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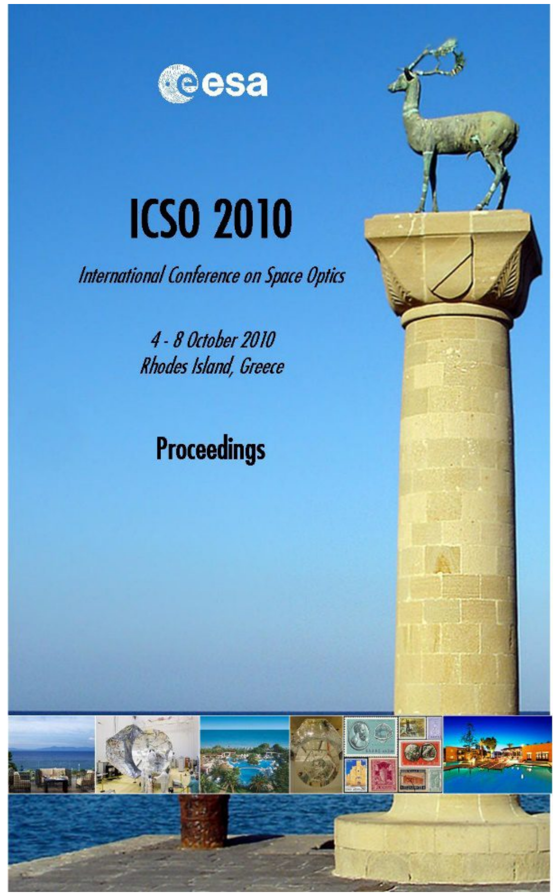

Now is the time for the sunsensor of the future

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NOW IS THE TIME FOR THE SUNSENSOR OF THE FUTURE

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INTRODUCTION

What started as an academic development in frame of the Dutch MicroNed program five years ago should culminate in the introduction of the smallest digital sunsensor available in (and probably outside) of Europe at the ICSO. At the ICSO, TNO plans to show for the first time a working mini-DSS, based on the APS+ chip. The sunsensor has been optimized for low power, low recurring costs and high repeatability in production. In order to achieve this, several innovations have been included and verified in a diverse range of supporting programs. During the presentation, trades performed that lead to the current setup, as well as the properties of the sensor system and interfaces will be discussed.

I. BACKGROUND

TNO has been involved in the design manufacturing and qualification of sunsensors for more then 30 years. At this moment we are transferring the manufacturing and testing for larger quantity sunsensors to Bradford Engineering in Heerle (The Netherlands) (www.bradford-space.com). This transfer of knowledge and projects has been initiated because we have been successful in selling comparatively large quantities of sunsensors to constellations like Galileo and Globalstar-2 (see fig1) and TNO as a contract research organization as such is not very suited to do large volume production.

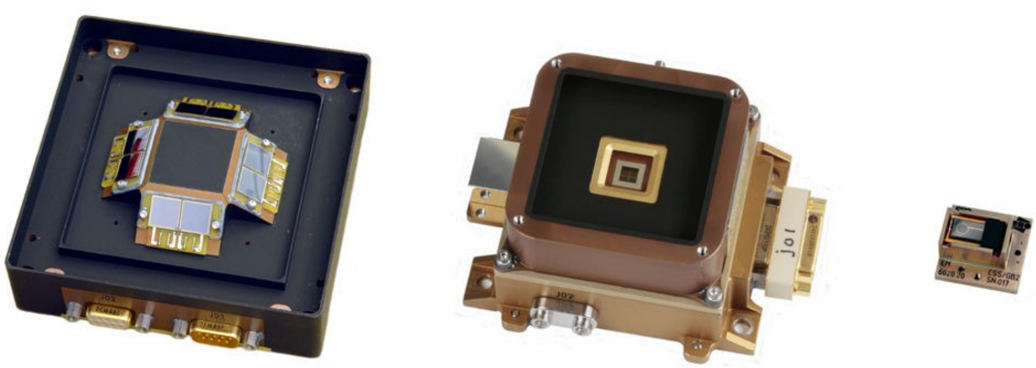


Fig 1 Coarse and fine sunsensors in production in (large) numbers for constellations

As we see a shift from mission specific sensors to more cost effective space grade of the shelf (SOTS) components, TNO is also offering to the market small sensors for use on for instance micro and nanosatellites through ISIS. www.isispace.nl. The SOTS program will be expanded with a small digital sunsensor and potentially a low cost coarse sunsensor in the future (see fig 2). All these sensors will be suited to serve a majority of missions at the right cost and reliability level for a substantially lower price then currently available on the market.

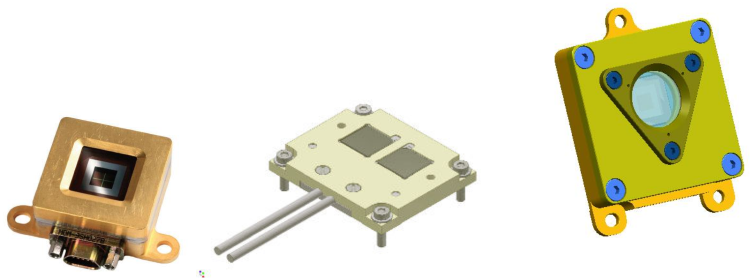


Fig 2 current and future space grade off the shelf components

The small digital sunsensor called mini-DSS is the actual topic of this paper.

The Development of the mini-DSS started with the Dutch technology development program MicroNed. Part of this program (the so called MISAT cluster) consisted of developing miniaturized subsystems for micro and nano satellites. The original idea submitted for this program consisted of a micro digital sunsensor. This sensor distinguished itself from other sensors by the fact that it was fully autonomous in the sense that the power supply was provided by a dedicated solarcell mounted on the top of the housing and that a wireless data interface was integrated with the electronics in the bottom of the housing (see fig 3).

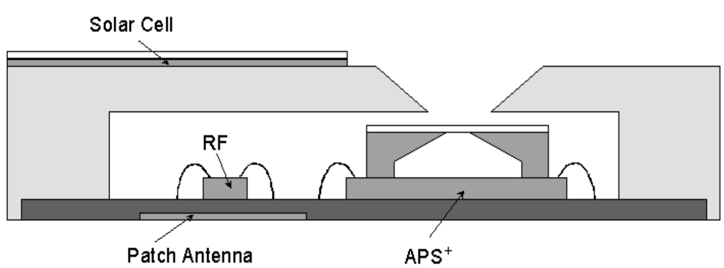


Fig 3 micro-DSS

This setup was the result of a short feasibility study looking at miniaturized sunsensors, which lead to the result that the size of the sensor was determined by the power consumption (solarcell size) in the X/Y directions and the connector in the Z direction. Based on these findings it was decided to develop a low power circuit and use an RF wireless interface for data communication.

The main deliverables for the MicroNed program were:

1. Autonomous Wireless Sun Sensor demonstrator (AWSS, based on a standard detector technology)
2. Demonstration of the immersed sunsensor technology where the carrier substrate of the aperture mask is also used as a spacer between the aperture mask and the detector
3. A highly miniaturized and power optimized ASIC called APS+ which is actually a sunsensor on a chip type of device (see fig 4).

The APS+ is an application specific integrated circuit (ASIC) specially designed and optimized for sunsensing application. The circuit combines an imager section with FPGA functionality, embedded in a single chip. Manufactured in 0.18 micron TSMC multi project wafer technology, the chip shows some very interesting properties that are well suited to low cost application in space like:

- radiation tolerance up to at least 100krad which is sufficient to withstand the doses received during the majority of missions
- low power dissipation
- High quality and uniformity of performance due to large volume of circuits produced.
- Low recurring costs due to the used multi project wafers and standard processes.

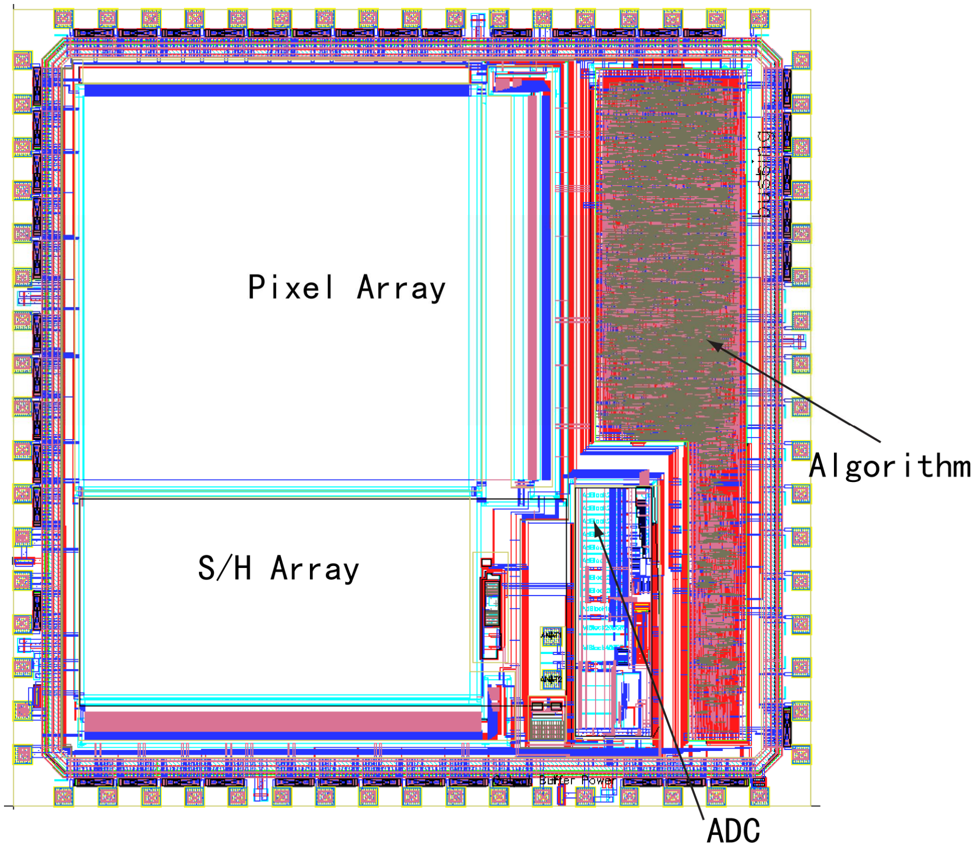


Fig 4 APS+ ASIC basic layout.

The APS+ itself is a so called system on a chip, who's main sub-circuit functions are:

- Active pixel array of 386*386 pixels with pixel size of 6.5 micron
- Pixel array control signal generator
- Analog to digital converter
- Digital signal processor for sun acquisition and sun spot centroïd determination
- Digital communication sub-circuits.

N.B The array controller, digital processor and communication circuits together are called algorithm in fig. 4

One of the main distinguishing features of this chip is the fact that the power consumption in both acquisition and tracking mode are approximately the same due to including some dedicated hardware. This feature allows to minimize the size of a solar cell required in case autonomous powering is used (because the size of this solar cell has to be sufficient to supply the peak current required.[R1]).

In order to build a full functional sunsensor out of this chip the only items needed are:

- 3.3V power supply
- 1.8V power supply
- Clock signal
- Membrane type of mask with pinhole aperture [R2]

II. LIFE AFTER MICRONED

As the MicroNed program goal was the development of the APS+ chip and the chip alone doesn't make a sensor system, TNO explored means to continue with the development of a sensor system. One of the steps taken was the consultation of key players in the field of sunsensor application, being satellite builders and space agencies. ESA, NSO, Thales Alenia Space, ASTRIUM, SSTL, OHB, AAC and a number of universities were approached. Although limited in span, the customer consultations lead to some interesting conclusions:

- Wireless interfaces are interesting but not mature enough to become offered as a standard solution at this time already.
- For the current generation and next generation satellites the main drive is not for the smallest system but for a versatile low cost system.
- Low power and high rigidity are seen as assets but high reliability is a main issue.
- Autonomous powering is very interesting as it will have a significant impact on the (reduction of the) amount of support circuits required at satellite level.

These conclusions have lead to the concept of the mini-DSS which is driven by low production cost, low power consumption and relative ease of qualification (rather than aiming for the absolute minimum size) and versatility (the mini-DSS design can be expanded with autonomous powering and wireless interfaces in case requested).

The building of a first demonstration unit is supported by the Netherlands Space Office (NSO) in the frame of a PEP (Prequalification for ESA Program) study. The aim of the study is to build an innovative digital sunsensor in a package which is significantly smaller then anything currently available on the market and demonstrate it's functionality.

To this extent TNO has sought cooperation with Lewicki Microelectronics in Oberdischingen (Germany) for high reliability pick and place and hybrid manufacturing technology and AXON Cable in Montmirail (France) for integrated micro connector technology. Details are further discussed in the next sections of this paper.

III. MINI-DSS

The current version of the mini-DSS is based on an all-Aluminum-oxide approach, as investigated in cooperation with Lewicki Microelectronics (see fig 5).

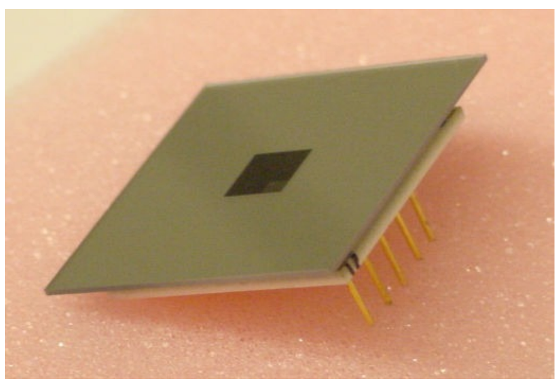
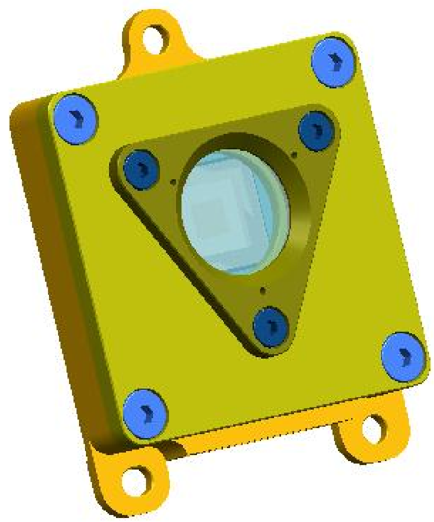


Fig 5 All Al2O3 sunsensor

For our sunsensor, one of the key parameters is the distance between the detector (APS+ image area) and the aperture [R2. In our design this distance is established by means of an Al2O3 spacer, polished to the right thickness. The APS+ chip will be mounted on an Al2O3 substrate and the membrane with the aperture mask is vacuum-deposited on crystalline Al2O3 (Sapphire). This leads to an all aluminum oxide solution which can be accurately assembled by means of a pick and place machine. Furthermore the minimal differences in coefficients of thermal expansion CTE of the materials used will ensure a very stable performance over temperature. In the current design outline, the membrane with the aperture mask is deposited on the face of the sapphire oriented towards the detector chip. This design choice not to use the developed immersed sunsensor technology (which would have the sapphire in between the aperture mask and the silicon detector chip) is based on risk assessment and on the desire to avoid cross coupling between the X and Y measurement axes of the sensor system. This coupling would be associated with refraction in the sapphire and would make ground calibration of the sensor accuracy performance more difficult.

For the mini-DSS the supporting circuits (like crystal oscillator, power supply circuits and buffers) are mounted on the same alumina substrate as the APS+ chip, and this substrate is mounted inside a package.

The mechanical outline of the mini-DSS is given in figure 6.



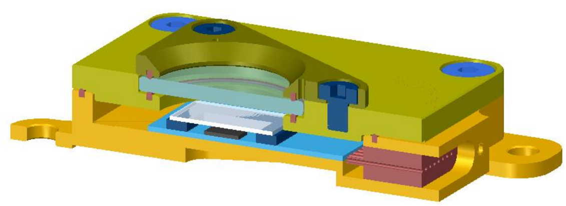


Fig 6 mini-DSS

In this design, the package is made of aluminum in stead of the more commonly used nickel iron alloy (Kovar). Aluminum is lighter, non magnetic and easier to obtain. In addition to this the aluminum has a good thermal conductivity which helps in preventing thermal problems. Another advantage is that it is easier to machine. Furthermore the aluminum doesn’t corrode as easily as Kovar. So it can be protected by means of a relatively simple chromate (alodine or equivalent) coating in stead of the gold coating which is typically used to protect Kovar. As the electrical interface connector needs to be glued into the structural part of the package, alodine treated aluminum offers a better adhesion for the glue than a gold plated surface.

In the design shown above, the package has a removable lid which holds a radiation tolerant sapphire window. The window is coated with an optical attenuation filter to avoid saturation of the APS image sensor. Although sapphire can be welded into aluminum packages, it has been decided to clamp the window in the package with rubber seals and bolts, in order to be able to exchange the filter if needed.

This approach allows for the fabrication of a generic sunsensor which can be programmed by means of straps inside the package even after the calibration is performed.

From the cross section depicted also in fig 6 it is clear that the connector is actually determining a significant part of the system height (as found before). The bottom of the structural part of the package has been elevated to improve the manufacturability of the sensor and to minimize the size of the window needed (in relation to the opening angle of the FOV of the sun sensor).

IV. MINI-DSS core properties

For the moment there is enough data available to define the specifications of the mini-DSS with a fairly high level of confidence. However, since there are no calibration results available yet, the official specifications are set with a considerable margin. This is the reason why the below table has three columns.

	Spec	Target	estimation	
size	51*51*14	51*51*14	51*51*14	mm^3
Weight	<50	<50	45	grams
Power	<100	<50	55	mW
Field of view	47*47 ± 2	47*47 ± 1	47*47 ± 1	Degrees
Non cal. Acc.	3	1	1.3	Degrees 3σ
Calibrated accuracy	0.3	0.1	0.1	Degrees 3σ

As the last version of the APS+ chip was received on 23th of June and still under evaluation, no further data could be provided for this paper apart from the fact that the testing until now has proven to be very successful.
It is the intention to show a working sensor at the ICSO conference.

V. CONCLUSIONS.

Since the APS+ is still under evaluation it is very difficult to give real conclusions, but based on the available data TNO seems well on its way to make a small and versatile mini digital sunsensor that can be used as an attitude sensor on the majority of satellites. The main features are a field of view slightly larger then 45 degrees that will allow for full hemispherical coverage by using 6 sensors on a satellite and the intention to deliver sensors with a guaranteed non calibrated accuracy which would allow for cost effective substitution of coarse sunsensors by mini digital sunsensors.

During the design of the mini-FSS a number of design decisions have been taken which should allow for cost effective manufacturing of the final devices and it is estimated that the price target set by ESA for a mini-DSS (20 kEur/pcs) can be met for recurring production in a Space grade Off The Shelf setting (if the NRE charges are not accounted for and volumes are high enough)

[1] N.Xie, A.Theuwissen,X,Wang*, "a CMOS image sensor with row and column profiling means", IEEE sensors transactions Lecce 2008*
[2] J.Leijtens, K.de Boom, "Micro optical sensors for sunsensing applications," *ICSO 2006*