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The AGILE silicon tracker: Pre-launch and in-flight configuration

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ABSTRACT

AGILE is an ASI (Italian Space Agency) Small Scientific Mission dedicated to high-energy astrophysics which was successfully launched on April 23, 2007. The AGILE instrument is composed of three main detectors: a Tungsten-Silicon Tracker designed to detect and image photons in the 30 MeV–50 GeV energy band, an X-ray imager called Super-AGILE operating in the 18–60 keV energy band, and a Mini-Calorimeter that detects gamma-rays and charged particles energy deposits between 300 keV and 100 MeV. The instrument is surrounded by an anti-coincidence (AC) system. In this paper, we present the noise characterization and the front-end configuration of the Silicon Tracker. Two crucial (and unique, among gamma-ray astrophysics missions) characteristic of the AGILE Silicon Tracker are the analog signal acquisition (aimed at obtaining an optimal angular resolution for gamma-ray imaging) and the very small dimension of the instrument (the total height including the active elements is $\sim$21 cm and therefore the Silicon Tracker is the lightest and most compact γ- ray imager sent in orbit). The results presented in this paper were obtained during the AIV (Assembly, Integration and Verification) pre-launch testing phase and during the post-launch commissioning phase. The AGILE Silicon Tracker has been optimally configured with a very good response of the frontend system and of the data acquisition units.

1. Introduction

AGILE (Astrorivelatore Gamma ad Immagini LEggero—Light Imager for Gamma-ray Astrophysics) is a scientific mission of the Italian Space Agency (ASI). The AGILE payload [1] is composed of three detectors: (1) a Tungsten-Silicon Tracker (ST) ([2,3]) with a large field of view (about 120°), a good time sensitivity and angular resolution; (2) a Silicon based X-ray detector, Super-AGILE (SA) [4], for imaging in the 18–60 keV energy range, and (3) a CsI(Tl) Mini-Calorimeter (MCAL) [5] that detects gamma-rays or particle energy deposits between 300 keV and 100 MeV. The instrument is surrounded by an anti-coincidence (AC) system [6] of plastic scintillators for the rejection of charged particles. ST, MCAL and AC form the so called Gamma-Ray Imaging Detector (GRID) for observations in the 30 MeV–50 GeV gamma energy range. The introduction of the most recent detector technologies in the construction of AGILE brings to the realization of a very light payload (100 kg) with an effective area adequate to produce new important scientific results. AGILE was successfully launched by the Indian PSLV C8 rocket from the Sriharikota base on April 23rd 2007, in a quasi-equatorial orbit with an inclination of 2.5°. The satellite in-orbit commissioning phase was carried out in the period May–June 2007. The scientific verification phase and scientific calibration (based on the Vela and Crab pulsars) were carried out during the period July–November 2007. The nominal scientific observation phase (AGILE Cycle-1, AO-1) started on December 1st, 2007.

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Fig. 1. Photo of the tracker before the assembly of the 2 front-end boards (June 2005).

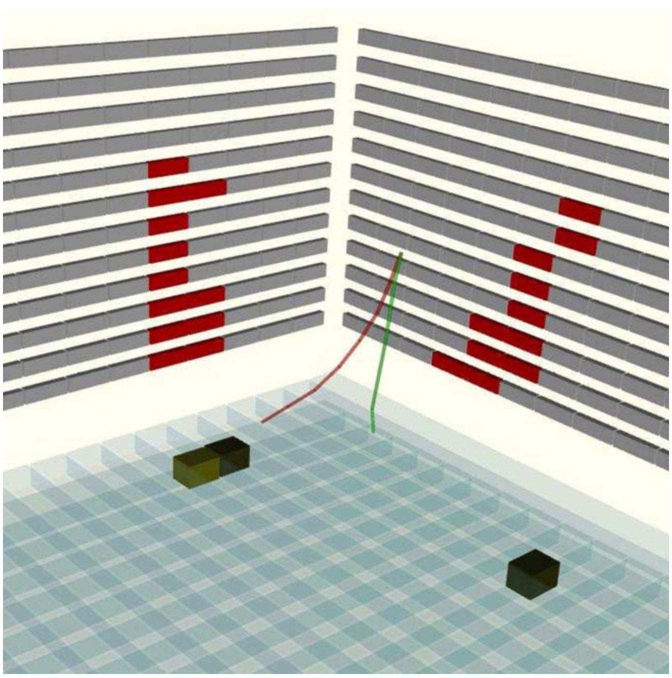

Fig. 2. A γ- ray event acquired in space with a reconstructed energy of ~ 100 MeV. Gray boxes represent the ASICs and they are colored in red if they have fired, dark-yellow boxes mark the hits of the event into the MCAL (the MCAL bars are cyan). The red and green lines are the reconstructed tracks (and thus the topology of the event) of the electron and the positron with a Kalman filtering technique. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In this paper we present the main results concerning the noise characterization and the front-end configuration of the Silicon Tracker. In particular, this work covers the configuration activities performed during the AIV (Assembly, Integration and Verification) phase of the Silicon Tracker, and during the in-flight commissioning phase. The main purpose of these activities was to reach an optimal ST efficiency.

The activities performed during the assembly phase of the modules of the AGILE Silicon Tracker are reported in Ref. [7].

The paper is organized as follows. The Silicon Tracker is described in Section 2 while Section 3 is devoted to the description of the on-board logic of the front-end for the determination of a GRID event cluster. Section 4 is dedicated to the identification procedure of the anomalous strips used during the assembly phase of the Silicon Tracker and Section 5 describes the parameters characterizing the noise. Section 7 reports some considerations about the concept of floating strip and the definition of the ST efficiency. The GRID clusters, the determination of the noisy strips and the characterization of the noise are the main tools used to optimize the ST efficiency, that is the final goal of this work, as described in Section 7. Sections 8 and 9 report the results obtained during the pre-launch AIV and in-flight commissioning phases.

2. The silicon tracker

The main purpose of the Silicon Tracker (Fig. 1) is to provide a compact imager for gamma-ray photons of energy above 30 MeV. The Tracker plays two roles at the same time: it converts the gamma-rays in heavy-Z material layers (245 μm of Tungsten, $0.07 X_0$), where the photon interacts producing an electron/positron pair (that are MIPs, Minimum Ionizing Particles corresponding to a most probable value of 110 keV deposited energy per layer) in the detector, and records the electron/positron tracks by a sophisticated combination of Silicon microstrip detectors and associated readout.

A GRID event is a collection of all the electron/positron interactions into the microstrips of the silicon detector (each interaction generates a *cluster* that is a group of neighboring strips collecting the charge deposited by the particle, see Section 3.3) together with the energy deposit in the MCAL bars and the information from the AC plastic scintillators (used as veto logic). A complete representation of the event topology allows the reconstruction of the incoming direction and energy of the γ-ray. A representation of a typical grid event is reported in Fig. 2.

The Silicon Tracker [3] consists of 12 *planes*, each of them made of two layers of 16 single-sided, AC-coupled, 410 μm thick, $9.5 \times 9.5\,\text{cm}^2$ silicon detectors. The 16 detectors of each plane side (*view*) are grouped in 4 *ladders* each one consisting of 4 detectors wire bonded one after the other along the direction of the strips. The two views of the plane are organized in a $X-Z$ configuration. Fig. 3 presents the reference system and the numbering and naming conventions of the Silicon Tracker used in this paper.

The physical strip pitch is 121 μm while the readout one is 242 μm: this "floating strip" scheme allows to read one strip every two thus decreasing the number of readout channels (and thus decreasing the power consumption of the instrument) while maintaining an excellent spatial resolution. Each ladder has 384 readout channels. The name "strip" throughout the paper refers to a readout strip unless otherwise indicated; "strip" and "channel" are equivalent. The readout ASIC is the TAA1 (Gamma Medica—IDEAS), a mixed analog-digital, low noise, self-triggering ASIC used in a very low power configuration (<400 μW/channel) with full analog readout. More details are reported in [2]. Each ASIC has 128 identical channels, containing a folded cascode pre-amplifier, a CR–RC shaper, a discriminator (with a threshold chosen by the user and a 3 bit trim DAC per channel for the fine setting) and a sample&hold circuit. The readout is a multiplexed one, with a clock maximum frequency of 10 MHz; the value chosen for the tracker is 3.5 MHz, meaning that the time needed to read one single ladder (that is 384 channels) is 109.7 μs. The total number of ASICs of the ST is 288, 24 ASICs for each plane.

Latch-up events and single event effects have been considered in the design of the electronics. Tests have been performed at the INFN Laboratories of Legnaro with ions to understand the behavior of the ASIC. In the final design, care has been taken to prevent the single event effects with a constant check of the trigger mask and the latch-up problem with control and recovery circuits.