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The AGILE Silicon Tracker: pre-launch and in-flight configuration

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1 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 60°), a good time esensitivity 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)

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Mini-Calorimeter (MCAL) [5] that detects gamma-rays or particle energy de-8 posits between 300 keV and 100 MeV. The instrument is surrounded by an 9 anti-coincidence (AC) system [6] of plastic scintillators for the rejection of 10 charged particles. ST, MCAL and AC form the so called Gamma-Ray Imag-11 ing Detector (GRID) for observations in the 30 MeV-50 GeV gamma energy 12 range. The introduction of the most recent detector technologies in the con-13 struction of AGILE brings to the realization of a very light payload (100 kg) 14 with an effective area adequate to produce new important scientific results. 15 AGILE was successfully launched by the Indian PSLV C8 rocket from the 16 Sriharikota base on April 23rd 2007, in a quasi-equatorial orbit with an in-17 clination of 2.5° . The satellite in-orbit commissioning phase was carried out 18 in the period May-June 2007. The scientific verification phase and scientific 19 calibration (based on the Vela and Crab pulsars) were carried out during the 20 period July-November 2007. The nominal scientific observation phase (AGILE 21 Cycle-1, AO-1) started on December 1st, 2007. 22

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.

²⁹ The activities performed during the assembly phase of the modules of the

³⁰ AGILE Silicon Tracker are reported in [7].

The paper is organized as follows. The Silicon Tracker is described in Section 31 2 while Section 3 is devoted to the description of the on-board logic of the 32 front-end for the determination of a GRID event cluster. Section 4 is dedi-33 cated to the identification procedure of the **anomalous** strips used during 34 the assembly phase of the Silicon Tracker and Section 5 describes the parame-35 ters characterizing the noise. Section 6 reports some considerations about the 36 concept of floating strip and the definition of the ST efficiency. The GRID 37 clusters, the determination of the noisy strips and the characterization of the 38 noise are the main tools used to **optimize** the ST efficiency, that is the final 39 goal of this work, as described in Section 7. Sections 8-9 report the results 40 obtained during the pre-launch AIV and in-flight commissioning phases. 41

42 2 The Silicon Tracker

⁴³ The main purpose of the Silicon Tracker (Figure 1) is to provide a compact ⁴⁴ imager for gamma-ray photons of energy above 30 MeV. The Tracker plays ⁴⁵ two roles at the same time: it converts the gamma-rays in heavy-Z material ⁴⁶ layers (245 μm of Tungsten, 0.07 X_0), where the photon interacts producing ⁴⁷ an electron/positron pair (that are MIPs, Minimum Ionizing **Particles** corre-

⁴⁸ sponding to a most probable value of 110 keV) deposited energy per layer

⁴⁹ in the detector, and records the electron/positron tracks by a sophisticated

⁵⁰ combination of Silicon microstrip detectors and associated readout.



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

A GRID event is a collection of all the electron/positron interactions into the 51 microstrips of the silicon detector (each interaction generates a *cluster* that is 52 a group of neighbouring strips collecting the charge deposited by the particle, 53 see Section 3.3) together with the energy deposit in the MCAL bars and the 54 information from the AC plastic scintillators (used as veto logic). A complete 55 representation of the event topology allows the reconstruction of the incoming 56 direction and energy of the γ -ray. A representation of a typical grid event is 57 reported in Figure 2. 58

The Silicon Tracker [3] consists of 12 *planes*, each of them made of two layers of 16 single-sided, AC-coupled, 410 μ m thick, 9.5 × 9.5 cm² 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. Figure 3 presents the reference system and the numbering and naming conventions of the Silicon Tracker used in this paper.

⁶⁶ The physical strip pitch is 121 μ m while the readout one is 242 μ m: this ⁶⁷ "floating strip" scheme allows to read one strip every two thus decreasing the ⁶⁸ number of readout channels (and thus decreasing the power consumption of ⁶⁹ the instrument) while maintaining an excellent spatial resolution. Each ladder ⁷⁰ has 384 readout channels. The name "strip" throughout the paper refers to a



Fig. 2. A γ -ray event acquired in space with a reconstructed energy of ~ 100 MeV. Gray boxes represent the ASICs and they are coloured 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.

readout strip unless otherwise indicated; "strip" and "channel" are equivalent. 71 The readout ASIC is the TAA1 (Gamma Medica - IDEAS), a mixed analog-72 digital, low noise, self-triggering ASIC used in a very low power configuration 73 $(< 400 \ \mu W/channel)$ with full analog readout. More details are reported in 74 [2]. Each ASIC has 128 identical channels, containing a folded cascode pre-75 amplifier, a CR-RC shaper, a discriminator (with a threshold chosen by the 76 user and a 3 bit trim DAC per channel for the fine setting) and a sample&hold 77 circuit. The readout is a multiplexed one, with a clock maximum frequency of 78 10 MHz; the value chosen for the tracker is 3.5 MHz, meaning that the time 79 needed to read one single ladder (that is 384 channels) is 109.7 μ s. The total 80 number of ASICs of the ST is 288, 24 ASICs for each plane. 81

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 behaviour 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.

The 12 planes of the Silicon Tracker are organized in 13 trays (as indicated on the right of Figure 3) with a pitch of 1.9 cm. Each tray consists of a 12 mm



Fig. 3. The reference system of the Silicon Tracker used in this paper. On the left a logical view of a single plane is shown: the gray boxes are the readout ASICs, the numbers into the blue plan represent the numbering convention used for the strips. A plan is composed of a Z view (blue, shown in the scheme) and a X view. The Y direction is oriented to the top of the ST. On the right side the trays and the planes are shown. The red box is the W layer, the blue box **represents** the Silicon views with the strips along the Z direction and the green box shows the Silicon views with the strips along the X direction. The elements are not in scale.

core of aluminum honeycomb covered on both sides by a 0.5 mm carbon fiber 90 layer. The first 10 trays are equipped with a tungsten layer 245 μm thick 91 glued on the bottom side of the tray itself and with the same area of the 92 silicon detectors. The overall on-axis ST radiation length is $0.8 X_0^{-1}$; the 93 silicon detector features allow to reach a spatial resolution of 40 μ m over a 94 wide range of incidence angles and an energy resolution (when working in the 95 GRID configuration mode) at 400 MeV of $\frac{\Delta E}{E} \sim 1$. The Silicon Tracker has 96 36 864 readout channels, and is logically and physically divided in 2 sides (a 97 side is a collection of all the views with the same strip direction), called X 98 and Z, each one controlled by a dedicated front-end board (FTB, Frontend 99 and Trigger Board, [8]). Each FTB is composed of 6 FEBs (FrontEnd Board) 100 and each FEB controls 2 views of the same type. The FTB has to generate 101 the voltages needed to operate the ASICs (± 2 V) and the bias voltage for the 102 silicon detectors, to set the threshold value, to manage the trigger signals and 103 the readout phase. The analog signals managed by the FEBs are Analog to 104 Digital converted and hardware processed by 3 PDHU (Payload Data Handling 105 Unit, see [9]) boards². The silicon detectors have been manufactured on six 106 wafers with resistivity above 4 $k\Omega$ -cm; the corresponding full depletion 107

¹ There are 10 layers of W, each one of 0.07 X_0 radiation length, and 24 layers of Si, each one of 0.0410 cm. With the Si layers we obtain 0.1 X_0 radiation length.

² FTBs and PDHU have been designed by Thales Alenia Space (formerly Laben).

 $_{108}$ voltage ranges between 25 and 45 V and the bias voltage used on the satellite $_{109}$ is 50 V.

The total height including the active elements is $\sim 21 \, cm$ and therefore the tracker is the lightest and most compact γ -ray imager sent in orbit.

112 3 ST front-end characterization

113 3.1 Electronic Noise

¹¹⁴ The overall noise of each ladder has two components (see [2]):

• the intrinsic random noise, **characterizing** each floating or readout strip,

- whose single components are the ones listed below:
- 117 the leakage current;
- 118 the polarization resistors;
- \cdot the resistance of the metal strip;
- 120 · the TAA1 readout ASIC.

The estimated *Equivalent Noise Charge* (ENC) is of the order of 800 electrons with the main contributions coming from the ASIC and the polarization resistor of the detector.

• the common mode (CM), that characterizes each ASIC, which is given by the fluctuation of all the channels at the same time mainly because of the pickup on the bias voltage.

The expected noise for each ladder is the sum in quadrature of the two com-ponents.

As far as the grounding of the detector is concerned, all the power supplies have a common return defined at the level of the PDHU. This common return is the general ground of the system. This solution has been verified in terms of noise to check it did not deteriorate the performances.

A too high CM could prevent the possibility of setting the trigger threshold at 134 1/4 of a MIP, that is the optimal value as specified in Section 6, thus reducing 135 the detector trigger efficiency. In particular, with a too high threshold the 136 floating strip could be lost. The CM has to be computed for each event to 137 be subtracted together with the pedestal from the raw data, an operation 138 performed by the FTB. For each ASIC j the CM component is calculated as

$$CM_j = \frac{\sum_{i=1}^{N} (raw_{ji} - ped_{ji})}{N_j} \tag{1}$$

where raw_{ji} is the raw content of the readout channel of the strip *i* in ADC counts, ped_{ji} is the channel pedestal (see Section 3.2) and N_j is the number of the ASIC good strips (noisy or dead strips are excluded).

142 3.2 Pedestal calculation

¹⁴³ The pedestal of a channel is its baseline level when no signal is present.

An on board procedure, activated by means of a dedicated telecommand, has been implemented for the pedestal calculation: the ASICs are divided in columns (corresponding to the first, second and so on ladders of each view); when the procedure starts each column is readout for 64 times generating random triggers and the values are stored on-board. The following quantities are then calculated, where j is the ASIC index and i is the strip index related to that ASIC:

- the mean value of each strip (36 864 values), ped_{ji} ;
- the rms value of each strip (36 864 values), rms_{ji} ;
- the common mode of each ASIC (288 values, one for each ASIC), CM_j , as
- reported in Equation 1.

In Figure 4 the histograms of the mean and rms (before the common mode subtraction) values and the common mode rms for each ASIC are presented. Given the overall noise rms is of the order of 30 ADC counts, and the common mode value is of the order of 6, the common mode contribution to the noise is **practically negligible**. Figure 5 shows the pedestal mean and rms for each strip of a single ASIC.

¹⁶¹ 3.3 Determination of a cluster in an event

A cluster is a set of contiguous strips registering the passage of a particle. The
 following on-board algorithm is used to identify the clusters:

the TAA1 ASIC contains a threshold discriminator per read-out channel. If the value of the charge of a strip is above this threshold (called *FTB threshold*) a *trigger signal* is generated (which is the OR of all the 128 channels of a TAA1). This signal starts a level 1 trigger algorithm (see [3]), that requires a signal in at least three out of four contiguous tracker planes, and a proper combination of fired AC panels;

if the previous level 1 trigger is passed, a *hold signal* is generated and an intermediate level 1.5 trigger (see [3] for details) evaluates the event topology defined by the distribution of the fired ASICs with respect to the fired AC panels;



Fig. 4. Histogram of the pedestal mean (ped_{ji}) and rms (rms_{ji}) and plot of the common mode rms of each ASIC (the x axis reports the index of the ASIC). The small peak below 10 ADC counts in the rms distribution is related to dead channels where only CM noise is present. The common mode rms near 0 ADC counts is due to a dead ASIC.



Fig. 5. Pedestal mean (ped_{ji}) and rms (rms_{ji}) of each strip of an ASIC.

• if the level 1.5 trigger is passed all the strips with signal above the threshold for the fired ASICs are acquired and their collected charge is converted into 12 bit digital values. To do this, the *front-end freeing* procedure implements a sparse readout of the triggered strips by means of a 5 MHz clock and the analog to digital converted values are saved in a

179 dedicated RAM;

- 180 at this point, a *preprocessing procedure* starts:
- $raw \ data \ pre-analysis:$ the pedestal and common mode values are subtracted; the pulse height of every strip i of ASIC j is thus defined as

$$C_{ji} = raw_{ji} - ped_{ji} - CM_j \tag{2}$$

¹⁸³ · zero suppression: each strip with a value C_{ji} smaller than N_1 times its ¹⁸⁴ rms is discarded. This reduces the data transfer to the PDHU. At the time ¹⁸⁵ of writing, $N_1 = 3$ [2];

cluster identification; this procedure starts after the preprocessing procedure and contains the following steps:

¹⁸⁸ · in a group of contiguous strips at least one strip m should have a value ¹⁸⁹ $C_m > H_m$, where H_m is N_2 times the rms_m calculated with the pedestal ¹⁹⁰ procedure. At the time of writing, $N_2 = 5$ [2];

¹⁹¹ • the **not suppressed** strips adjacent to the strip m are considered. This ¹⁹² group of strips is called a cluster. If in this group there are two strips with ¹⁹³ a signal C larger than N_2 times their rms noise and they are not adjacent ¹⁹⁴ to **one another**, two clusters are generated with a shared strip.

¹⁹⁵ For each cluster the payload telemetry contains:

- the total charge (the sum of the charges of all the cluster strips);
- the total width (the number of strips) of the cluster;
- the charge of the 5 central strips of the cluster, reduced to 8 bits (the least significant bits are removed). In this paper the central strip is called C_3 , the left side strips are called C_1 and C_2 , and the right side strips are called C_4 and C_5 .
- In addition, the following data are acquired for a full representation of theGRID event:
- the time of the event;
- the energy deposited in each Mini-Calorimeter bar;
- the configuration of the fired AC panels;

• the extra fired ASICs index: for each view of the Silicon Tracker the maximum number of triggered ASICs that can be acquired is 8. If more than 8 ASICs trigger, only the indexes of the additional triggered ASICs are sent to ground with the telemetry. The ASICs are ordered according to their physical position: from the first tray on the top of ST to last tray at the bottom, and for each tray according with the index reported in Figure 3.

213 3.4 The GRID Operation mode

²¹⁴ The PDHU provides three main working modes for the GRID subsystem:

1 observation mode: with this configuration the GRID subsystem is ready 215 to acquire photons in the 30 MeV-50 GeV energy band. A set of dif-216 ferent on-board triggers (level 1 and level 1.5 hardware trigger, already 217 described in Section 3.3, and a level 2 software trigger, see [9]) enables the 218 discrimination of background events (mainly muons on ground or parti-219 cles in the AGILE Low Earth Orbit) from gamma-ray events. This is the 220 acquisition mode used during the calibration activities and in-flight. The 221 corresponding telemetry flow is indicated as 3901; 222

223 2 physical calibration mode: in this configuration mode only the first step of
 level 1 trigger that requires a signal in at least three out of four contiguous
 tracker planes has been enabled. This data acquisition mode has been
 used extensively during the various AIV activities. The corresponding
 telemetry flow is indicated as 3902.

3 electrical calibration mode: this mode is used to check the behaviour (in terms of gain and stability) of each single strip in test mode; all the strips except one are disabled and a pulse with a variable amplitude is injected into the preamplifier input 64 times, after having set a proper threshold.
The output is the number of times the strip has triggered. The procedure is repeated for every strip. The corresponding telemetry flow is indicated as 3904.

²³⁵ 4 Procedure for the identification of anomalous strips

The procedure for the identification of anomalous strips has been defined during the assembly of the Silicon Tracker performed at Mipot S.p.A.³ by the INFN Trieste team.

A channel is considered *anomalous* or *bad* from the point of view of the noise 239 if the noise level is too low (low or dead channel) or too high (noisy channel). 240 It can be observed that, excluding the anomalous channels, the plot of the noise 241 versus the channel number is a function that has a continuous component. This 242 is probably due to the fact that the physical properties that have influence on 243 the noise level vary continuously (e.g. across the strips of the silicon detectors). 244 An example of this behaviour can be seen in Figure 6, where the noise of the 245 384 channels of a unit of electronic readout (a PCB with three ASICs, not 246 connected to the silicon detectors) is shown: being the traces of the PCB 247 not connected to the corresponding strips on the silicon, the noise 248 level is mainly determined by the different length of the strips on the board, 249 that vary slightly from a channel to the next **one**. 250

For this reason, the procedure starts with a fit of the noise level versus the channel number with a curve of the second order; a different curve is obtained for each ASIC. Then, a sort of level of anomaly for each channel $(ANOM_n)$

³ Mipot S.p.A., Via Corona 5, Cormons (GO, Italy); http://www.mipot.com

is defined dividing the level of the noise of the single channel (rms_n) by the corresponding theoretical level calculated from the fit. In this way, a quite flat function of the channel number is obtained, whose median is 1; a channel is being defined bad considering how far its anomaly level is with respect to 1.

The noise level (rms_n) , which is the rms value of a set of measurements of the 258 pedestal acquired at different instants, has in turn a variance, that propagates 259 to the anomaly level. Hence, for each ASIC, the median, the lower quartile q_1 260 and the upper quartile q_3 of the set of the 128 anomaly levels in the ASIC 261 are calculated. Then, every single $(ANOM_n)$ is compared to q_1 and to q_3 : 262 the cut level is defined with the help of an arbitrary constant L, so that a 263 channel n is defined "low" or "dead" if $ANOM_n < q_1^L$, while it is "noisy" if 264 $ANOM_n > q_3^L$. In the analysis, it has been chosen L = 15. 265

An example concerning one of the 24 views is presented in Figure 7; the data shown in this picture refer to measurements acquired from a tray alone, not assembled on the payload, shielded against EM interference, and connected to a testbench electronic interface.

It has to be remarked that before every fit, the channels in the ASIC that are clearly anomalous must be excluded from the fit algorithm, otherwise a bad curve is obtained. The channels that are to be excluded from **the** fit are determined by applying an algorithm similar to the one just described above, except that the "fitting curve" is a flat line whose level is the median of the (rms_n) in the ASIC.

During the analysis, it has been noted that the noisy channels are better
highlighted after the common mode subtraction. Therefore, noise after the
common mode subtraction has been preferably used, instead of the raw rms,
to find the noisy channels, applying the same procedure described above.

²⁸¹ 5 Other quantities to characterize the GRID noise

This section describes the other quantities, in addition to those defined in the pedestal calculation procedure (described in Section 3.2), that characterize and optimize the overall GRID noise and efficiency.

285 5.1 Pull and SNR of a cluster

The pull [2] is defined as the ratio between the signal of the strip with the maximum (C_3) and its rms.



Fig. 6. Noise profile of the 384 channels of a PCB not connected to the silicon detectors. The typical shape of the profile is determined by the different length of the strips on the PCB that are connected to each channel of the ASIC. A dead channel can also be seen.



Fig. 7. Rms and anomaly level of the 1536 channels of an entire view (12 ASICs). In the upper plot, the parabolic fits of the ASICs can be seen; in the anomaly graph, the two cut levels for the evaluation of the low and of the noisy channels are also shown. Dead channels are 598, 768, 1024, 1120, 1152; noisy channels are 383-384, 1150, 1521 to 1523.

²⁸⁸ The signal/noise ratio (SNR) of a cluster is defined as

$$SNR = \frac{\sum_{i} C_{i}}{\sqrt{\frac{\sum_{i} rms_{i}^{2}}{N}}}$$
(3)

where the sum is performed over all the strips N in the cluster itself. Both 289 these quantities have been used for the characterization of the Silicon Tracker. 290 In particular, the peak of the pull (calculated as the most probable value of the 291 fit with a Landau [2]) and the on-axis pull (the pull of particles or converted 292 γ -ray events with incidence angle $< 5^{\circ}$) have been used for a check on the 293 threshold setting values N_1 and N_2 once the Silicon Tracker was integrated into 294 the spacecraft. In addition, the on-axis pull has been used for the evaluation 295 of the presence of events with particle crossing near the floating strip during 296 the various phases of the configuration (see Section 6). 297

298 5.2 Zero cluster events

During the AIV activities, it has been found that the generation of GRID events with no clusters depends on the noise level of the Silicon Tracker itself. When the level 1.5 trigger is passed, all the ASICs over threshold are acquired and the preprocessing procedure is performed; during this procedure it is possible that all the ASICs are zero-suppressed but the on-board logic sends these events to ground within telemetry all the same.

This generation of zero cluster events is due to the fact that if the system is noisy the pedestal rms values are large and the two trigger levels can be passed all the same; on the other hand, the procedure of the pedestal/common mode subtraction and zero suppression eliminates all these clusters. For this reason the number of zero cluster events has been used as a noise indicator during the AIV and in-flight configuration of the Silicon Tracker front-end.

311 5.3 Extra-fired ASICs

As already stated, for each view of the Silicon Tracker the maximum number of triggered ASICs that can be acquired is 8. If more than 8 ASICs trigger (because of physics or because of the noise level of the detectors), only the index of the additional triggered ASICs is sent to ground within the telemetry. These ASICs are called *extra fired* and their number has been used as an additional indicator of noise.

318 5.4 Silicon Tracker rate-meters

The PDHU implements several rate-meters that can be used as indicators of the noise level of the system. In particular, the *ST rate-meters* are the OR of the trigger signals of all the TAA1 ASICs of a view (see Section 3.3). One rate-meter for each plane is generated, but only one view is sampled: the selection of the odd or even views is performed by means of a telecommand. Each rate-meter has an integration window of 16 s.

326 5.5 Central strip charge

The distribution of the charge of the cluster central strip C_3 can be used as indicator of the noise level of the Silicon Tracker. As reported in Section 8, the most probable value of the MIP charge is 630 ADC counts for central strip C_3 , with a tipical distribution that can be fitted with a Landau function. For this reason the percentage of clusters with the central strip charge $C_3 < 100$ ADC counts has been evaluated, since this value is an indicator of a cluster triggered by noise.

³³⁴ 6 Floating strip and efficiency measurement

³³⁵ The total charge collected by the readout strip depends on

• the diffusion during the charge collection;

- the capacitive charge coupling between the strips;
- the incidence angle of the incoming and secondary ionization particles.

As already stated, the AGILE Silicon Tracker is characterized by one float-339 ing strip between each readout strip. If a particle crosses the detector at the 340 position of the floating strip, the charge is collected on this strip and induced 341 on the nearby ones; capacitive charge division will then result in signals on 342 more than one strip. Given the parameters of the detector strip (such as 343 width and pitch of implant strips and Al read-out electrodes), when 344 a particle crosses a floating strip, on each of the adjacent readout ones 38%345 of the produced charge is collected, as determinated experimentally [3]. Such 346 values are compatible with a 100% efficient detector if the trigger threshold 347 is set at 1/4 of the charge released by a MIP crossing the silicon detector. A 348 too high FTB threshold could reduce the detector efficiency preventing the 349 readout strips to generate a trigger in case of an event on a floating strip. 350

If all the parameters are set correctly, the on-axis pull for the strip with the 351 maximum signal in the event shows clearly the presence of the floating strip 352 as presented in Figure 8, obtained with the Silicon Tracker in the final con-353 figuration, already integrated in the spacecraft before the launch. The peak 354 on the left (whose most probable value is 10.6) corresponds to the case of the 355 particle crossing nearby a floating strip, while the peak on the right (with 356 a most probable value at 23.4) is the one of the readout strip collecting the 357 whole charge. 358



Fig. 8. On-ground configuration: on-axis pull for the strip with the maximum with a FTB threshold set to 7 in physical calibration mode (data acquired on RUNID 11119). The peak on the left is due to the floating strip, while the peak on the right to the readout strip. The two peaks are fitted with a simplified Landau. The plot includes the data from all the ST planes.

³⁵⁹ The easiest way to measure the plane efficiency is the following

$$eff(N) = N_s/N_t \tag{4}$$

where N_s is the number of GRID events with a signal (at least one cluster for 360 each plane) in the planes N-2, N-1, N, N+1, N+2 and N_t is the number of 361 GRID events with a signal (at least one cluster for each plane) in the planes N-362 2, N-1, N+1, N+2. The ST efficiency is the mean value of the plane efficiencies. 363 The formula cannot be applied for planes 1, 2, 11 and 12, but due to the fact 364 that there is a difference between the efficiencies of the different planes of the 365 order of 1 - 2%, this formula has been used for the determination of the ST 366 efficiency. 367

³⁶⁸ The optimization of the ST efficiency was the main goal of the ST configura-

tion performed during the AIV and in-flight commissioning phases.

370

³⁷¹ 7 FTB threshold scan and strip mask definition

During the AIV activities several levels of the FTB threshold have been tested. 372 All the tests have been performed with the same environmental conditions. 373 For each threshold different strip masks have been chosen; in fact, the number 374 and identity of noisy strips change as a function of the threshold and differ-375 ent masks of disabled strips have to be defined. This iterative procedure for 376 the FTB threshold scan and noisy strip disabling has allowed the final con-377 figuration of the Tracker front-end; for each threshold the following steps are 378 required: 379

• First step:

a set of consecutive (typically 8-10) pedestal runs (telemetry type 3903)
 is performed allowing to create a first list of noisy strips resulting from
 the statistical analysis of the pedestals themselves (i.e. tagging individual
 strips displaying fluctuations not compatible with those expected
 according to poisson statistics from average strip signal);

a second list is produced with the analysis of an electrical calibration (telemetry type 3904); the strips above a threshold (5 times the mean value of the number of triggers of all the strips of an ASIC) are selected. The digital value of the parameters used for electrical calibration are 1 for amplitude and 5 for threshold (see Section 3.4);

These two lists are merged with a list of 242 noisy strips (about ~ 0.6% of total strips) identified during the Silicon Tracker assembly with the procedure described in Section 4.

Second step: this first list is uploaded in the PDHU and an acquisition of 394 GRID events in physical calibration mode (telemetry type 3902) is per-395 formed. Noisy strips are searched for in this data set: for each ASIC the 396 mean μ of the number of times δ_i that a strip *i* is a center of a cluster is 397 calculated. A strip i is noisy if $\delta_i > \mu N$. A typical value of N used during 398 this analysis is 3; with this value a good equalization of the counts of each 399 strip has been obtained. At the end of this procedure a new list is produced. 400 Third step: the list is tested with a new physical calibration and the proce-401 .

dure is repeated if there are still noisy strips. The ST rate-meters are used as a quick look of the data quality of the configuration and the already described noise indicators (see Section 5) and the ST efficiency are evaluated. The procedure stops when good noise indicators have been obtained and a run of GRID observation (telemetry type 3901) is performed as the last check of the current configuration. This run allows to evaluate the efficiency and noise level of the system with the same parameters used in physical ⁴⁰⁹ calibration together with the topology of the acquired events.

⁴¹⁰ Once this procedure is completed, the FTB threshold is changed and the ⁴¹¹ process restarts.

 $_{\rm 412}$ $\,$ The lower the FTB threshold, the higher the ST efficiency. The FTB threshold

scan procedure stops when the ST noise becomes too high and too many strips (more than 6 - 7%) should be disabled.

⁴¹⁵ The values of FTB thresholds reported in this paper are digital values without ⁴¹⁶ a direct correspondence with the MIP.

⁴¹⁷ For each strip mask the following quantities have been used to decide if the ⁴¹⁸ current configuration is correct and the noise is under control:

- maximum peak of the pull and presence of the floating strip peak in the on-axis pull;
- SNR ratio;

Table 1

- ₄₂₂ percentage of zero cluster events;
- ⁴²³ percentage of extra-fired ASICs;
- ST rate-meters;
- counts of clusters with $C_3 < 100$ ADC counts.

A configuration is good when the first 2 parameters of the list (in addition with
the ST efficiency) have been maximized and the remaining ones minimized.
In addition, the value of ST rate-meters should be uniform for each view.

In Table 1 the number of disabled strips for each configuration is reported. The
configuration named 5 has been used during the GRID calibration performed
in November 2005 at the INFN Laboratories of Frascati (Rome), while configuration 6 was the on-board configuration selected before the launch campaign.
Configurations 7 and 8 have been defined during the in-flight commissioning
phase performed in May-June 2007.

| Configurat | ion | Nr of disabled | % of total | | |
|----------------|------|----------------|------------|--|--|
| Name (I ID) | Mask | strips | strips | | |
| 5 | | 1956 | 5.3 | | |
| 6 | | 529 | 1.4 | | |
| 7 | | 407 | 1.1 | | |
| 8 | | 665 | 1.8 | | |

Number of disabled strips for each configuration

⁴³⁵ 8 ST characterization at the end of the AIV activities

The ST final configuration is a trade-off between the noise level and the efficiency of the Silicon Tracker and is the result of 597 runs in observation mode (telemetry type 3901) and 996 runs in physical calibration mode (telemetry type 3902) during the AIV activities. Each run is identified by its own RUNID number in the AGILE test environment (see [11]-[14]). In the following, one of the final runs is presented as an example (RUNID 11119). The main parameters of this final pre-flight configuration are the following:

- side X pull: 16.7 ± 0.2
- side Z pull: 16.2 ± 0.2
- events with less than 3 clusters: 1%
- clusters with less than 100 ADC counts for the central strip: 0%
- side X efficiency: $95 \pm 2\%$
- side Z efficiency: $97 \pm 2\%$

⁴⁴⁹ The strip mask used for this configuration is named 6 with 529 disabled strips.



Fig. 9. On-ground configuration: cluster total charge in ADC counts with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ . Data acquired on RUNID 11119; the plots contain the data from all the ST planes.

Figure 9 shows the total charge deposit in ADC counts of each cluster with
the FTB threshold set to 7 with data acquired in physical calibration mode.
Figure 10 presents the charge (in ADC counts) of the cluster central strip: for

⁴⁵³ near on-axis events it is possible to clearly distinguish the two peaks (first plot

⁴⁵⁴ at the upper left of the Figure) corresponding to the floating strip (peak on the



Fig. 10. On-ground configuration: charge in ADC counts of the central strip C_3 with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ . In the first plot the peak on the left is due to the floating strip, the peak on the right to the readout one. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.



Fig. 11. On-ground configuration: pull for the strip with the maximum signal in the event with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ . Data acquired on RUNID 11119; the plots contain the data from all the ST planes.

left) and to the readout one (peak on the right). The two peaks merge into onefor increasing incidence angles as a consequence of the charge signal spreading



Fig. 12. On-ground configuration: SNR with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ . Data acquired on RUNID 11119; the plots contain the data from all the ST planes.



Fig. 13. On-ground configuration: total width of the clusters with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ . Data acquired on RUNID 11119; the plots contain the data from all the ST planes.

⁴⁵⁷ over more strips for large inclinations. **Considering all inclinations** the ⁴⁵⁸ most probable value is about 630 ADC counts; this means that the conversion ⁴⁵⁹ factor between C_3 (ADC counts) and MIP signal is about 0.174 keV / ADC 460 count.

⁴⁶¹ Figure 11 shows the pull for different incidence angles of GRID events.

⁴⁶² Figure 12 shows the SNR for different incidence angles and Figure 13 the total

⁴⁶³ width of the clusters. This Figure demonstrates clearly why only 5 strips have

⁴⁶⁴ been sent to telemetry.

⁴⁶⁵ 9 The threshold scan during the in-flight configuration

⁴⁶⁶ During the in-flight configuration performed in the commissioning phase in ⁴⁶⁷ May-June 2007 a scan of the FTB thresholds with the definition of new strip ⁴⁶⁸ masks has been performed. The Silicon Tracker has been switched on the first ⁴⁶⁹ time after the launch with a FTB threshold set to 20; the tests reported in ⁴⁷⁰ Table 2 and Table 3 have been carried out after a verification that everything ⁴⁷¹ was working correctly.

Figures 14-17 report the on-axis pull for 3 values of the threshold (20, 6 and b) and for the chosen final configuration (FTB threshold set to 6 and strip mask definition identified as configuration 8).



Fig. 14. In-flight configuration: pull with the threshold set to 20 and strip mask ID 6 in physical calibration mode (data acquired with orbit 253) for GRID events with different incidence angles θ . The plots contain the data from all the ST planes.

Table 2 reports the noise and efficiency indicators in physical calibration mode and Table 3 in observation mode.

Figure 14 shows the pull of the first in-flight switch-on of the Silicon Tracker after the launch with the FTB threshold set to 20; as expected, the peak of



Fig. 15. In-flight configuration: pull with threshold set to 6 and strip mask ID 6 in physical calibration mode (data acquired with orbit 510) for GRID events with different incidence angles θ . The plots contain the data from all the ST planes.



Fig. 16. In-flight configuration: pull with threshold set to 5 and strip mask ID 7 in physical calibration mode (data acquired with orbit 522) for GRID events with different incidence angles θ . The plots contain the data from all the ST planes.

the floating strip is not present, but this Figure, together with the additional parameters of the orbit 253 reported in Table 2 has proven that everything worked well after the launch.

 $_{\tt 482}$ $\,$ Figure 15 reports a test in physical calibration mode with the FTB thresholds $\,$

⁴⁸³ set to 6 and the same strip mask defined with the on-ground configuration.



Fig. 17. In-flight configuration: pull with threshold set to 6 and strip mask ID 8 in physical calibration mode and final strip mask configuration (data acquired with orbit 535) for GRID events with different incidence angles θ . The plots contain the data from all the ST planes.

Table 2

On-ground (first row) test performed at the end of AIV activities and in-flight test performed during the commissioning phase in May-June 2007 (see Table 1 for a definition of the strip mask identifier): comparative table for GRID physical calibration mode. The orbit 535 has the same configuration of orbit 536.

| Orbit | FTB Thr | Mask ID | Pull X/Z | % event < 3 cl | $\% C_3 < 100 \\ ADC$ | Eff. X | Eff. Z |
|--------------|------------|------------|---|----------------------|-----------------------|-------------|------------|
| RUN 11119 | 7 | 6 | $\begin{array}{c} 16.7/16.2 \pm \\ 0.2 \end{array}$ | 1.0% | 0.0% | $95\pm2\%$ | $97\pm2\%$ |
| 253 | 20 | 6 | $\begin{array}{c} 16.7/16.7 \pm \\ 0.3 \end{array}$ | 1.5% | 0.2% | $80\pm 3\%$ | $83\pm2\%$ |
| 510 | 6 | 6 | $\begin{array}{c} 18.1/17.4 \pm \\ 0.1 \end{array}$ | 5.0% | 2.5% | $96\pm1\%$ | $97\pm1\%$ |
| 522 | 5 | 7 | $\begin{array}{c} 17.0/17.4 \pm \\ 0.2 \end{array}$ | 7.5% | 2.5% | $96\pm2\%$ | $97\pm1\%$ |
| 536 | 6 | 8 | $\begin{array}{c} 17.2/17.2 \pm \\ 0.2 \end{array}$ | 7.0% | 2.0% | $96\pm2\%$ | $98\pm2\%$ |

It is possible to see that with respect to the data acquired on-ground (see Figure 11) an additional noise peak was present (last plot) in events with an incidence angle greater than 50°: this means that for the higher incidence angle events a larger fraction of clusters due to noise are recorded,

Table 3

In-flight test performed in GRID observation mode during the commissioning phase in May-June 2007 (see Table 1 for a definition of the strip mask identifier): comparative table.

| Orbit | FTB Thr | Mask ID | Pull X/Z | % ex- tra fired | $\% \ C_3 < 100 \ { m ADC}$ | Eff. X | Eff. Z |
|-------|------------|------------|---|-----------------------|-----------------------------|------------|------------|
| 494 | 20 | 6 | $17.9/17.4 \pm 0.2$ | 1.0% | 1.0% | $84\pm3\%$ | $88\pm3\%$ |
| 495 | 10 | 6 | $17.8/17.0 \pm 0.3$ | 2.0% | 1.0% | $92\pm2\%$ | $93\pm2\%$ |
| 507 | 7 | 6 | $17.8/17.0 \pm 0.1$ | 6.5% | 1.0% | $94\pm2\%$ | $95\pm2\%$ |
| 509 | 6 | 6 | $\begin{array}{c} 17.8/17.0 \pm \\ 0.2 \end{array}$ | 10.0% | 2.0% | $95\pm3\%$ | $95\pm3\%$ |
| 520 | 6 | 7 | $\begin{array}{c} 17.7/17.0 \pm \\ 0.2 \end{array}$ | 6.6% | 2.0% | $94\pm2\%$ | $95\pm1\%$ |
| 523 | 5 | 8 | $\begin{array}{c} 18.2/17.0 \pm \\ 0.3 \end{array}$ | 11.0% | 1.5% | $96\pm2\%$ | $95\pm1\%$ |
| 538 | 6 | 8 | $\begin{array}{c} 17.5/17.0 \pm \\ 0.2 \end{array}$ | 8.0% | 1.0% | $96\pm2\%$ | $95\pm1\%$ |

a characteristic present only after the launch with this strip mask configu-488 ration; for highly incidence angle events the noise peak becomes relatively 489 more important with respect to the bulk of particle clusters (because they 490 are less) and thus it can be easily identified. To reduce this problem a new 491 strip mask (called 7) has been defined and new tests with the orbit 522 have 492 been performed (see Figure 16 and Table 2). Due to the time constraint of the 493 commissioning phase, also a test with the FTB threshold set to 5 has been 494 performed in the same orbit. 495

The final configuration has been reached with orbits 535-536 (see Figure 17 and Table 2). For a better stability of the system during the nominal phase a threshold of 6 has been chosen with the strip mask indicated with 8 with 665 disabled strips corresponding to 1.8% of the overall Silicon Tracker channels. A test in the GRID observation mode has been performed with the same configuration used in the physical calibration mode. The main results are reported in Table 3.

It is important to note the progressive trend towards improving of the in-flight ST configuration. In particular, the quite high values of the overall ST detection and trigger efficiency (95-96 %) have to be underlined. Considering the peculiar AGILE ST working and readout system based on analog signals, these **high efficiencies** are very important for an optimal scientific performance of ⁵⁰⁸ the instrument.

509 10 Conclusions

This paper presents the main results of the extensive testing campaigns of the 510 AGILE Silicon Tracker electronic configuration. The ST has been configured 511 in different steps, and it reached an optimal performance during the pre-512 launch and post-launch tests. After almost 2 years of in-orbit operations the 513 ST configuration that was consolidated during the commissioning phase is 514 quite stable. Additional noisy strips (about 20) have been identified during 515 the day-by-day data observations in the first 2 years with a negligible effect 516 on the overall performance. The AGILE Silicon Tracker, that is the heart of 517 the instrument, is then optimally configured and its digital readout system is 518 remarkably stable for scientific observations in space. 519

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