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SiPM-based azimuthal position sensor in ANITA-IV Hi-Cal Antarctic balloon experiment

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Abstract. Hi-Cal (High-Altitude Calibration) is a balloon-borne experiment that will be launched in December, 2016 in Antarctica following ANITA-IV (Antarctic Impulsive Transient Antenna) and will generate a broad-band pulse over the frequency range expected from radiation induced by a cosmic ray shower. Here, we describe a device based on an array of silicon photomultipliers (SiPMs) for determination of the azimuthal position of Hi-Cal. The angular resolution of the device is about 3 degrees. Since at the float altitude of ~38 km the pressure will be ~0.5 mbar and temperature ~ – 20 °C, the equipment has been tested in a chamber over a range of corresponding pressures (0.5 ÷ 1000) mbar and temperatures (–40 ÷ +50) °C.

1. Introduction

The ANITA (Antarctic Impulsive Transient Antenna) project is a scientific balloon experiment dedicated to the measurement of ultra-high energy neutrinos and cosmic rays by detection of radio-frequency signals resulting from interactions with molecules in the Earth's atmosphere and surface ice [1, 2].

Since the radio-frequency signals can be detected both directly and as ice reflections, these measurements provide information about the roughness and reflectivity of the Antarctic surface. The ANITA-II [2] and ANITA-III experiments have determined the surface reflectivity at elevation angles of 12-30 degrees by using the Sun as the radiation source, while lower incidence angles have been studied with the external radiation source Hi-Cal-1 (High-Altitude Calibration). It tracked ANITA for a small fraction of the ANITA-III flight at a distance of 650-750 km providing a direct and ice-reflected signal, which allowed direct determination of the Antarctic surface reflectivity in the radio-frequency mode.

The received ANITA-III signal depends on the relative orientation of the HiCal dipole transmitter relative to the ANITA gondola. For the upcoming ANITA-IV experiment this azimuthal orientation will be determined using the SiPM-based azimuthal position sensor "ATSA".

2. Hi-Cal-2 design

The Hi-Cal payload is shown in figure 1. The payload is attached to a small balloon and consists of an ABS (Acrylonitrile-Butadiene-Styrene) pressure vessel containing two motor-powered piezo sparkers which produce radio signals in the bi-cone dipole antenna. The operation is controlled by the NASA-standard MIP (Micro-Instrumentation Package) electronics, which manage communications and telemetry, and provide GPS time and position information.

Figure 1. Hi-Cal payload.

3. ATSA board

Since the Hi-Cal payload is constantly rotating, it is desirable to know its azimuthal orientation in relation to ANITA-IV. For this purpose the ATSA device has been designed. It uses 12 silicon photomultipliers (SiPMs) with bias voltage of 5 volts operating as photodiodes. These 1×1 mm SiPMs were designed and assembled at NRNU MEPhI (Moscow Engineering Physics Institute). The ATSA board schematic is shown in figure 2 and a photograph is presented in figure 3.

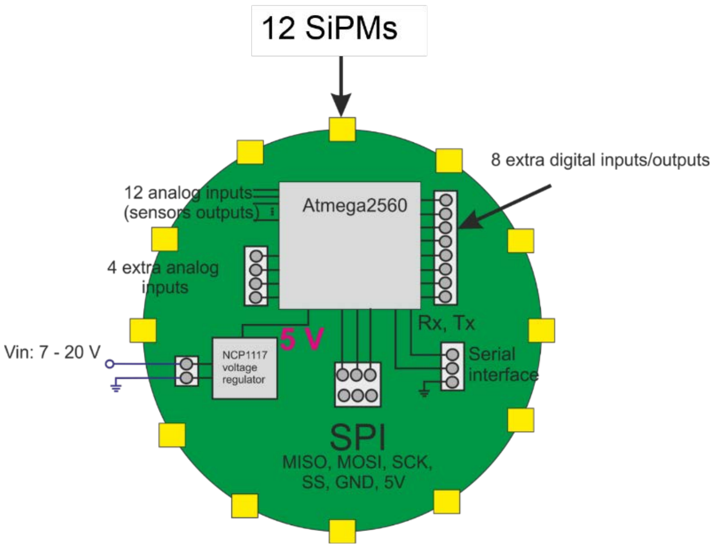

Figure 2. The ATSA board contains 12 SiPMs located 30 degrees apart from each other and powered with 5 V bias. Sensor readouts are directly connected to an Atmega2560 chip with a built-in 16-channel 10 bits ADC. One of the extra analog inputs is used for time-stamping (see below). This board can be powered either with 5 V distributed off the Hi-Cal board or by an external (7 – 20 V) power supply. ATSA has two interfaces: SPI for communication with the Hi-Cal board and a standard serial port for debugging using a personal computer.

In order to avoid electromagnetic noise, the board was placed in a lightweight metal case (figure 4). The total device mass is 110 grams.

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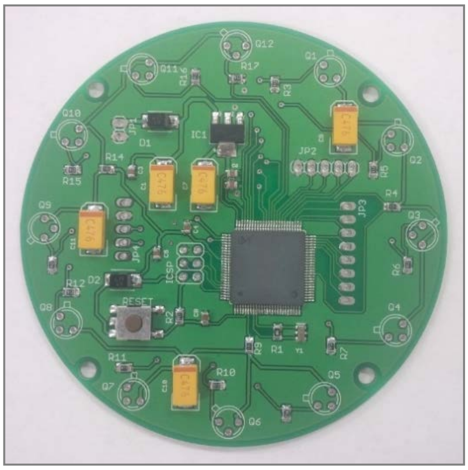

Figure 3. The ATSA board.

Figure 4. ATSA azimuthal sensors.

The light produces current through the SiPMs which is then read out via a 100 kΩ resistor. The digitized values of the voltage on the SiPMs output are averaged and then fit to a second-order polynomial, The firmware for the device were created using standard Arduino IDE and libraries.

4. ATSA calibration

The calibration of ATSA was carried out using the Sun as a light source. The device was rotated in 3 degree steps in relation to the Sun (figure 5).

Figure 5. ATSA calibration.

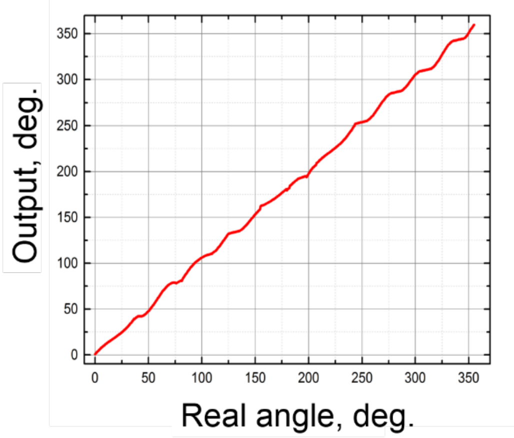

Figure 6. Calibration curve.

The obtained calibration values were interpolated with a 0.5 degrees step and the resulting calibration curve (figure 6) was integrated in the device firmware with a step of 0.5 degrees.

5. Results and tests

Figure 7 shows the correlation between the angle set during manual rotation of the ATSA device and the device output, using the Sun as source. The resulting resolution is under 3 degrees, which is sufficient for the Hi-Cal experiment.

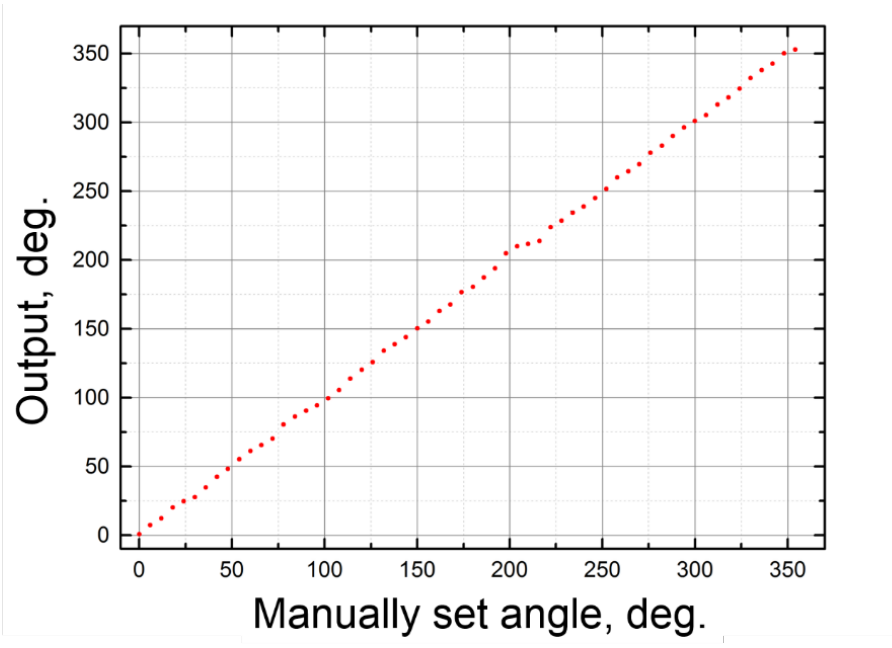

Figure 7. Results of ATSA device implementation.

Since during the flight at the altitude of ~38 km the pressure will be ~ 0.5 mbar and temperature about –20 °C, the equipment has been tested in a chamber at different pressures (0.5 ÷ 1000) mbar and temperatures (–40 ÷ +50) °C.

6. Time stamping

Another important function performed by ATSA is time-stamping. A small pick-up antenna that detects radio-frequency signal from the transmitter is located inside the pressure vessel. The signal from it is then transferred to ATSA, where a logic pulse indicating the spark is generated and later processed on the Hi-Cal board. This data is integrated into the GPS stream and used to determine the time of each radio-frequency signal with 50 μs accuracy.

7. Conclusion

The ATSA device for the forthcoming Hi-Cal-2-ANITA-IV experiment has been built using SiPMs designed and assembled at NRNU MEPhI. It will be used to determine the azimuthal orientation of the Hi-Cal transmitter in relation to the Sun with an angular resolution of less than 3 degrees. Tests simulating flight conditions (temperature and pressure) have been carried out to verify the equipment's ability to operate at float altitude.

References

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