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NOVEL STAR SENSOR

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ABSTRACT - The design and functionality of a novel Star Sensor system is presented. TNO-TPD is developing a Star Sensor Camera, based on a qualified design. The Camera employs a unique reflective straylight baffle, has a field of view of 20 x 15 degrees, is much more light sensitive than its predecessor and can operate at an up-date rate of 10 Hz. Austrian Aerospace has developed and is qualifying a dedicated DSP based Star Sensor Electronics Unit, that includes all functions to allow for interfacing the Camera and the S/C and for the autonomous attitude determination algorithms and star catalogues to be implemented.

1 - INTRODUCTION

TNO-TPD and Austrian Aerospace are both involved in the development of a Star Sensor system, that will become a low-cost versatile autonomous attitude measurement system for use in a variety of missions. TNO-TPD is developing a Medium Field Star Tracker (MEFIST) an up-graded version of its qualified Wide Field Star Sensor Camera. Austrian Aerospace is developing an Electronics Unit dedicated to the MEFIST Camera.

The design of the predecessor of MEFIST was initiated in the frame of phase B for the new generation European telecommunication satellite ARTEMIS. The ARTEMIS constraints were for a star sensor camera suitable for operation on board a GEO telecommunication satellite with the following two major tasks continuous yaw measurement at any epoch and fast recovery operation in case of S/C attitude anomaly. To fulfil these objectives, the field of view of the camera needed to be as large as 30° X 40° and the number of stars needed in the FOV could remain very small. Bright (focussed) star detection capability was sufficient for the task envisaged in the GEO telecom missions. Stringent requirements were imposed on reliability aspects. To make the Star Sensor system free of single point failures, even in case of sunblinding of a camera, a multiple camera configuration with an internally redundant electronics unit was foreseen for telecom applications.

The breadboard hardware was built by TNO-TPD (Camera) and Matra Marconi Space UK (Electronics Unit). The breadboard EU was capable only to provide the pixel coordinates of the brightest pixel in the FOV of the Camera. As a follow-on activity, a contract was granted to TNO-TPD directly by ESA to pursue the upgrading of the breadboard design of star sensor hardware to the level of a qualification model. The upgrading work concentrated on the Camera. This qualification model Star Sensor Camera has been developed, built and succesfully qualification tested using ARTEMIS test requirements (Ariane 5 launcher)[1,2]. The mechanical outline of the qualification model Star Sensor Camera is presented in Fig. 1.

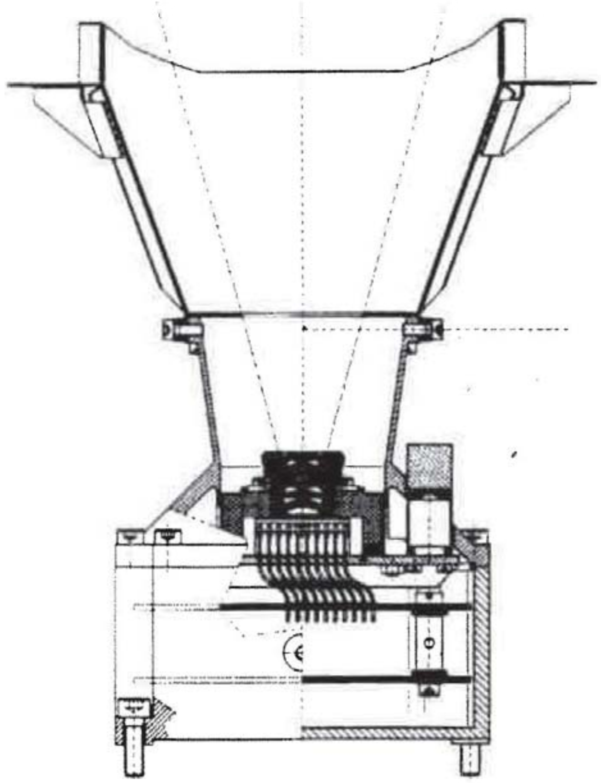

Fig. 1 Outline of the qualification model of the Star Sensor Camera.

In order to be responsive to the needs expressed by potential users, more demanding requirements were imposed on both the Star Sensor Camera and Electronics Unit:

- The FOV should be smaller for higher accuracy and more easy accomodation onto the S/C
- The sensitivity should be higher to enable the detection of weaker (thus more) stars
- The accuracy should be improved by using star centroiding algorithms.
- The applicable update rate should be as high as 10 Hz
- The number of simultaneously detectable stars should be larger
- The implementation of autonomous attitude determination software should be possible.

Based on these requirements, the MEFIST Camera and an improved Electronics Unit were defined. The MEFIST Camera development is running under national and company funding. The Electronics Unit is presently under design in the frame of the ASTE technology program of ESA-ESTEC, in a joint activity from Austrian Aerospace (former Schrack Aerospace) with TNO-TPD as a sub-contractor (ESA contract 11858/96/NL/DS)

The resulting Star Sensor system provides a flexible concept with the following advantages

- Passive cooling of the Camera CCD detector through the unique baffle concept
- Camera including baffle weighs < 1.1 kg and dissipates < 1 Watt
- Repetition rate can be set through the command interface up to 10 Hz.
- Up to 3 Cameras can be connected to the EU.
- Few interface lines between Camera and EU
- Possibility to implement a wide range of star detection/attitude determination algorithms
- Possibility to trade power consumption for processing performance.
- Possibility to load S/W into the Electronics Unit (EU) via the command interface.
- Possibility to adapt to different S/C command interfaces
- Possibility to implement Camera failure detection and recovery procedures.

2 - STAR SENSOR CAMERA

The qualification model of the Star Sensor Camera comprises an EEV MPP frame transfer CCD and optics that facilitate a wide FOV of 30 X 40 degrees. The unique 2-stage baffle design provides straylight suppression with a sun rejection angle of 55 degrees combined with a passive cooling function for the CCD. Without active cooling components, the system can handle S/C interface temperatures up to + 50 degrees C. The front-end electronics provides the analog video signal of all pixels in the CCD, amplified for safe transport across interface cabling. The gain can be controlled in steps (1,2,4,8) by the EU, as well as the integration time (in steps of 100 ms, with 100 ms as minimum). So the maximum update rate is 10 Hz. The video-output is automatically clamped to a dynamic average of the darkcurrent.

TNO-TPD is developing the MEFIST Camera, a design upgrade of the existing quailification model of the Star Sensor Camera, maintaining the many attractive features of the existing design, such as the CCD and front-end electronics, the passive cooling approach via a reflective straylight baffle, low power consumption, mechanical shielding against particle radiation, etc.

The developments for the MEFIST Camera concentrate on the optics and on the accomodation of the straylight baffle to the new optics. The existing rad-hard optics with F/2 performance and a focal length of 12 mm will be replaced by a rad-hard custom-made F/0.9 objective with an aperture diameter of 27 mm. Chromaticity, spot size and shape and relative illumination over the FOV have been analyzed and optimized, yielding a 6 single optical elements imaging system. The FOV of the design upgrade is 15° x 20°, which is a good compromise between accuracy that can be achieved about the pitch / yaw axes (which improves for smaller FOV) and about the roll axis (which reduces for smaller FOV). Furthermore, the new optics is defocussed to allow for accuracy enhancement by means of star centroiding. The limiting star sensitivity of the new design will improve with three magnitudes: the instrument magnitude will be $M_v = 6$ BOL at an update rate of 2 Hz. The size of the starcatalog will be larger than 2000 stars and the average number of stars in the FOV will be larger than 10. Preliminary calculation on the performance of this Star Sensor Camera indicates an average star availability of approximately 20 stars per frame at 5 Hz repetition rate, allowing for more advanced attitude determination algorithms to be applied in the EU.

The EEE components applied are rad-hard to at least 50 krad. Much care is taken with regard to shielding of the CCD. Radiation sector analysis has shown that the existing design offers sufficient radiation shielding for a 10 year GEO mission with two abnormally large solar flares.

3 - STAR SENSOR ELECTRONICS UNIT

The developed Star Sensor Electronics Units (EU) comprises the following functions

- Power supply; interfacing with the spacecraft power subsystem and providing the power for the EU internally and for the Camera in operation.
- Clock generation for the Camera.
- Clock logic for the internal EU control of the video signal from the Camera.
- Cross-strap module for interfacing up to 3 Cameras.
- DSP based video signal processing, yielding the desired flexibility and functionality.
- Flexible telecommand and telemetry interface with the S/C data handling sub-system.

The EU is powered by the S/C DC primary power bus. The command and control interface can be made mission-specific; the prototype will include a RS-422 serial interface. The design is based on a Digital Signal Processor core (rad-hard type TEMIC TSC21020E), which handles most of the tasks. This provides a very flexible concept which allows mission-specific requirements to be introduced in the S/W. Since the current development concentrates on the hardware design, the S/W implemented in the prototype only provides the function of acquisition and tracking of the brightest star in the FOV. However, the EU provides ample processing power and memory space to allow for more complex autonomous attitude determination algorithms and larger star catalogues to be implemented. Due to the flexibility of the design, the amount of memory can be adapted to the specific needs. A block diagram illustrating the EU architecture is shown in Figure 2.

The EU incorporates a cross-strap module for interfacing each of the two EU sections to up to three Cameras. The cross-strap module switches power and clock signal lines from the active functional chain of the EU to the Camera to be used and routes the video signal from this Camera to the powered ADC module. Which Camera is active is typically defined by means of a telecommand. However, considering autonomy requirements it would be possible to implement control S/W to automatically perform switching of the Camera in case of an anomaly.

The EU is powered by a 28V DC primary power bus. The internally needed voltages are converted from this primary bus by means of the DC/DC converter. The modular design approach can accomodate different telecommand/telemetry interfaces, such as MACS, Mil-Std 1553, etc. The present program includes the hardware for a bi-directional command and data bus type RS-422. The EU also provides features such as a Watch Dog and a Direct Memory Access (DMA).

The preliminary mechanical configuration of the EU is shown in Figure 3. The structure is built up with three layers

- The lower frame contains the nominal and redundant DC-DC converters, with circuitry completely electrically separated and with a heatsink in between.
- The middle frame comprises an single board with the video-processing (ADC and DSP), TM/TC interface and cross-strap electronics
- The upper frame comprises the redundant video processing board.

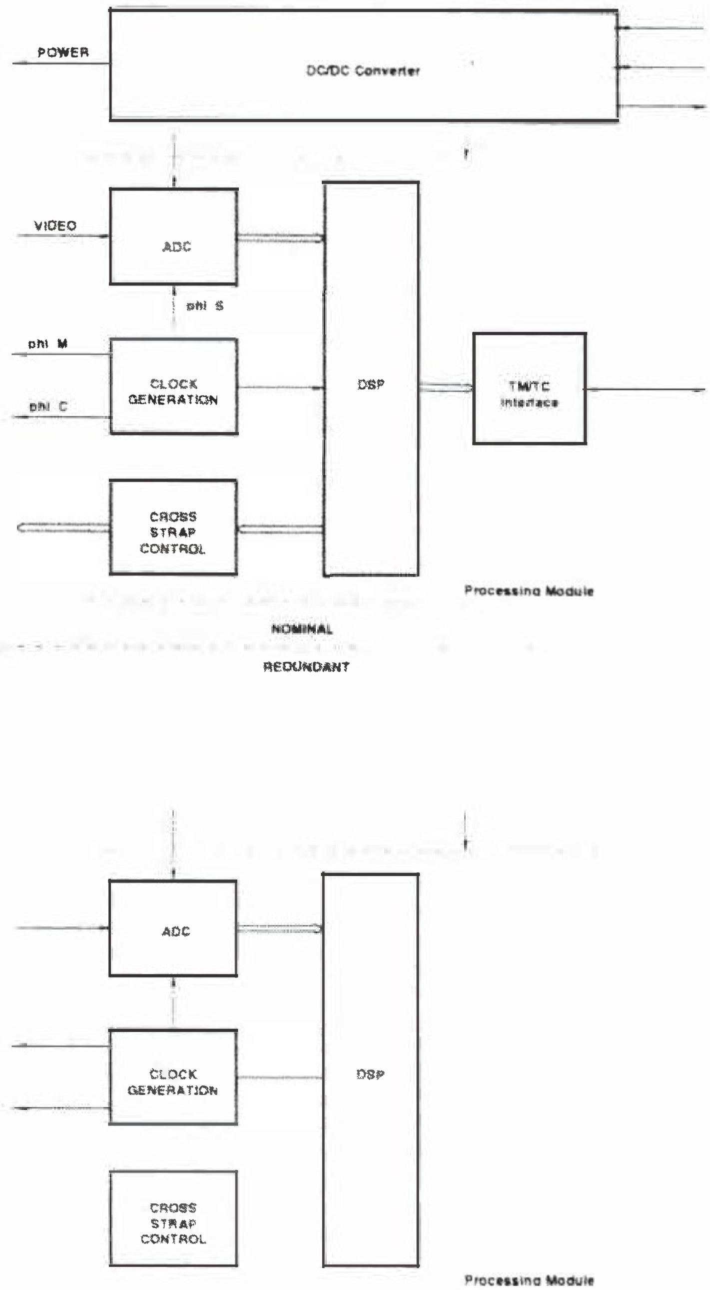

Fig 2 Architecture of the internally redundant EU, under development at AAE

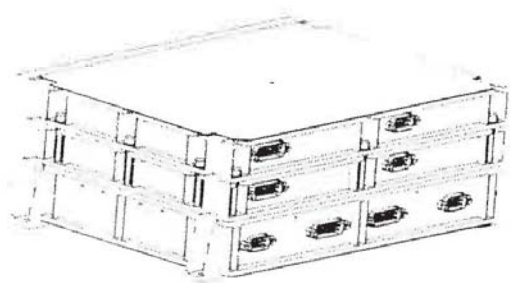

Fig. 3 Mechanical outline of the redundant EU

4 - SYSTEM BUDGETS

The budgets and performance chracteristics of the MEFIST Camera and Electronics Unit, based on the application of the MMS-UK/Quine star identification algorithms is shown in Table 1.

Table 1 Budgets and Performance characteristics for the Star Sensor system

Parameter / Characteristic	Budget / Performance
Total mass	1.1 kg (Camera) + ca. 2.8 kg (redundant EU)
Power consumption	1 W (Camera) + ca. 6 W (EU)
Envelope dimensions incl. baffle	100 x 102 x 115 mm^3 (Camera, no baffle) 277 x 178 x 100 mm^3 (redundant EU)
Full FOV	15° x 20°
Limiting starmagnitude	$M_S = +6$ @ 2 Hz (BOL)
Noise equivalent angle (NEA, 1s) *	< 5 arcsec @ pitch/yaw < 30 arcsec @ roll
Output frequency	Programmable from 1 Hz to 10 Hz. (CCD integration time range of 100 to 1000 ms)
Magnitude accuracy	0.2 M_S
Operating temperature	-20°C to +50°C
Reliability (2 Cameras + 1 EU)	> 0.99 for a mission duration of 10 years
Data interface	RS422 (other bus I/F's optional)

The Noise Equivalent Angles (NEA) for pitch/yaw and roll were derived for the worst case of 4 detected stars within the FOV. The roll accuracy is based on the assumption of an average star angular separation of half the FOV.

5 - ACKNOWLEDGEMENTS

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