

International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

Edited by George Otrio



Development and application of a fine sun sensor

Karin Schröter, Eckehard Strumpf, Werner Reich



International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 105701K · © 1997 ESA and CNES · CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2326558

DEVELOPMENT AND APPLICATION OF A FINE SUN SENSOR

Karin Schröter, Eckehard Strumpf,
Werner Reich

Jena-Optronik GmbH, Prussingstraße 41
07745 Jena, Germany

ABSTRACT - For earth orbiting satellites low cost, compact attitude sun sensors are needed with moderate accuracy, high reliability, and a simple system interface. Jena-Optronik Company (DJO) has developed a Fine Sun Sensor (FSS) suitable for 3-axis stabilised spacecrafts and applicable to LEO- and GEO-missions. Our FSS is a minimal configuration analogue design with low power, mass and volume budgets. The sensor design includes advanced technologies in the hardware realization. The modular design concept allows the manufacturing of one-axis and two-axis sun sensors under the same functional principle. By varying only one geometrical parameter sun sensors of different fields of view (FOV) and logically of different measuring accuracies in dependence of those can be manufactured. Because of the modular concept and the simple system interface the FSS can be adapted to different mission requirements. An Engineering Model (EM) of a one-axis sensor head and an EM of a two-axis sensor head with FOV's of ± 64 deg were ground-tested before the Conference. In the scope of this paper the technical approach of the two-axis FSS is presented in detail.

1 - INTRODUCTION

The development of the Fine Sun Sensor suitable for application in telecom missions and small satellites represents a new generation of sun sensors at DJO and is partly funded by a national programme called RAMSES (Raumfahrt Anwendungen der Mikro-Systemtechnik zur Entwicklung von Satelliten).

Advanced technologies and innovative architectures were employed to develop a new sun sensor concept in order to realise savings in mass, dimensions, power consumption and cost. The compact opto-mechanical integration of Si-micro-structures with silicon detectors creates stable, small-sized, thermal-matched sun sensors applicable in wide ranges of thermal and mechanical operating conditions. The modularity of the sensor concept is given by a customized detector layout and a field of view and system interface on request.

The FSS Main Technical Data

Field of View		$-64^\circ \leq \alpha \leq +64^\circ$ $-64^\circ \leq \beta \leq +64^\circ$
Accuracy	Noise Equivalent Angle (1σ) Bias (3σ)	≤ 0.04 deg ≤ 0.5 deg
Mass	one sensor head	250 g
Dimensions	one sensor head	90 mm x 94 mm x 51 mm
Power Consumption		$U_{Bias} = -5V$, $I_{Bias} = 5mA$

2 - DESIGN CONCEPT

Fig. 1 represents the main functional principle of the sun sensor.

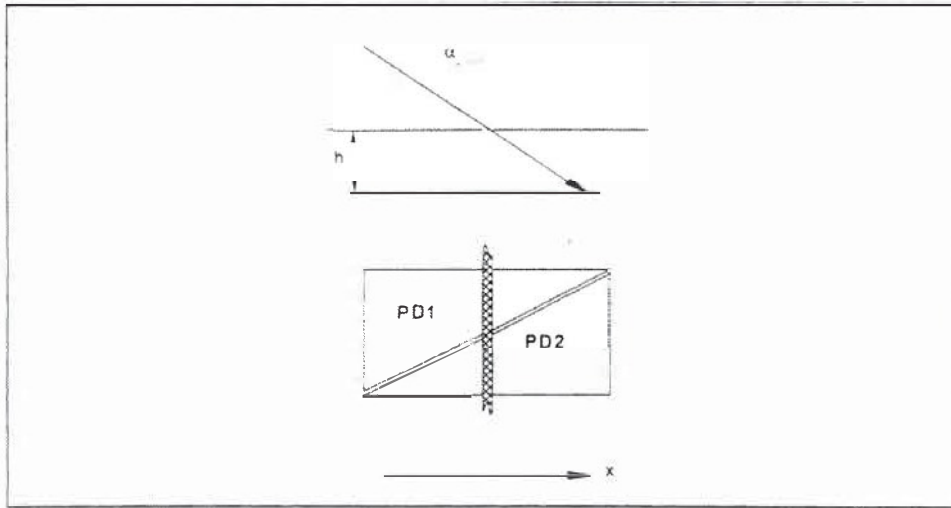


Fig. 1: FSS main functional principle

Via a slit the sunlight illuminates the two triangular shaped photo diodes *PD1* and *PD2*. The movement of the slit image follows the $\tan(\alpha)$ -relation of the incident light angle α and is given by:

$$\Delta X(\alpha) = h \times \tan \alpha \quad (2.1)$$

The illuminated area of the photo diodes *PD1* and *PD2* and thus the generated photo currents are a function of the incident light angle α . The relative position of the slit image on the triangular shaped photo diodes *PD1* and *PD2* can be calculated by the contrast algorithm:

$$X_{rel} \alpha = \frac{I_{D1} - I_{D2}}{I_{D1} + I_{D2}} \approx \frac{I_{ph1} \alpha - I_{ph2} \alpha}{I_{ph1} \alpha + I_{ph2} \alpha} \quad (2.2)$$

Due to the division by the sum signal the determination of the slit position does not depend on the light intensity. Therefore the $\cos(\alpha)$ -loss over the field of view has no impact on the measurement accuracy. The described algorithm relates to the determination of the X-directional component of the sun vector and is also valid for the Y-directional component. The Z-directional component is given by the distance h between chip plane and slit plane.

The main subsystems of the sun sensor head are the

- Measuring system with the components
 - Photo diode array with carrier (special development)
 - Slit carrier with spacer manufactured monolithically in a common silicon wafer
- Thermal extension compensation unit
 - Compensation frame
 - Compensation ring
- Housing with the components
 - Base plate
 - Entrance window with window mounting

The measuring system of the two-axis FSS shown in Fig. 2 consists of four one-axis measuring subsystems (redundancy including).

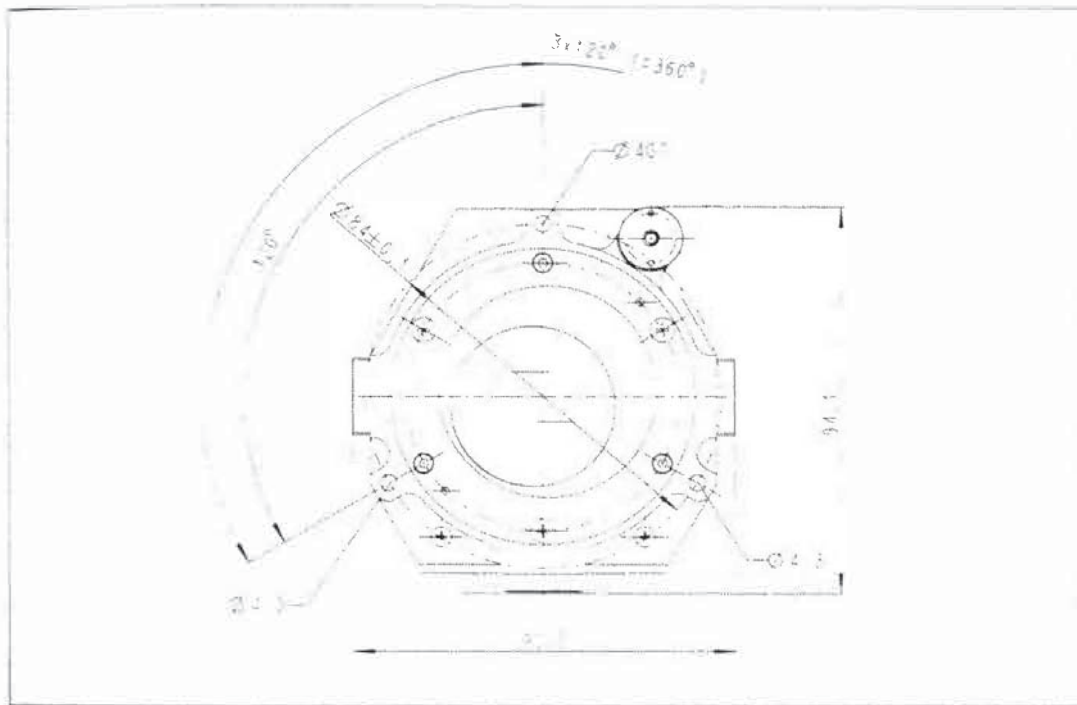


Fig. 2: FSS head overall mechanical design of a two-axis head with redundancy in construction

By using of semiconductor technologies a slit/spacer structure is generated in a silicon wafer. The structuring of the needed four slits in the Si-wafer surface is made in a single photolithographic process step. The applied semiconductor manufacturing technologies for the FSS measuring system are of a high productivity and guarantee high reproducibility and quality. These properties are reflected in a high performance, lifetime, reliability and in a very cost-saving manufacturing process.

A relatively high reflectance of the light-sensitive areas requires reflection reducing measures aimed at a straylight reduction. This requirement is realised by anti-reflective coating of the diode surface and by blackening of the reflecting surfaces of the silicon slit/spacer with Black Silicon.

Photo Diode Array

The customized photo diode array consists of 8 photo diodes (F...N) . 1 dark current reference diode R and the separation diode S (see Fig.3). The diodes F...N will be used for the sun angle measurement in two axis.

The photo diode array is made of silicon. The optical-mechanical structure of the photo diode array consists of a plane-parallel plate.

The light-sensitive area of the photo diode array must be in parallel with the slit plane in a defined distance.

Slit

By manufacturing the slit plane in monolithic manner a fixed position of the slits to each other and to the chip plane is ensured.

All four slits (two-axis with redundancy) are located in the same plane and represent an opening manufactured in the photo-lithographic technology.

Apart from the slit the silicon wafer is light-tight.

Spacer

The required distance between the slit carrier and the photo diode array and the position of the slit plane in parallel with the light-sensitive area of the photo diode array are determined by a spacer.

The spacer and slits form one unit made of a silicon wafer by which the same extension behaviour as in the chip is ensured

Entrance Window

To avoid multiple reflections at small incident angles ($\alpha, \beta \approx 0$) the entrance window is tilted to the slit plane. For this reason an eccentric position of the window is necessary to ensure the free FOV of $\pm 64^\circ$

Compensation of Extension

The measuring system is connected to the housing via an extension compensation unit in order to compensate the difference of the extension behaviour between these components. This unit consists of elastically deformable parts.

Electronic Parts

Besides customized photo diode array, two resistors and one capacitor are the electronic parts within the analog sun sensor. The overall photo diode chip organisation of the two-axis FSS is shown in Fig.

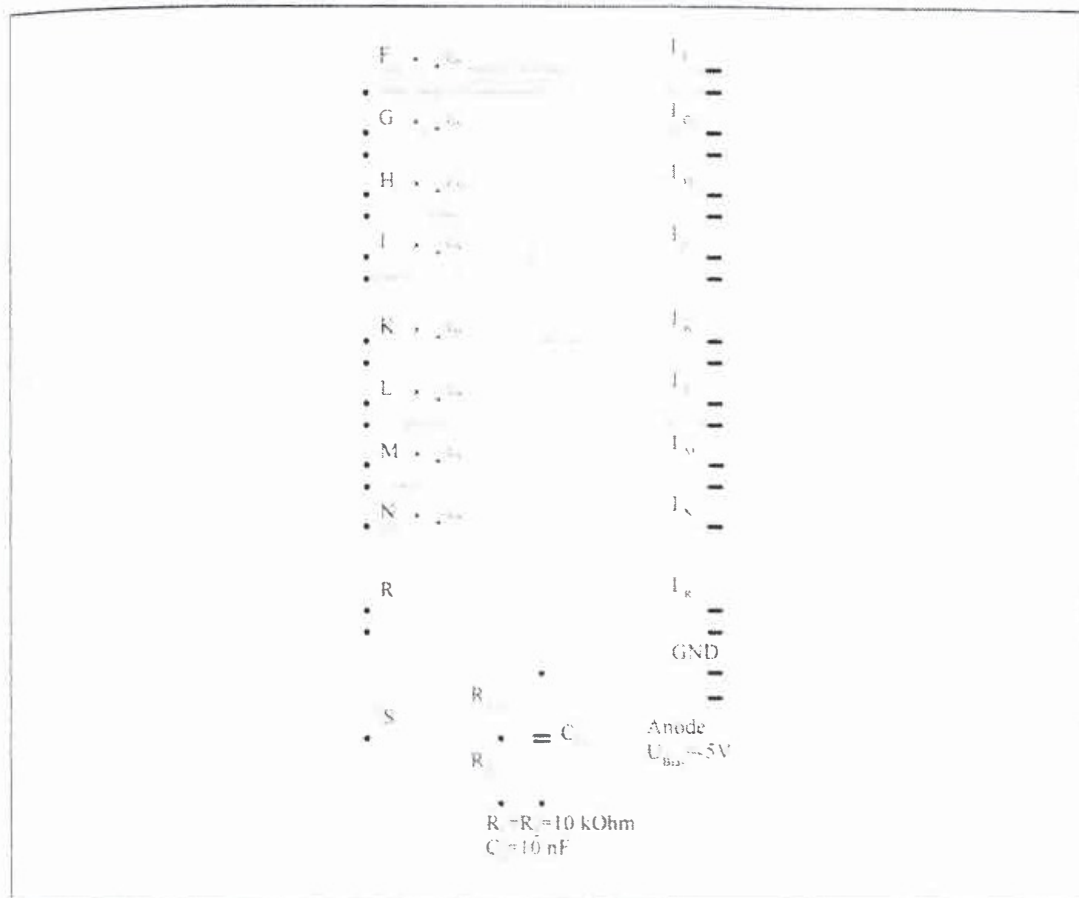


Fig. 3: Photo diode chip organisation & FSS Electronics

The output signals of the photo diodes F to N are routed directly to the Interface Electronics of the Spacecraft Computer.

All of the 8 diodes are biased via a common anode with a defined bias voltage of -5 V. The chip layout contains an additional separation diode structure in order to prevent the cross talk behaviour. The separation diode is biased with -2.5 V.

The dark current reference diode (R) is also directly routed to the interface. It is not light sensitive and can be used to monitor changes of the dark current of the photo diodes depending on temperature changes. The value of the dark current can be used to minimise the offset errors.

Under these conditions the expected photo currents amount to:

- Diodes F to N: $\approx 2 \dots 180 \mu\text{A}$
- Dark current reference diode $\approx 20 \text{ pA} \dots 25 \text{ nA}$
(depends on the $I_{\text{dark}}(T_0)$ and the temperature)

3 - DESCRIPTION OF ELECTRONICS UNIT

Fig. 4 shows the block diagram of the electronics unit and the connected FSS head. The electronics unit is located in the I/O electronics unit of the spacecraft computer.

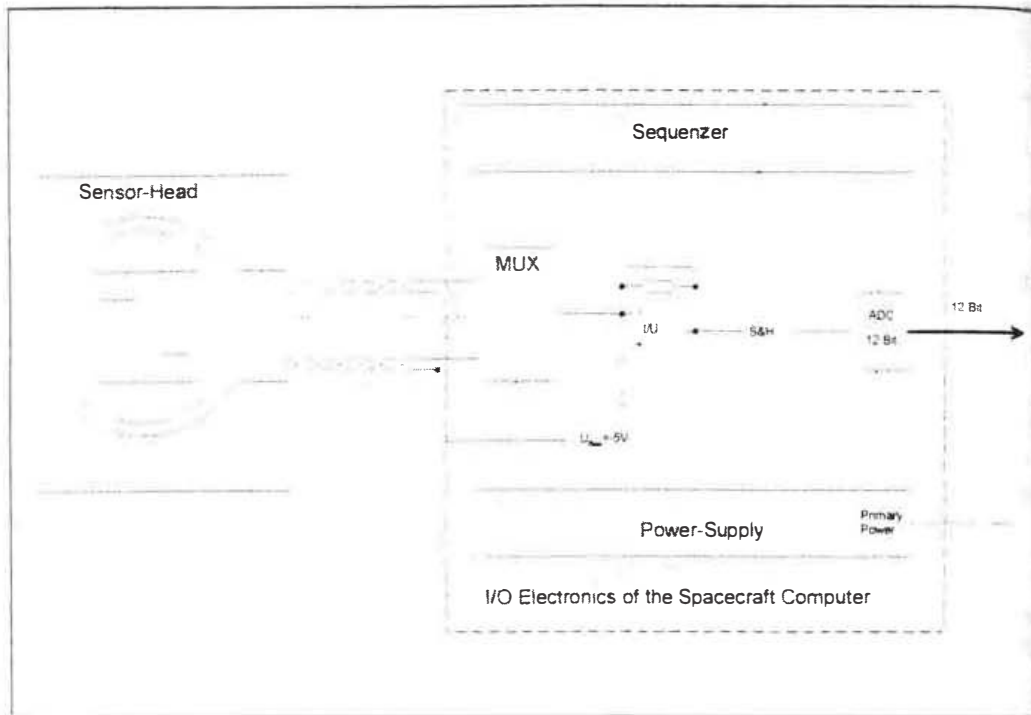


Fig .4: Block diagram of the electronics unit and the connected FSS head

The electronics unit includes the following parts with the associated functions:

Electronic part	Functions
Multiplexer	<ul style="list-style-type: none"> • selection of the photo diode the current of which is measured for fine angle calculation • switching the several photo diodes to the I/U converter
I/U Converter	<ul style="list-style-type: none"> • amplification of the photo currents • conversion of the photo currents in corresponding voltages
Sequencer	<ul style="list-style-type: none"> • controls all activities of the Multiplexer
Analog to Digital Converter	<ul style="list-style-type: none"> • converts the analog output signal of the I/U converter to digital signals • the resolution of the ADC should be 12 bits
Power Supply	<ul style="list-style-type: none"> • DC/DC converter

An other conceivable principle of an electronics unit can be an integrator, which directly integrates the multiplexed photo currents. There are known a lot of basic circuits the output signal of which can be evaluated directly with a simple digital electronics without an ADC.

4 - SENSOR DATA EVALUATION

To calculate the angles α and β the following transfer functions shall be used:

$$\tan \alpha = \frac{a}{2h} K * a_1 + a_0 \quad (4.1)$$

$$\tan \beta = \frac{b}{2h} K * b_1 + b_0 \quad (4.2)$$

$$K = \frac{I_{ph2} - I_{ph1}}{I_{ph2} - I_{ph1}} \quad (4.3)$$

a, b	width of the photo diode element
h	distance between slit plane and light-sensitive area of the photo diode array
I_{ph1}, I_{ph2}	current of the photo diodes
a_0, a_1, b_0, b_1	correction coefficients consider the errors of scale and offset

5 - CONCLUSION

A new generation of fine sun sensors with low budgets in terms of dimensions, mass and power consumption was designed in Jena-Optronik Company. The mechanical design has been streamlined to facilitate low cost manufacture. Because the accuracy is dependent on the FOV the degree of accuracy can be increased by using smaller fields of view. This process is ensured by the modular design concept by varying the distance between slit plane and photo diode array without changing the manufacturing technologies.

Referred to the requirement of the customer various configurations of data handling and processing are possible. For raw data transfer just the sensor head is needed, for transfer of the angular values an electronic box is necessary, too.

In parallel to the two-axis sun sensor development a one-axis sensor with higher performance was developed under a similar design concept, too.