PROCEEDINGS OF SCIENCE

Technical Design of the first Thai Space Consortium Satellite (TSC-1) and its Polar Orbiting Ion Spectrometer Experiment (POISE) Payload

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TSC-1 is the first Thai scientific research mission on a microsatellite, which has been designed and developed by the Thai Space Consortium. The satellite is planned to operate in Sun-synchronous Earth orbit at 500 - 600 km altitude and should be launch ready at the end of 2026. All design, construction, system integration, and testing are to be carried out in Thailand. The payloads include a Hyperspectral Imaging Camera and the Polar Orbiting Ion Spectrometer Experiment (POISE). The POISE detector is developed to characterize energetic ions for space weather monitoring. It uses the ΔE-E technique, comprising semiconductor detectors based on P-I-N junction parts designed and fabricated by Thai engineers and researchers, which in later versions will be combined with standard commercial parts (PIPs and silicon strip detectors) for benchmarking purposes. We will summarize the overall plan of TSC-1 and POISE, including the technical design, scientific concepts, geometrical acceptance, design of compact charge sensitive preamplifiers, and evaluation of the electronic dead-time of the data acquisition system. Radiation testing results for the engineering model prototype will also be presented.

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1. Introduction

Cosmic rays are energetic particles or gamma rays originating from space. They constitute a significant component of the high energy radiation environment in space. The cosmic ray sources include our Sun producing solar energetic particles (SEPs) and supernovae throughout our Galaxy, which generate Galactic cosmic rays (GCRs). A third type, known as anomalous cosmic rays (ACRs), originates from interstellar neutral atoms that enter the heliosphere, become ionized, and are accelerated at the solar wind termination shock. The Sun produces energetic particles due to occasional, sudden eruptions on its surface, called solar storm. These events can accelerate particles to relativistic energies (ions up to tens of GeV, electrons up to tens of MeV) for durations up to about an hour. Additionally, a type of storm called a coronal mass ejection (CME) can drive an interplanetary shock that accelerates ions up to tens of MeV. These particles, known as energetic storm particles, can persist for several days. The particles produced by solar storms pose radiation hazard to astronauts and passenger on high-altitude flight for short but unpredictable periods, as well as damaging expensive satellites and spacecraft. These and other effects of solar storms, including ionospheric disturbances, geomagnetically induced currents, and power outages, are called “space weather” effects.

The interest in space-borne particle/astroparticle physics experiments is growing. The achievements of the early space-borne particle detectors on missions such as IMP [1], HEAO-3 [2], EGRET [3] lead to more advanced experiments such as ACE [4], AMS-01 [5], PAMELA [6], AGILE [7], Fermi [8], AMS-02 [9] and CALET [10]. Among these successful mission, several detectors are specifically designed to study cosmic ray ions. Although the detector systems vary widely in size and complexity, only a few techniques are commonly used to identify ions from cosmic rays. The most important technique is detection of ionization energy loss, which occurs when charged particles pass through matter. The ionization energy loss per unit track length, or dE/dx, is accurately described by the Bethe-Bloch equation [11] and depends on the particles’s charge and mass. Thus, ion identification ability of the detector can be accomplished by the standard technique called the “ΔE-E technique”. The technique requires measuring the energy loss ΔE of a particle penetrating at least one detector layer; of known thickness. Then, the kinetic energy E of the incoming particle can be calculated by summation of the total energy deposited inside the detector, if the particle fully stops inside any detector layer. Thus, the detector is required to have a high density for a high stopping power and a wide deposited energy range.

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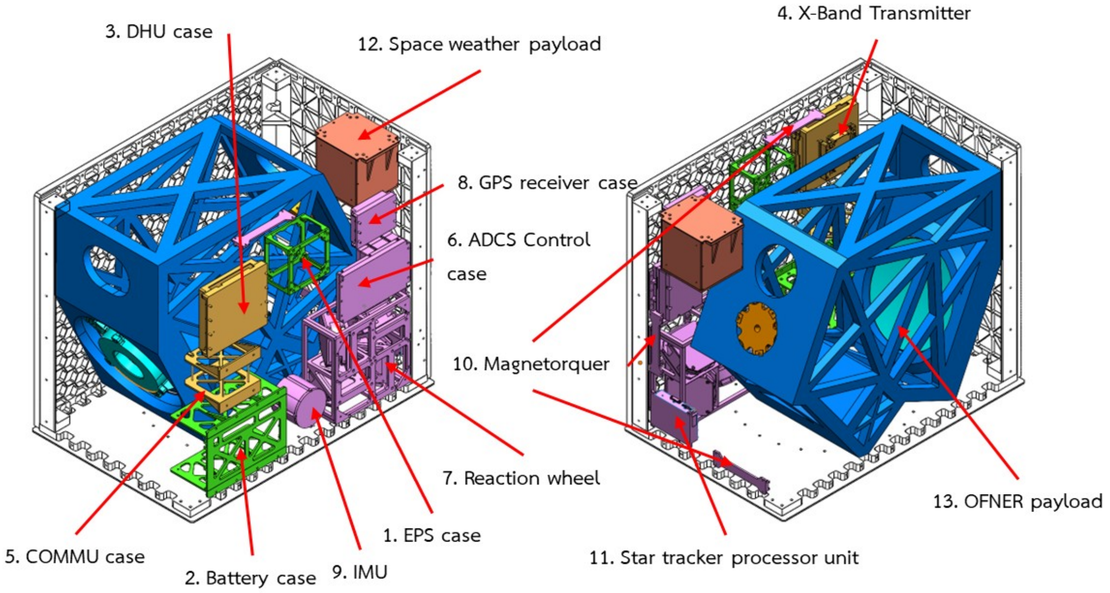


Figure 1: The overall design of the TSC-1 Sattelite.

2. Overview of the TSC-1 Satellite

The TSC-1 satellite is a low-earth orbit microsatellite weighing approximately 120 kilograms, developed by Thai engineers under the Thai Space Collaboration Partnership Program. Its mission is to validate technologies designed and constructed domestically, featuring key scientific payloads such as a Hyperspectral Imager and a Space Weather monitoring device. For the communication between the satellite and the ground station, the data transmission will be operated through the X-band, S-band, and UHF, and the data reception through the S-band and UHF.

The satellite is designed to capture hyperspectral images of the Earth's surface, covering all regions of Thailand, providing in-depth insights into land cover characteristics through statistical analyses and AI-based analyses. The payload was designed to have a ground sampling distance resolution of 30 m. The payload's applications include assessing forest health, identifying weed species in degraded areas, analyzing crop types and yields across seasons, and diagnosing water or nutrient deficiencies in crops. This innovation advances precision agriculture, enhancing productivity through high-resolution, space-based data tailored to specific regions, thus supporting policies to improve quality of life. The payload is developed by NARIT's Center for Optics and Photonics Technology, leveraging astronomical expertise to meet space-grade requirements.

Space Weather Monitoring Device: This device is designed to monitor space weather conditions that can affect Earth, developed by Mahidol University.

3. The POiSE Payload Design and Simulation

Many compact design flight detectors have successfully used silicon stacks such as CRaTER [12] and MAST [13]. Scintillator-based detectors were also used for many particular purposes. The

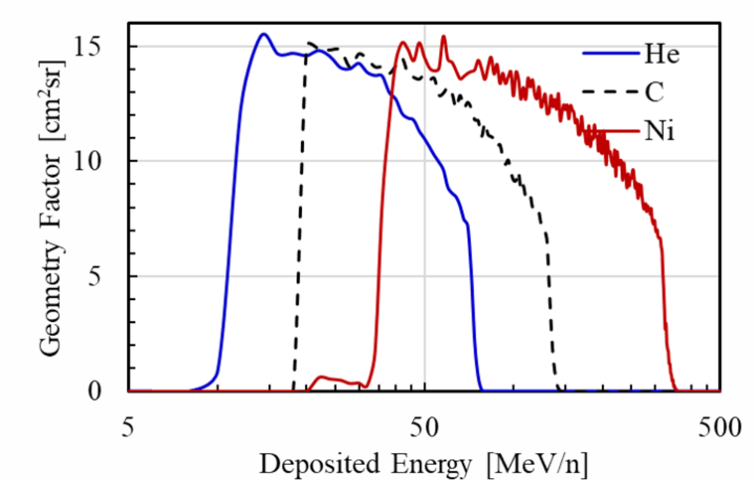


Figure 2: The geometry factor of the simulated detector for He, C and Ni as a function of the total deposited energy per nucleon.

silicon solid-state detector, which has a wide angular acceptance or large geometric factor and high stopping power, was selected. Figure 1 shows the drawing of our detector in the POiSE mission. We have been doing collaborative research with the Thai Microelectronics Center (TMEC) under the National Electronics and Computer Technology Center (NECTEC). We aimed to apply their experience with semiconductor devices to develop half of the thin silicon detectors in the detector stack within Thailand, which will greatly reduce the cost of our proposed space weather detector and help develop space technology in our nation. The first state preamplifier was designed and constructed. The consistency performance of the parts is testing together with the development of the next level of the readout parts to digitized the particle signal and communicate with the BUS system.

Our detector design inspired by the MAST detector [13], was simulated to prepare the appropriate simulation environment and data library for designing and confirming the correction of the preliminary analysis algorithm. Geant4 is an open-source platform for "the simulation of the passage of particles through matter" using Monte Carlo methods [14]. The simulation was applied in a wide range of fields including high energy physics, nuclear physics, proton therapy, etc.

4. Electronics Design

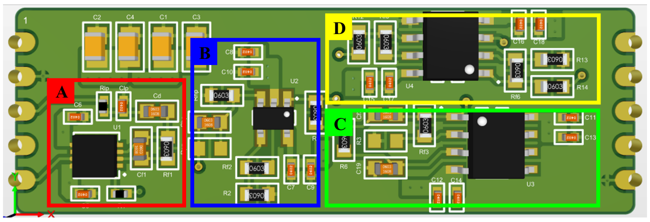


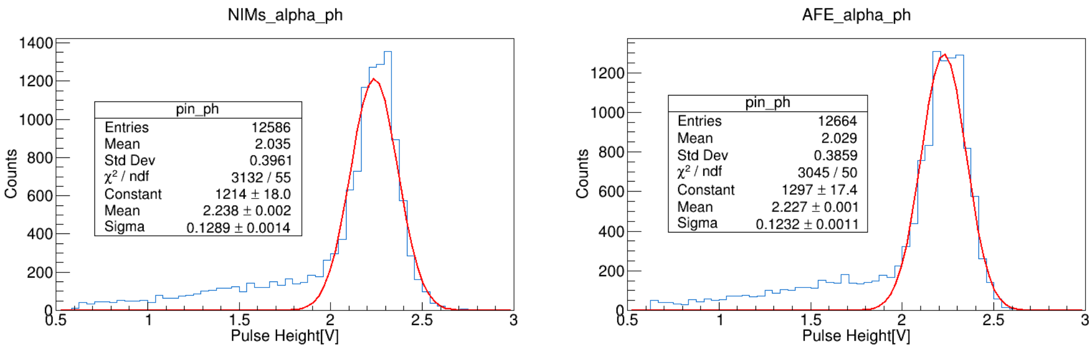
Figure 3: POISE PIN Analog Front-End module

The POISE PIN Analog Front-End (AFE) module consists of four main components, as shown in Figure 3: (A) a charge-sensitive preamplifier (CSP), (B) a first-order high-pass filter (HPF), (C) a fourth-order low-pass filter (LPF), and (D) a fully differential amplifier (FDA). The CSP converts the charge deposited by a particle on a Silicon PIN (Si-PIN) detector into a voltage pulse, which discharges slowly with a time constant $\tau = C_f R_f$, where C_f and R_f are the feedback capacitance and resistance, respectively, resulting in a long-tail triangular pulse. The HPF accelerates the decay of the pulse to prevent pile-up. This signal is then shaped into a smooth Gaussian-like pulse by the LPF, and finally amplified by the FDA.

5. Experiments

5.1 Calibration of electronics

The standard electronic instrumentation module used in particle physics experiments is known as the Nuclear Instrumentation Module (NIMs). To calibrate POISE PIN AFE, we used a Si-PIN detector with an Am-241 source, which emits alpha particles with discrete energies. Our investigation involved comparing two electronic modules: the NIMs and POISE PIN AFE. The pulse height distributions are shown in Figure 4, where the x-axis represents the pulse height in volts and the y-axis represents the number of counts. The blue line shows a histogram of the pulse height distribution, while the red line is a Gaussian fit used to determine the peak position. Figure 4a presents the result from the NIMs module, showing the pulse height of 2.24V. while Figure 4b shows the result from POISE PIN AFE, with a pulse height of 2.23V. The difference between two electronic modules is approximately 0.5%.

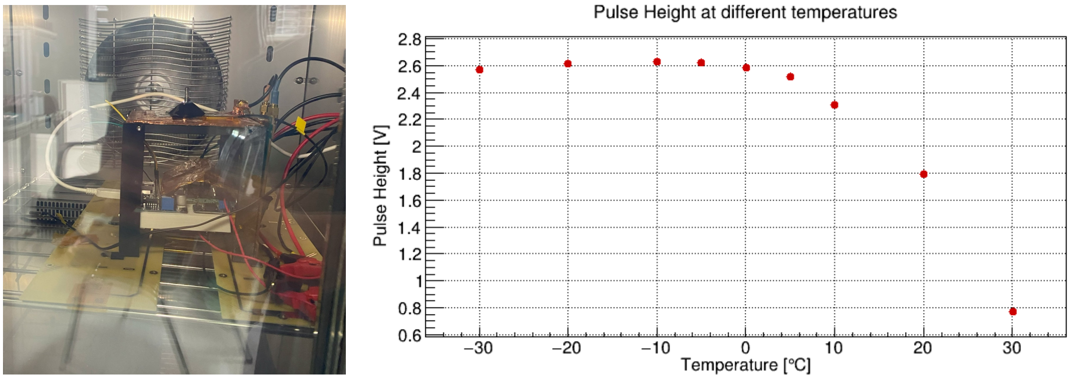


(a) The result from the NIMs. **(b)** The result from POISE PIN AFE.

Figure 4: The pulse height distribution of an Am-241 source.

5.2 Temperature testing

POISE PIN AFE and a Si-PIN detector were subjected to thermal cycling chamber. The temperature range was set from -30°C to 30°C to identify the maximum performance. Figure 5a demonstrates the configuration inside the thermal cycling chamber, and Figure 5b shows the dependence of the pulse height from an Am-241 source on temperature. the x-axis represents the controlled temperatures in degrees Celsius and the y-axis represents the pulse height in volts, while each red point indicates the pulse height from an Am-241 source at a determined temperature. In summary, high temperatures result in decreased performance; therefore, the suitable temperature for the maximum performance of the POISE PIN AFE and a Si-PIN detector is -10°C.



(a) Temperature testing setup. **(b)** The dependence of the pulse height from an Am-241 source on temperature.

Figure 5: Temperature testing

5.3 Measurement of coincidence

Measurement of coincidence is used to confirm that two detectors have detected signals from the same event. Our investigation involved a Si-PIN detector placed between two 0.5 mm thick plastic scintillators, with a 3 cm gap between a Si-PIN detector and each scintillator. The configuration of coincidence as shown in Figure 6.

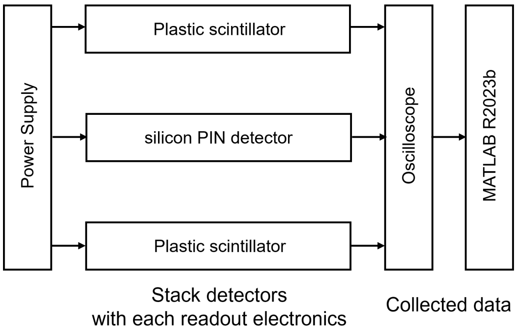
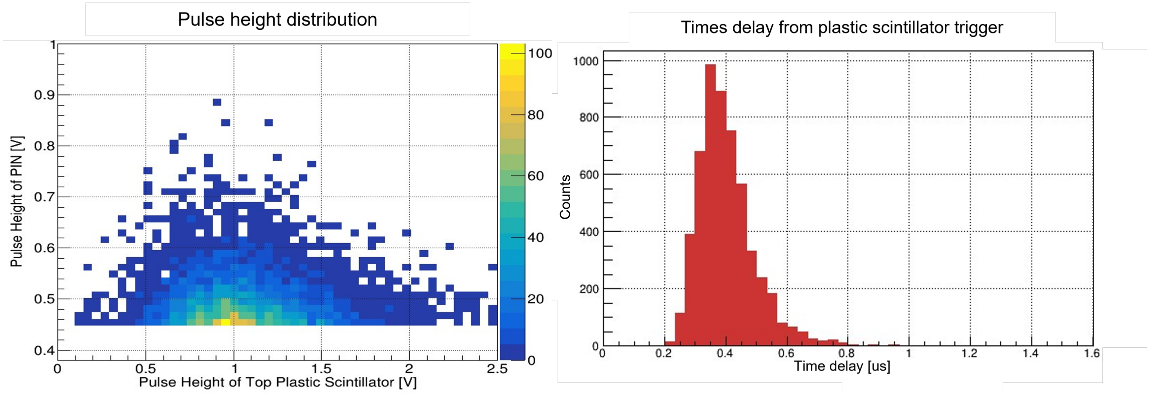


Figure 6: A block diagram of the configuration of coincidence

For the result, Figures 7a shows a 2D histogram of pulse height distribution (in volts) between the top plastic scintillator and a Si-PIN detector. The color scale on the right indicates the number of events, where blue means fewer events and yellow means more events. Figures 7b shows times delay determined by subtracting time at top plastic scintillator pulse height from time at PIN pulse height. The x-axis represents times delay in microsecond (μs) and the y-axis represents the number of events.

- Beta rays from a Sr-90 source



(a) a 2D histogram of pulse height distribution. **(b)** Times delay from plastic scintillator trigger.

Figure 7: Measurement of beta rays from a Sr-90 source coincidence with plastic scintillator.

In this setup, we place a Sr-90 source on top plastic scintillator to detect beta rays. Then, threshold at POISE PIN AFE is set to about 438 mV. The top plastic scintillator pulse heights for most event are about 0.9–1.1 V, while a Si-PIN pulse heights for most event are about 0.45–0.48 V. Detectors are in coincidence, with a time delay of 0.3 μs between two detectors.

6. Acknowledgments

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