APPLICATIONS OF APS DETECTOR TO GNC SENSORS

Franco BOLDRINI, Elisabetta MONNINI, Dorico PROCOPIO
Galileo Avionica Space Equipment B.U. – A Finmeccanica Company
Via A. Einstein 35, 50013 Campi Bisenzio (Firenze) - Italy
Phone : +39 055 8950700, Fax No: +39 055 8950613
E.mail: franco.boldrini@officine-galileo.finmeccanica.it
elisabetta.monnini@officine-galileo.finmeccanica.it
dorico.procopio@officine-galileo.finmeccanica.it

Abstract
CMOS Active Pixel Sensors (APS) are becoming attractive devices for space applications. Many technological improvements have been gained in the last years, so that present APS’s feature radiation hardened design, on chip AD converter and Fixed Pattern Noise suppression circuits.

Several programmes have been funded by ESA to support the development of the APS and the applications of this device to attitude sensors and vision cameras.

In the frame of these ESA contracts, Galileo Avionica is currently involved in the design and development of APS based sun sensors, star trackers and navigation and vision camera, with the main goal to significantly reduce the mass, size and recurring costs of these sensors.

1. INTRODUCTION

The Galileo Avionica’s heritage on attitude sensors for space platforms is well consolidated and can take advantage of more than three hundreds of successfully flown instruments.

Earth sensors, sun sensors and star sensors have been delivered to customers all over the world.

In order to maintain the necessary technological survey and expertise, Galileo Avionica are developing several programs based on the introduction of APS detectors for new generation of Sun and Star Sensors and for Navigation Cameras. Further, the experience gained with APS can be easily applied to smart cameras for planetary exploration.

An overview of the running activities is presented in this paper.

2. APS DETECTOR

In the frame of the ESA/ESTEC contract for the realisation of a Smart Sun Sensor (SSS) prototype, the development of an APS was carried out by FILLFACTORY, under GALILEO AVIONICA specifications.

The detector is a CMOS image sensor that contains an array with 1024 by 1024 pixels at 15-µm pitch. It includes on-chip Fixed Pattern Noise (FPN) correction, a programmable gain amplifier a 10-bit Analogue to Digital Converter (ADC) and antiblooming feature.

All circuits are designed using the new radiation tolerant design rules for CMOS image sensors, to allow a high tolerance against total dose effects.

Radiation testing performed on this detector has shown electro-optical functionality after total dose radiation up to 1 Mrad.

3. SMART SUN SENSOR

The Smart Sun Sensor (SSS) consists of an attenuation filter with a photoengraved pin hole, an APS detector for the Sun spot imaging, a proximity electronic for data processing (baricentre detection of the incident energy of the Sun) and power interfaces.

The summary of the SSS key characteristics is:

- Dimensions: 110x108x42mm
- Mass: < 330gr
- Operating temp.: -35°C to +70°C
- Power cons.: <1W with DC/DC
- Field of view: 128 x 128 deg
- Accuracy: < 0.02 deg (2σ)
- Resolution: < 0.005 deg

All the functions are controlled by the logic implemented in an ASIC.

Electronics have been selected to withstand a total dose greater than 100 Krad.

In the acquisition mode, the whole FOV is searched in order to find the sun presence. Then, coarse sun coordinates (few pixels accuracy) are estimated and the Sun tracking mode automatically commanded. A pixel window is addressed around the centre estimated in the previous cycle and accurate Sun position is calculated. The Sun will be tracked till its image remains in the
FOV. When the Sun is lost, the Sun acquisition mode is addressed again.

**Fig. 1 Smart Sun Sensor**

The SSS I/F are:

- Sub-pixel Sun position and housekeeping digital I/F
- Bi-level Sun Presence (SP) line for signalling the presence of the Sun in the FOV
- Unregulated power converter from 24V to 50V or pre-regulated +5V
- Test interface for testing purpose with Sun electrical stimulation

The SSS has been successfully subjected to a test campaign, aimed at the concept and performance validation. Validation is performed using calibrated rotation axis and a sun simulator with 1/100 of the sun constant as depicted in Fig 3.

**Fig. 3 Validation test set up**

A calibration procedure has been performed to compensate the mechanical tolerance of the assembly. Dedicated calibration can improve the accuracy in a reduced FOV. In Fig. 4 the achievable accuracy is reported as function of the field of view and demonstrates that 36 arcsec 1σ residual error can be achieved in the whole FOV (±64°). More complexity of the calibration polynomial leads to better accuracy maintaining the resources occurred in terms of memory and floating point operations within the availability of the AOCMS.

**Fig. 4 Accuracy vs FOV**

The SSS functionality’s have been verified after environmental stress. The sensor has been submitted to thermal between –35°C to +70°C and vibration tests up to 21 grms with performance confirmation.
The sensor is considered commercially attractive in terms of price – performance ratio, and thanks to its flexibility design, is able to cover a wide range of applications.

4. APS BASED STAR TRACKER

GALILEO AVIONICA is one of the world wide leader in the design, manufacturing and testing of CCD based star trackers.

Star trackers have been delivered for several missions: ISO, SOHO, XMM, INTEGRAL, ROSETTA, MARS EXPRESS, CASSINI, MESSENGER, STEREO and RADARSAT2.

As natural evolution of this wide experience, GALILEO AVIONICA is currently involved on a ESA contract for the development of the APS based miniaturised star tracker for harsh environment for the Bepi Colombo spacecraft.

The contract started January 2002, and a successful Critical Design Review was held on December 2002.

The star tracker is based on the same STAR 1000 APS used on the Smart Sun Sensor.

The sensor is conceived as a single case sensor (see fig 5), with the boresight orthogonal to the mounting plane.

The main structure supports also the baffle that prevents optics from stray light.

The sensor architecture is reported in figure 6.

The APS, provided with the A/D converter, is directly interfaced with an ASIC designed by GALILEO AVIONICA. The ASIC performs image processing, star data extraction and timing and control of the APS, on the basis of the commands received by the µP.

EEPROM and RAM with Multi Chip Module (MCM) technology has been used to minimise PCB size and thus mass.

A low power consumption synchronous RS422 serial DS 16 I/F is used for telecommand reception and telemetry transmission.

Fig. 6 Bepi Colombo Star Tracker architecture

The use of components radiation tolerant, combined with the use of the specifically designed radiation tolerant APS, makes this sensor particularly robust to space radiation environment. In addition, since of the direct access readout of the APS, these components are free from Charge Transfer Efficiency (CTE) reduction effects, that can limit CCD operations in high flux proton environment.

The robustness of the star tracker to radiation environment is further increased by dedicated features:

- Algorithms that allow to perform attitude determination, within 9 seconds, even in presence of 1400 false events per frame have been studied and validated
- EEPROM and RAM are EDAC protected, so that single bit error is corrected and double bit error is detected
- An autonomous procedure for hot pixel detection is implemented for in flight maintenance of hot pixels look up table.

The sensor is provided with 4 main operatives modes:

- High Angular Rate Mode (HARM)
- Autonomous Attitude Determination Mode (AADM)
- Nominal Environment Autonomous Tracking (NEAT)
• Harsh Environment Autonomous Tracking (HEAT)

The HARM is used to determine the angular rate of the spacecraft for rates up to 4 deg/sec. This mode can be useful during the first stabilisation phase, to support rate reduction.

The AADM is capable of attitude initialisation without any external support (lost in space solution).

The NEAT mode performs attitude tracking, once initial attitude has been computed.

The HEAT mode performs in a similar way to the NEAT, but operates with a reduced number of tracking windows of larger size.

This mode is suitable for tracking during main engine fairing, where high vibration and acceleration can lead the star spot to lay outside the window size of the NEAT.

The HEAT mode can be also used for direct entrance in tracking mode, when the initial attitude is known with an accuracy better than 0.3 deg.

The sensor is provided with other operative modes used for sensor management;
• Initialisation mode (INI) used for H/W initialisation
• Stand by (STB) used to maintain the sensor ready to operate
• Photo mode (FOTO) to transmit a portion of the raw image
• Software Maintenance (SWM) to perform in flight upload/download
• Commanded tracking (CTM) for calibration and on ground testing

The following rules for state transition apply:

1) HARM mode to AAD transition will autonomously occur when measured rate will be lower than a prefixed value.

2) In case of failure of the HEAT or NEAT mode, the AAD is autonomously attempted.

3) If after a prefixed number of attempts, the STR is not able to perform attitude determination, the HARM node is autonomously addressed.

4) The HEAT mode can be commanded with a parameter to enter in NEAT autonomously after a settable number of HEAT cycles

The APS based star tracker key characteristics are reported in the following table.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV</td>
<td>20 ° full cone</td>
</tr>
<tr>
<td>Attitude accuracy</td>
<td></td>
</tr>
<tr>
<td>Pitch, yaw</td>
<td>7 arcsec (2σ)</td>
</tr>
<tr>
<td>Roll</td>
<td>55 arcsec (2σ)</td>
</tr>
<tr>
<td>Star magnitude limit</td>
<td>Mi=5.2</td>
</tr>
<tr>
<td>Prob. of attitude determination</td>
<td>&gt; 99.9 % @ 0 SEU/frame</td>
</tr>
<tr>
<td>within 9 seconds</td>
<td>&gt; 99 % @ 1400 SEU/frame</td>
</tr>
<tr>
<td>Update rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Outputs</td>
<td>Quaternion</td>
</tr>
<tr>
<td></td>
<td>Angular rate</td>
</tr>
<tr>
<td>Mass</td>
<td>1.090 Kg (including baffle with 40° exclusion angle)</td>
</tr>
<tr>
<td>Size</td>
<td>115 x 115 x 100 without baffle</td>
</tr>
<tr>
<td></td>
<td>115 x 115 x 183 mm with baffle</td>
</tr>
<tr>
<td>Power consumption</td>
<td>3.8 W</td>
</tr>
<tr>
<td>Data I/F</td>
<td>Synchronous RS422</td>
</tr>
</tbody>
</table>

Table 1 Bepi Colombo star tracker characteristics

6. CONCLUSIONS

APS detectors can find a large spectrum of applications for attitude sensors and vision based navigation cameras.

In particular, the high tolerance to radiation of this device, allows to potentially extend the sensor operability to high proton flux environment, where CCD can suffer for charge transfer efficiency degradation.

The single voltage supply, and the full digital I/F allows to significantly reduce the amount of needed electronics, and overall mass and power consumption.

7. REFERENCES


8. ACKNOWLEDGEMENTS

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The development of the Bepi Colombo star tracker is performed under ESA contract no. 15933/02/NL/ JA