \Delta\phi) = (0.4^\circ, 1.7^\circ)$. Throughout

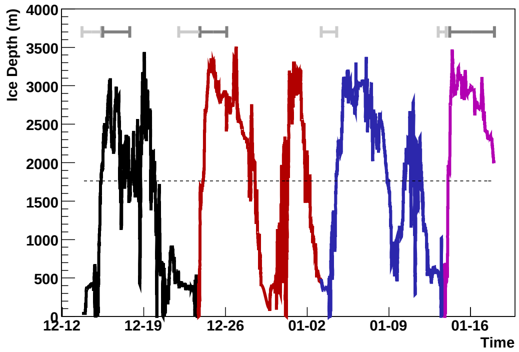

Figure 3: Ice Depth vs. Time for the 4 ANITA orbits; the average ice depth of 1761 m is shown as a dotted line. The depth data is taken from the BEDMAP project[8]. The pale and darker grey lines above the depth plot indicate the times for which McMurdo and the Amundsen-Scott Station were respectively within 680 km of ANITA. After 01/05 ANITA operated with a reduced duty cycle.

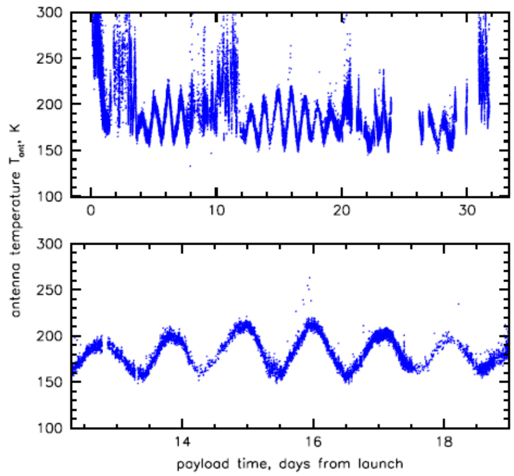

Figure 4: Top: Average measured power over the full ANITA bandwidth vs. days in flight. Bottom: Zoom-in on a quiet portion of the flight. The modulation is due to the diurnal change to the solar angle.

the flight, the four deck-mounted bi-cone antennas pulsed periodically, allowing a system check through the entire flight.

The ANITA instrument, particularly the RF system, performed well during the first three weeks of the flight. When not within view of an inhabited base, the effective antenna temperature was $T_{ant} \sim 180$ K, which corresponds well with the beam average of the ice, $T \sim 240$ K, and the sky, $T \sim 10 - 20$ K (see Figure 4). In the latter part of the flight, ANITA operated with a reduced duty cycle due to an intermittent fault.

Outlook

ANITA stands to report important results regarding the flux of UHE neutrinos when data calibration and analysis are complete. Planned future flights that will presumably not suffer the same flightpath or reduced livetime of this initial flights will also increase ANITA's sensitivity.

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