Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 565 (2006) 677–685
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Pre-flight performance and radiation hardness of the Tokyo Tech pico-satellite Cute-1.7

J. Kotoku[a,*], J. Kataoka[a], Y. Kuramoto[a], Y. Tsubuku[a], Y. Yatsu[a], R. Sato[a], T. Ikagawa[a], T. Saito[a], N. Kawai[a], K. Konoue[b], N. Miyashita[b], M. Iai[b], K. Omagari[b], M. Kashiwa[b], H. Yabe[b], K. Imai[b], Miyamoto[b], K. Fujiwara[b], S. Masumoto[b], T. Usuda[b], T. Iljic[b], A. Konda[b], S. Sugita[b], T. Yamanaka[b], D. Matsuura[b], T. Sagami[b], S. Kajiwara[b], Y. Funaki[b], S. Matsunaga[b], T. Shima[c], S. Kishimoto[d]

[a]*Department of Physics, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8551, Japan*
[b]*Department of Mechanical and Aerospace Engineering, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo, Japan*
[c]*RCNP (Research Center for Nuclear Physics), Osaka University 10-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan*
[d]*Photon Factory, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*

Received 16 February 2006; received in revised form 11 April 2006; accepted 22 May 2006
Available online 12 July 2006

Abstract

The Cute-1.7 was launched successfully in February 2006 as a piggyback satellite of the Astro-F mission. The Cute-1.7 dimensions are $10 \times 10 \times 20\,cm^3$ box with a total mass of 3.6 kg. It is the second pico-satellite to have been developed completely by students of the Tokyo Institute of Technology (Tokyo Tech.) after the successful launch of the CUTE-I in June 2003. The goals of the Cute-1.7 mission are two-fold: (1) to validate high-performance, commercially available products for the first time in space. We particularly use personal digital assistants (PDAs) as a main computer in orbit (2) to demonstrate new potential uses for small satellites in various space studies, as proposed by the "satellite-core" concept. For the Cute-1.7 mission, we will carry avalanche photo diodes (APDs) as a high-count particle monitor in low-Earth orbit. Here we present details of various ground tests and pre-flight performance of the Cute-1.7 immediately before the launch. Results of the Cute-1.7 mission will provide quick feedback for space applications of APDs in Japan's future X-ray astronomy mission *NeXT*.

PACS: 07.85; 95.55.−n; 85.60.Dw

Keywords: Cute-1.7; Pico-satellite; PDA; Satellite core; Avalanche photo-diode

1. Introduction

Laboratory for Space System (LSS) at Tokyo Institute of Technology (hereafter Tokyo Tech) is pushing ahead with its CubeSat program: an international, educational, and challenging project proposed by Professor R. Twiggs (Stanford University) in 1999. Through this project, students in more than 40 universities around the world are developing their own small satellites of 10 cm cubes, and less than 1 kg mass. Resources are available by communicating directly with other developers and attending CubeSat workshops. In other words, the CubeSat program strives to provide practical, reliable, and cost-effective launch opportunities for small satellites and their payloads. It is extremely advantageous to achieve performance tests for the demonstration of new techniques or to benchmark new devices in a space environment.

At Tokyo Tech, the "university satellite" program has been actively promoted through the joint collaboration of the LSS and the Laboratory for Experimental Astrophysics (LEAP, shown in Fig. 1). In June 2003, the first Tokyo

*Corresponding author. Tel./fax: +81 3 5734 2388.
E-mail address: kotoku@hp.phys.titech.ac.jp (J. Kotoku).

0168-9002/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2006.05.247

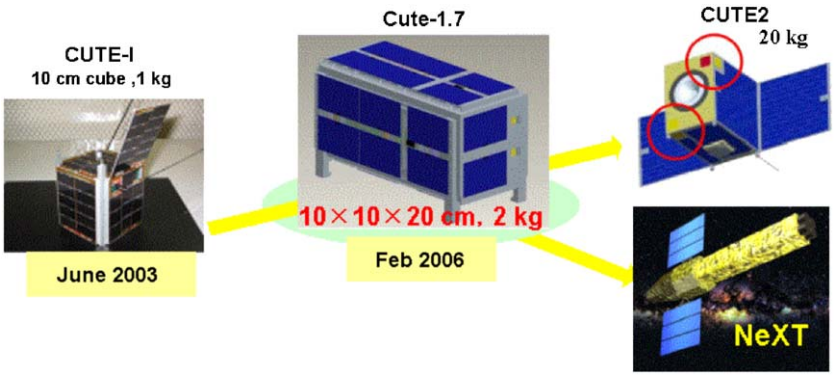

Fig. 1. Future plans for satellite development at Tokyo Institute of Technology.

Fig. 2. (left): The launch of the first university satellite CUTE-I in 2003 by a Russian rocket. (right): Side view of the CUTE-1.

Tech CubeSat, "CUTE-I" [1,2], was launched by a Russian rocket, ROCKOT (Fig. 2). Today, CUTE-I is actively working in orbit, sending experimental and status data, as it does every day, to the ground station constructed by the LSS at Tokyo Tech. The Cute-1.7 [3,4] is a *new* satellite project following the CUTE-I. Again, it is completely developed by students at Tokyo Tech, but has a "science mission payload" that has been newly developed by the LEAP at Tokyo Tech. The design, development and various tests of this payload are the main topics of this paper. After the launch of Cute-1.7, we plan to develop 50-kg class satellites, CUTE2 [5] and HURING [6], for future advanced X-ray and γ-ray astronomy including hard X-ray polarimetry.

This paper is organized as follows. In Section 2, we present an overview of the Cute-1.7 satellite and its mission goals. Next, in Sections 3 and 4 we discuss the merits of using the PDA in orbit as a main computer. Its radiation hardness is based on a proton beam test. In Section 5, we present a detailed design of an APD module developed by the LEAP and its gain control system. We show a high-counting response of an APD module using a synchrotron beam facility, and use the proton cyclotron beam and γ-rays from ^{60}Co to discuss possible radiation damage caused by energetic particles. We summarize our results in Section 6.

2. Cute-1.7 mission and its goals

By virtue of the successful CUTE-I mission, which has continued since 2003, we have confirmed that our basic design of a satellite system functions fairly well in orbit. Furthermore, we have established a fabrication process, various design parameters, construction of the ground station, and detailed operation methods throughout our university. We, therefore, planned to develop a small satellite to be launched subsequent to the CUTE-1 mission using advanced technologies for various mission goals. The Cute-1.7 satellite will be launched in February 2006 as a piggyback satellite of the Astro-F mission [7,8]. The dimensions of Cute-1.7 are a $10 \times 10 \times 20\,\mathrm{cm}^3$ box with a total mass of 3.6 kg.

The goals of the Cute-1.7 mission are two-fold. First we hope to validate commercially available products, which are very compact and high-performance, but have not been used in space so far. We particularly used personal digital assistants (PDAs, NPD-20JWL; Hitachi Ltd.) as a main computer in orbit. The operating system of the PDA is Windows CE.NET 4.1. Furthermore, we use many other easily available consumer electronics in Cute-1.7, such as memory cards, USB hubs, digital cameras, and handheld transceivers. The PDA is connected to all the sub-systems, including APD module, via the USB or serial interfaces, as shown in Fig. 3.