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Christian Elstner

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PRECISION SUN SENSOR „PSS“

Christian ELSTNER

Jena-Optronik GmbH, Prißingstraße 41,
07745 Jena, Germany

ABSTRACT - The Precision Sun Sensor PSS has been designed for 3-axis stabilised spacecrafts and is applicable to LEO- and GEO-missions. Due to the large field of view (FOV = $127^\circ \times 127^\circ$) of the 2-axis Precision Sun Sensor Head (PSSH), only 3 Sensor Heads are necessary for a complete sun coverage within the equatorial plane of the S/C - including a sufficient overlapping region. Due to its embedded software the PSS provides features like autonomous Sun acquisition within the FOV of all PSS Heads, automatic switch over to Sun tracking after acquisition, alternating Sun tracking with two PSSHs in the overlapping regions, and direct output of the tangens of the measured Sun angles. Furthermore the PSS provides measurement data with high accuracy in the presence of rotation rates up to 15deg/sec and data with reduced accuracy in case of rates up to 300 deg/sec.

1 - INTRODUCTION

The PSS was developed by Jena-Optronik GmbH and Dornier Satellitensysteme (DSS) in two phases. Phase 1 - a company internal predevelopment - was concluded with an engineering model of the PSS and the verification of the functional principle by test. Phase 2 was the final development and qualification of the PSS within the ARTEMIS program funded by the European Space Agency (ESA). Within phase 2 an EM, an EQM and a PFM/FM were manufactured, successfully tested and provided to ESA/ALenia.

The PSS provides an accuracy of 0.15° (3σ value) under quasi stationary conditions (e.g. GEO) and about 1° in presence of rotation rates of 300 deg/sec. This accuracy is achieved by utilization of a long linear CCD detector with 5000 photosensitive pixels which provides a pixel resolution of about 0.05° , an evaluation procedure to determine the center of gravity (CoG) of the slit images, utilization of high precision optical parts and a special calibration procedure.

Meanwhile a slightly modified PSS flight model for application on EUTELSAT, SIRIUS and ARABSAT satellites has been manufactured and tested. This state-of-the-art PSS will be integrated to the AOCS 3000 of DSS which is the advanced attitude and orbit control system for communication satellites.

2 - DESIGN APPROACH

2.1 - Precision Sun Sensor System Configuration

The PSS consists of two redundant sets of nominal three PSS-Head's and a separate signal processing electronics unit PSSE. The PSSE contains two completely redundant channels labelled with PSSEC1 and PSSEC2. Figure 2-1 shows the overall Precision Sun Sensor configuration. In case of implementation constraints of the PSS on the satellite up to four PSSH's may be used per PSSE channel. Concerning the Serial Command and Data Interface two types of Interfaces were realised:

- the OBDH interface used within the ARTEMIS project and
- application specific synchronous 16 Bit differential line point to point interface

Fig 2-1 PSS System Configuration

The main sensor parameters are

Field of View of one PSSH		127° x 127°
Accuracy	Bias	0.015° (3σ)
	Noise	0.005° (1σ)
Update rate		10 Hz
Rotation Rate		up to 300°/sec
Detector		CCD line with 5000 photosensitive pixels
Power consumption	PSSH	2 W
	PSSEC	6 W
Mass	PSSH	0.72 kg
	PSSE	5.5 kg

2.2 - Precision Sun Sensor Head

The optical concept is based on a 90°- arrangement of two entrance slits above a CCD line which is mounted under 45° w r t the two slits. Figure 2-3 shows the corresponding arrangement of the slit-images in the detector plane. The advantage of this configuration is, that both of the sun vector components defined by α and β can be measured simultaneously with a single linear detector. The design of the plane optics is based on the CCD containing one central line of 5000 photosensitive

detector elements with a size of $7\mu\text{m} \times 7\mu\text{m}$ each. The optics is designed for a FOV of $\alpha = \beta = \pm 63.5^\circ$. This has been done by proper selection of the slit geometry and the values of h_1 and h_2 .

Figure 2-4 shows a typical slit image generated with the described arrangement and Figure 2-5 represents the resulting resolution per pixel. To achieve the final accuracy of 0.015° it is necessary to apply a further evaluation procedure to determine the center of gravity (CoG) of the slit images.

Fig. 2-3: Slit images within the detector plane

Fig. 2-4: CCD slit image

With the geometrical arrangement of the slits relative to the detector as described above, the achieved FOV is larger than the specified one. To realize the specified FOV of $\alpha = \beta = \pm 63.5^\circ$ it is necessary to introduce a FOV-limitation in front of the entrance slits. To prevent the PSS from straylight disturbances S/C components must not be mounted within the shape of FOV and FOV_{mob}.

The design of the PSSH optics is shown in Figure 2-6. It consists of three parts of plane optics. The lower plane optics (LPO) is directly glued to the detector housing and realizes therefore a stable alignment between both components. Both the top and the lower sides of the middle plane optics (MPO) are evaporated with special coatings. The coating on the lower side forms the two entrance slits and the coating on the top side forms the FOV limitation. The necessary attenuation filter is realized by applying a neutral density filter coating on the lower side of the upper plane optics (UPO). During integration of the PSSH on the S/C the neutral density filter acts as autocollimation mirror. All parts of the plane optics have the same dimensions in length and width and are made of a special radiation hard glass.

Fig. 2-5: PSSH pixel resolution

Fig. 2-6: PSSH optics design

Figure 2-7 shows the block diagram of the PSSH electronics. The electrical interface between the PSSH and the PSSEC is minimized to reduce the mass of the harness and to keep the part, necessary for multiplexing the sensor heads within the PSSE, at a minimum. The PSSEC provides to the PSSH's all secondary voltages needed and two timing signals - clock and synchronization - to control both the CCD exposure and the CCD-, PROM-, and housekeeping data readout. The analog CCD-Video signal is fed into the PSSE. PSSH-housekeeping (voltage and temperature) and PROM-data are transferred additionally via the video signal line.

Fig 2-7 Block diagram of PSSH electronics

Fig 2-8 PSSH

The *Control Unit* decodes the digital timing signals clock and synchronization and generates all signals needed within the PSSH for CCD control, the analog signal processor, the multiplexer, and the PROM.

Within the *Driver* special hybrids are used to provide the clock driver capability with high current output from a TTL logic level. The supplies to the clock drivers are decoupled to prevent interference to other parts of the proximity electronics.

The *Signal Processor Analog* comprises video signal conditioning and amplification of the two CCD video outputs, the S & H circuitry, and an additional amplifier (factor of 10) which can be activated for test purpose if the PSSH is stimulated with an 0.1 SC Sun simulator only.

The *Multiplexer* is controlled by commands of the PSSEC and transmits the CCD video outputs, the PROM calibration or the house-keeping data via the *Video Buffer* to the PSSEC.

Figure 2-8 shows the completely assembled PSSH. The mass of PSSH is less than 720 g and the overall dimensions are 136 mm x 110 mm x 60 mm.

The housing is made of titanium to achieve low mass and dimension with high stability and thermal compatibility between housing and optics. PSSH optics are located in the upper part of housing. Also in the upper part of the housing four alignment mirrors are arranged perpendicular to the X- and Y-axis, respectively. The attenuation filter of upper plane optics can be used for alignment measurements parallel to Z-axis.

The PSSH will be mounted with three mounting feet on the S/C interface. The single mounting hole on the -X-side has a diameter of 4.1 mm. The others are elongated holes so that the PSSH can be adjusted on the platform in the X-Y-plane for $\pm 0.3^\circ$ by swinging around the 4.1 mm diameter hole.

The upper part of the PSSH is specially formed for MLI accommodation.

2.3 - Precision Sun Sensor Electronics

The PSSE consists of the two completely redundant Electronic Channels PSSEC1 and PSSEC2. Each of the channels controls up to four sensor heads (PSSH's). Figure 2-9 shows the block diagram of one Electronic Channel (PSSEC).

Fig. 2-9: PSSEC block diagram

Each PSSEC consists of four modules:

- Preprocessor (PP)
- Digital Signal Processor (DSP)
- Sensor Data Interface (SDI)
- DC/DC Converter

The *Preprocessor* (PP) interfaces the Sensor Head Interface electronics with the Digital Signal Processor. The main tasks of the PP are as follows:

- to provide secondary power and timing signals for the PSSH's
- to receive, process and digitize analog video signals, calibration and housekeeping data from the PSSH's
- to receive configuration signals via DSP-data bus and to provide interrupt signals to the DSP for synchronization of data transfer and frame-control

The DSP configures the Sequencer to select individual sensor heads to be powered. Depending upon the operational mode any combination of the sensor heads can be powered. All digital line drivers of the PSSH's not powered are in the high impedance state.

The buffered PSSH video signals are routed via a matched cable to the PSSEC. In an input network high frequency common mode distortions are eliminated and the transmission line is adequately terminated. Clamp diodes are used to protect the input of an instrument amplifier suppressing low frequency common mode noise and thus referencing the video signal to PSSEC ground. A subsequent low-pass filter serves for band limiting and level adjustment. The PSSH video line is used for the data transfer of analog (video signals and housekeeping data) and digital (calibration data from PROM) information from the PSSH to the PSSEC. A 12 bit ADC is used to improve linearity and signal to noise ratio of the sensor raw data. The sensor raw data are processed with 8 bit resolution.

The *Digital Signal Processor* (DSP) is responsible for the overall control of the Sun Sensor and for all data processing needed to determine the sun position with the required accuracy. The main tasks of the DSP are as follows:

- to receive commands via the Sensor Data Interface
- to control all modes of the PSSEC
- to configure and synchronize the Preprocessor

- to receive digitized video, calibration data and housekeeping data from the Preprocessor
- to search for and identify the sun within the FOV's of the related PSSH's
- to track an identified sun within the FOV's
- to calculate the position of the identified sun
- to provide data to the Sensor Data Interface being transmitted via the Serial Interface
- to control the Sun Presence Signal Line

The processor operates with an input clock of 10 MHz resulting in an instruction cycle time of 400 ns. The processor has two independent address and data busses for program and data area. The program memory size is 4 k x 24 Bit. The RAM size provided on the DSP is 8 k x 16 bit. During RAM writing operations the Wait State Generator extends the processor cycle by another full cycle.

The *Sensor Data Interface* (SDI) is designed to connect the PSS to the S/C is capable to provide the following functions:

- to receive the selection signals from the redundant IFU modules
- to receive the 100ms synchronization signal provided by the selected IFU
- to provide serial response to the selected IFU
- to receive serial commands from the selected IFU
- to provide interfaces to the DSP for status, response and command transfer
- to provide Sun Presence interface to the redundant RM modules
- to receive Power ON/OFF commands from the redundant RM modules
- to provide Power Relay Status output to redundant IFU modules

One SDI module is interfacing one PSSEC to the redundant RM and IFU modules of the OBCU. The active PSSEC provides via its SDI a data output using a digital serial channel 16 bit interface. As a minimum the data output fully describes the angle of the sun relative to the α and β axis, the present operating mode and the status of the PSS.

Fig. 2-10 Precision Sun Sensor Electronics

Figure 2-10 shows the Precision Sun Sensor Electronics. Both channels are packed into one box. Therefore, the box provides space and connectors for eight functional modules. The p.c. boards are riveted to the module frames. The module frames are screwed to the basic plate. Wiring of modules with each other is made by means of connectors in a wiring frame. The wiring frame is attached to the base plate.

The dimension of the internally redundant PSSE is 193 mm x 224 mm x 175 mm, the mass is less than 5500 g.

3 - PRECISION SUN SENSOR OPERATION

3.1 - PSS Commands

Power on/off of the PSS is controlled by on/off pulse commands and utilization of the dedicated on/off status signals. To command the PSS via its Command and Data Interface only one word is necessary during in orbit utilization. The following commands are defined

- POWER ON/OFF selected PSSH's
- ACQUISITION MODE command
- TRACK MODE command
- TOGGLE MODE command
- STAND-BY MODE command
- S/W RESET command

3.2 - PSS Output Data

The PSS provides the following output data

- 7 words Standard Response (2 words flags, 2 words $\tan \alpha$, 2 words $\tan \beta$, 1 word check sum)
- 27 words Housekeeping data (26 words data, 1 word check sum)
- 253 words Engineering data (252 word data, 1 word check sum)

3.3 - PSS Operational Modes Description

After Power On the PSS is held in a hardware reset state until the secondary voltages have reached their nominal values. If the PSS is released from the reset state, the PSS performs an initialisation (INIT Mode) including synchronization with the OBCU via the serial interface and self-test procedure. After finalization of the self-test the PSS automatically switches to the STAND-BY mode. The transition from the STAND-BY mode to the operational modes is initiated by command.

Within the STAND-BY mode the commanded set of PSSHs is powered but PSSH data acquisition is not performed. The PSS provides status (housekeeping) data of the PSS only every 100 ms.

The task of the ACQUISITION Mode is to identify the sun within the FOV of all powered PSSH's. For this purpose every 12th pixel pair of the whole CCD-line is evaluated. The sun position is roughly calculated. If the position of the sun image does not change more than 24 pixels between two successive measurements the PSS switches to the TRACK Mode automatically.

In the TRACK Mode two 216 pixel windows (for α and β slit images respectively) are created around the centre pixels of the identified sun images and only pixels within this windows are evaluated for sun position calculations. In case of angular motion the window positions are adjusted for the next frame. If the sun is lost or the position of one sun image changes by more than 40 pixels between successive measurements the PSS switches to the ACQUISITION Mode automatically.

The TOGGLE Mode is used during the transfer of the sun between FOV's of two adjacent PSSH's. The PSS looks for the sun within the FOV's of the selected PSSH's and toggles the data acquisition in succeeding 100 ms frames between the two PSSH's. The TOGGLE Mode can be reached by an command only.

4 - TEST

4.1 - Test Setup

For all tests of the PSS the following test equipment was used

- 1 SC (Solar Constant) Sun simulator for adequate stimulation of the PSS Head's. The used Sun simulator has a collimation angle of 32 arcmin and an exit aperture of 200 mm.
- Two axes turntable as high precision angular reference
- Unit Tester

4.2 - Test Results

The following figures show the results of a so called *Basic Pointing Test*. During this test at 10,000 statistically distributed measurement positions within the operating FOV of the tested PSSH 10 consecutive measurements are taken. From this measurement the sensor accuracy in Bias (difference of sensor output mean minus turntable position) and Noise (standard deviation of the 10 consecutive measurements) are derived. Figure 4-1 shows a 2-dimensional plot of the resulting Bias and Noise for α w.r.t. α and β each. Figure 4-2 shows a 3-dimensional plot of Bias α .

Figure 4-1 PSSH Bias and Noise in α (2-dimensional plot)

SN PSSS 002 PSSH 009

Figure 4-2: PSSH accuracy in Bias α (3-dimensional plot)

4 - CONCLUSION

A Precision Sun Sensor (PSS) for high accuracy applications was developed and qualified by Jena-Optronik GmbH. Measurements during EM, EQM, PFM and FM tests confirmed the technical features of the sensor and the measurement accuracy specifically 7 Flight models are provided for ARTEMIS, EUTELSAT, SIRIUS and ARABSAT type satellites. The first launch of a satellite with an integrated PSS will be in october 1997.