# A SIMPLE LOW COST DIGITAL SUN SENSOR FOR MICRO-SATELLITES

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ABSTRACT

A Digital Sun Sensor (DSS) has several advantages if compared to the analogue one. It achieves higher accuracy and avoids the problems with light being reflected from the Earth's surface. The gradual degradation of the sensitivity of the elements due to radiation effects is not crucial for its proper functioning. The advances in CCD and recently in CMOS technology make possible to implement the DSS at relatively low prices. The described sensor has accuracy about 0.05°. It contains two mutually perpendicular CCD or CMOS linear arrays and uses no lenses. Its advantages are low mass (0.12kg) and low size (65 x 55 x 25 mm). It provides complete sun vector (two perpendicular angles to the Sun) at a standard serial interface. The digital values of signal of all pixels are also accessible for test purpose.

## 1. INTRODUCTION

The Sun sensor is an important part of an attitude determination system on most of the satellites. The analogue cosine law Sun sensors commonly used in the past had several drawbacks, the main being the following: The reflected light from the Earth's surface could deteriorate the accuracy of the measurement on Low Earth Orbits. Degradation of the photosensitive elements caused by radiation drove down the accuracy of the sensor drastically and the re-calibration during the flight was problematic.

A better solution is a digital slit sun sensor. It allows achieving higher accuracy and avoiding the above-mentioned drawbacks. The first version of DSS developed in the Institute of Atmospheric Physics of the Czech Republic comprised image sensor and AD converter, however a separate data processing unit was necessary to compute the sun vector, and to communicate with a supervising computer. Consequently we have been developing new version of the sensor fitted in a small case, behaving like a fully autonomous independent unit, capable o data processing.

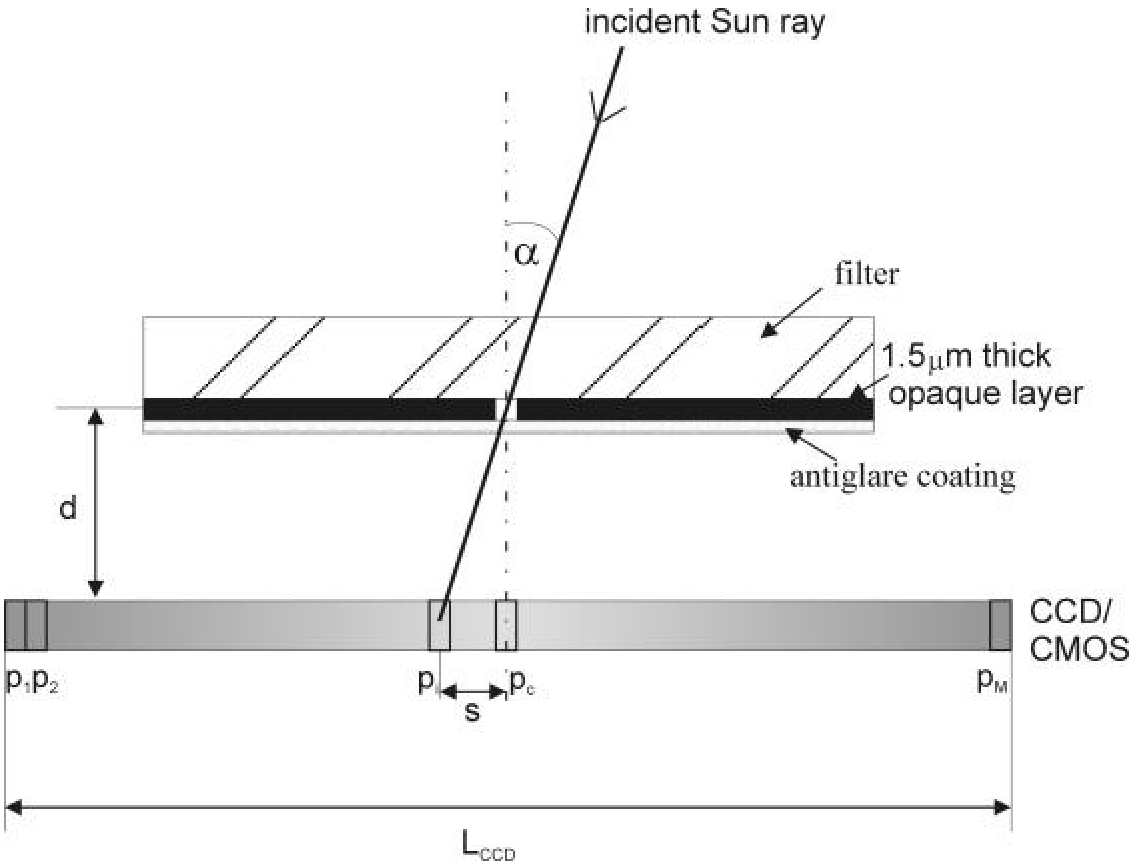
A measurement principle and structure of the sensor is described in the next paragraph.

## 2. SENSOR DESCRIPTION

### 2.1 Principle of measurement and description of the optical part of the sensor

The principle of the measurement and construction of the DSS is schematically shown in Fig. 1. A thin opaque layer with a narrow slit is placed above the CCD or CMOS linear image sensor. Thus the Sun illuminates different pixels in dependence on the angle to main sensor axis. Anti-glare coating coats the opaque layer in which the slit is made to avoid unwanted reflections between filter and image sensor surface. The distance between the image sensor and the slit defines the field of view (FOV) of the DSS. To protect the image sensor against direct Sunbeams and radiation, and to fit the appropriate exposure of the image sensor a special attenuation-filter is used as a front window. There are two identical mutually perpendicular linear image arrays placed in one case. Thus we get two angles between Sun and sensor axis measured in two perpendicular planes what makes the determination of Sun vector possible.

The FOV of a single pixel is about 0.05° degree, and the light intensity of the Sun is several orders higher than the intensity of the light reflected from the Earth. Hence the reflected light does not deteriorate the accuracy of measurement unlike in the case of cosine law sensor, where reflected light can be viewed at very large FOV by an photosensitive element. As a result of that, the digital sensor using a slit sensor is applicable also for satellites on Low Earth Orbits.




$tg\,\alpha = s/d$; $s = k \cdot (p_i - p_c)$
here: $\mathbf{p_c}$ is pixel illuminated at $\alpha = 0$, $\mathbf{p_i}$ is pixel illuminated by the Sun at measured angle, and **k** is constant representing pixel spacing.

**Fig. 1**: Principle of the Digital Sun Sensor. Cross section of the sensor with simplified math is presented. In reality, it is necessary also consider that the opaque layer may not be perfectly plan-parallel to CCD/CMOS surface, and that not only one pixel is illuminated by the Sun.

2.2 Description of the electronics and data handling

All electronics is placed in a small case of size of 65 x 55 x 25 mm and provides the timing for the linear arrays, computation of Sun vector and data communication with the supervising computer or data collection system.

A block scheme of the sensor electronics is presented in Fig. 2. The analogue signal from both linear sensors is tied to the multi-channel AD converter and by means of Direct Memory Access (DMA) transferred in digital form to the SRAM memory. Both the AD converter and DMA controller are the inner parts of the main microprocessor. The auxiliary microprocessor provides the proper timing for image arrays, whereas the main microprocessor is responsible for data processing. According to the regime chosen a computed Sun vector (two mutually perpendicular angles), or signal levels of all pixels are communicated serially to a supervising data collection system or board computer. The latter regime is predominantly used in the case of testing the device.

An optional sub-board with DC/DC converter can be inserted to extend the supply voltage range.

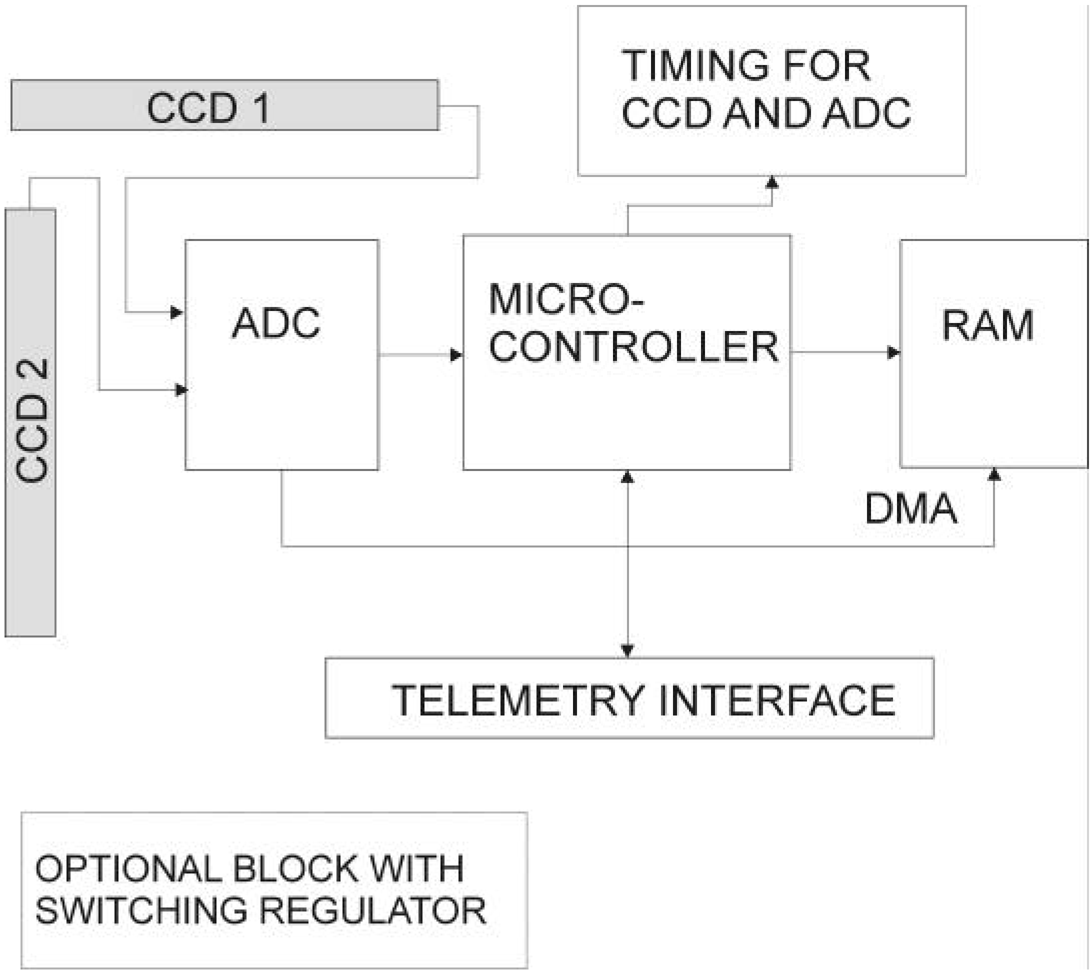



**Fig. 2**: Block schema of the electronics of DSS

## 3. TECHNICAL DATA

| | |
|---|---|
| Number of pixels: | 2048 |
| Field of view (FOV): | 90° (± 45° ) |
| Accuracy: | ~ 0.05° |
| Electric interface: | one of the RS485, RS422 |
| Mass: | 0.12 kg |
| Sizes: | 65 x 55 x 25 mm |
| Power consumption: | < 500mW |
| Digital Output: | computed Sun vector or signal from all pixels |
| Supply Voltage: | nominally 5V, by inserting internal DC/DC converter the Supply Voltage can be extended up to 30 V |

## 4. USING CCD or CMOS

First technological tests of the sensor have been carried out. Since the range of exposure time and dynamical range of the linear CCD sensors, which we have applied were lower than those ones of CMOS, it is more comfortable to use the CMOS sensors. Working with CCDs, it is necessary to find proper attenuation filter for CCD so that the illumination would be on proper level, what is rather cumbersome. Although the linear CMOS sensors have quite recently appeared on the market and are more expensive than the CCD ones, we have decided to use the CMOS in final version to avoid problems with optimal exposure fitting and charge leakage between adjacent pixels. The CMOS sensors have also advantage of lower power consumption.

## 5. CONCLUSIONS

A simple, small (65 x 55 x 25 mm), low weight (0.12 kg), fully autonomous digital sun sensor, suitable for small satellites, has been developed. It consists of two mutually perpendicular linear image sensors mounted below a simple optical system and of data acquisition and processing electronics; all placed in one case. Communicating through standard serial interface, it provides Sun vector with the accuracy about 0.05°. For the final version, linear CMOS image sensors are preferred to CCD ones.


## 6. ACKNOWLEDGEMENTS

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