Measurement & Instrumentation Systems
Ørsted•DTU
Technical University of Denmark

Advanced Stellar Compass
User's Manual

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Ref.: CNES-DTU-MA-2001-FM1 Issue: 2.0
Date: 25 November 2002

Change Record

Version	Date	Changed paragraphs	Remarks	Author
draft	16/11/01		New release	M. Betto
1.0	08/03/02			M. Betto
2.0	25/11/02	All		P.S. Jørgensen

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List of Acronyms

A/D	Analog to Digital converter
ABL	As Build Log
AGC	Automatic Gain Control
AOCS	Attitude and Orbit Control System
ASC	Advanced Stellar Compass
AU	Astronomical Unit
BBO	Big Bright Object
BOL	Beginning Of Life
CCD	Charged Coupled Device
CHAMP	CHAllenging Minisatellite Payload for geophysical research and application
CHU	Camera Head Unit
CPU	Central Processing Unit
DPU	Data Processing Unit
DSN	Deep Space Navigation
DTU	Technical University of Denmark
EGSE	Electronic Ground Support Equipment
EOL	End of Life
EPROM	Erasable Programmable Read-Only Memory
FOV	Field Of View
GFZ	GeoForchungsZentrum Potsdam
GPS	Global Positioning System
GUI	Graphical User Interface
HK	House Keeping
HW	HardWare
I/F	InterFace
ICD	Interface Control Document
LEO	Low Earth Orbit
LEOP	Launch and Early Operations Phase
LIS	Lost In Space
MET	Mission Elapsed Time
MIS	Measurement & Instrumentation Systems
MLI	Multi-Layer Insulator
NEA	Noise Equivalent Angle
O/B	On-Board
OBDH	On-Board Data Handler
PROBA	PRoject for On-Board Autonomy
RAD	RADiation
RDM	Residual Design Margin
S/C	SpaceCraft
SCOE	Support Check Out Equipment

SCRS	SpaceCraft Reference System
SEL	Single Event Latch-up
SEU	Single Event Upset
SFS	Star Field Simulator
SMPS	Switch Mode Power Supply
SW	SoftWare
TC	TeleCommand
TM	TeleMetry

1 Scope and Applicability

The Advanced Stellar Compass (ASC) is a highly advanced and fully autonomous star tracker designed, developed and produced by the Measurement and Instrumentation Systems (MIS) Section of the Ørsted Department at the Technical University of Denmark (DTU).

This document describes the instrument and its use.

There are five major parts:

- Description of the instrument, its operating modes and functionality
- Ground support equipment
- Ground operations
- In-flight operations
- Pre-launch check out & maintenance

The detailed interfaces between the Advanced Stellar Compass and the spacecraft are defined and described in specific Interface Control Documents (ICD's).

The procedures to handle the instrument and to integrate it in the spacecraft are described in specific documents and ICD's.

2 Documents

2.1 Applicable Documents

AD 1. DSO/ED/MS/PR/2000-130, Version 2.3, Star Sensor Performance Specification

2.2 Reference Documents

RD 1. CNES-DTU-ICD-2001, Issue 1.3, Mechanical Interface Control Document

RD 2. CNES-DTU-ICD-2002, Issue 1.3, Thermal Interface Control Document

RD 3. CNES-DTU-ICD-2003, Issue 1.4, Electrical Interface Control Document

RD 4. CNES-DTU-ICD-2004, Issue 1.7, TM/TC Interface Control Document

RD 5. CNES-DTU-PR-2001, Issue 1.4, Handling Procedures

Part I
General Description

3 Description of the Instrument

3.1 Function of the Advanced Stellar Compass

The Advanced Stellar Compass (hereafter ASC) is used as an attitude sensor by the AOCS of a satellite, or by specific payloads, to determine the 3-axes attitude of the satellite - or payload - frame with respect to an inertial reference frame.

The ASC delivers in real-time the three axes attitude of its reference frame with respect to the J2000 inertial reference frame at any user specified epoch.

The data delivered by the ASC can directly be used to control the attitude of the satellite.

3.2 System Description

An ASC consists of separate units: one to four Camera Heads Unit (hereafter CHU) with baffle system(s) and one Data Processing Unit (DPU). Each CHU is connected by a *pigtail* type cable, to the DPU.

The reasons for this division are multiple, the most important are:

- ☻ The CHU can be manufactured to impose very low magnetic disturbance;
- ☻ The CHU is very light, ≈300g including standard shielding and excluding the baffle, hence, it can be placed near the most attitude critical instrument;
- ☻ The light sensitive device, a CCD-chip, in the CHU requires a rather low operating temperature. If placed in an environment of high power dissipation, active cooling would be mandatory. Together with the very low power consumption of the CHU, passive cooling poses an attractive solution;
- ☻ The use of more than one CHU will reduce the operational constraints, like for instance Sun in the field-of-view, and will increase the performance.

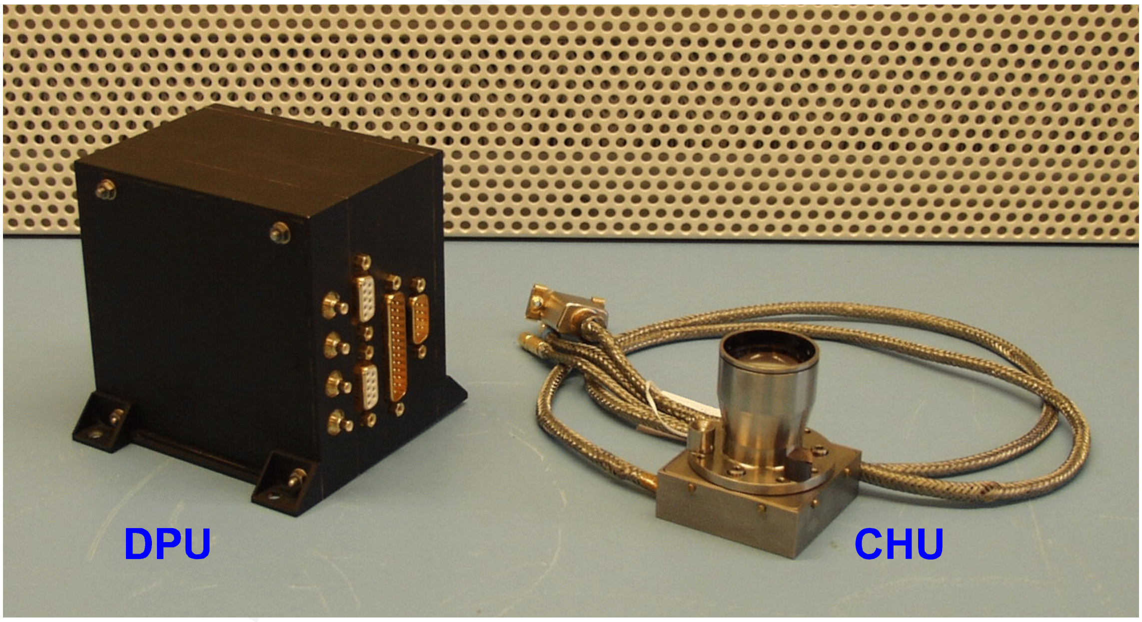

Figure 1 *A single DPU and a single CHU, flight grade.*

3.2.1 CCD Physical Description

The CCD has a physical size of 7.95 x 6.45mm. It is made up of 752 x 588 pixels. The dimension of each pixel is 8.6 x 8.3µm.

3.2.2 The DPU Memory

The DPU consists of three types of memory:

4MB Flash memory

4MB Ram memory

64kB BIOS memory

3.3 Principles of Operations

The starlight is collected during the integration phase on the CCD of the CHU. The duration of integration is selectable via SW between 0.0625s (1/16) and 4s. However, an integration time of either 1, 0.5 or 0.25 second is recommended for operation during moderate S/C attitude rates. The optimum performance is a trade-off between sensitivity and dark-current noise. All attitude data refer to the centre of the integration period.

During readout of the CCD, the analog data are transmitted from the CHU to the Data Processing Unit (DPU), where they are digitised and stored for analysis. Raw images can, by request from the S/C or ground, be stored and transmitted to ground at a later convenient time. The image can be compressed in one of five formats before transmission, by user selectable command. This facility is especially useful for anomaly diagnosis and during pre-flight system checks and calibration.

The image is sifted for stars and, depending of the current SW settings and the part of night sky viewed, a number of stars between, say, 20 and a couple of hundreds are detected and warped to remove the lens distortion. The centroids and magnitude of a pre-selected maximum number of stars are determined and used for the attitude determination. These centroids can be routed to the S/C or ground by request.

In normal operation, the difference in the attitude determined from two consecutive images is so small that the following procedure is adequate. All (selected) stars are matched against the star catalogue. Based on this match, the new attitude is found. The quality of the fit, both w.r.t. the number of stars not matched, number of stars matched and their average residual (angle error), is reported along with the attitude. A SW settable threshold value is compared to the match quality. If the threshold is superceded the following procedure is initiated automatically.

Stars, brighter than a certain value, are scanned for nearest and next nearest neighbours. The resulting sets of triplets are then matched against a pre-flight compiled version of the star catalogue: the star database. This match gives a crude attitude (some 1/50 of a deg) and it is used to seed the normal operation algorithm described above.

The latter procedure, called the initial attitude acquisition algorithm, is also used in a number of other situations, e.g. after power-on, after a SEU detection and following non-valid images like those produced by very bright objects – the Sun or the Earth – in the CHU field of view.

The ASC time-stamps all attitudes and data with an accuracy of 0.2msec. Based on whether the timing information from the S/C has been received or not, the time stamp refers to the S/C time, or the internal time since power-on. The ASC accepts both synchronized and non-synchronized timing information.

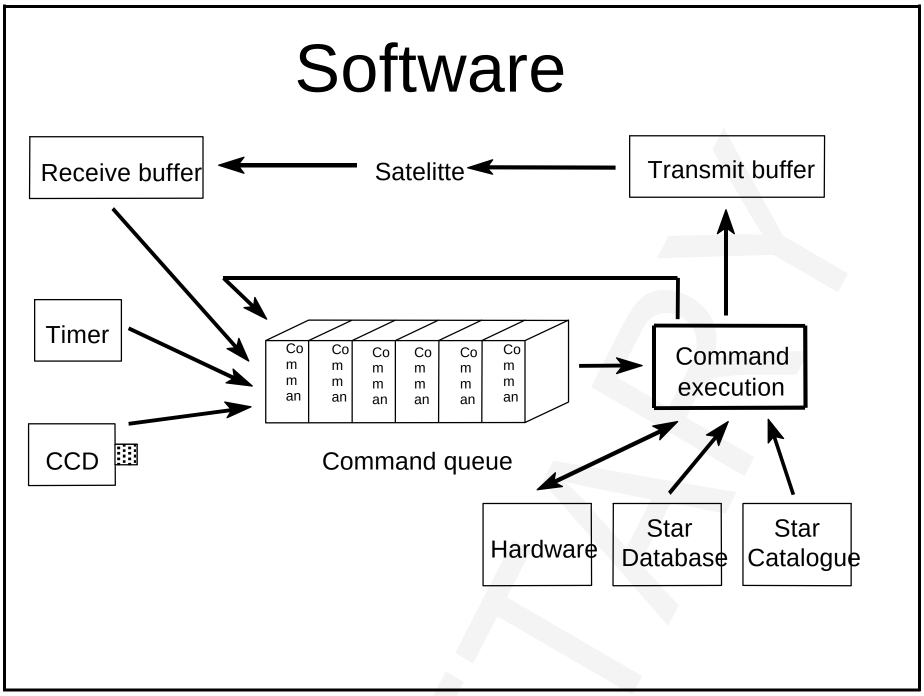

Figure 2 *Command queue and execution structure*.

The aberration correction is split in two components: one to compensate for the motion of the Earth/Moon system about the Sun and the second to compensate for the orbital motion of the S/C. For the first correction, only the date is needed and the updates do not need to be frequent. The second correction is performed by an on-board orbit model requiring in input the S/C state vector, inertial position and velocity, and the time. The filter update rate depends on the required accuracy and the perturbations affecting the orbit and it can vary from minutes to hours or even days. By request, the orbit model output can be routed to the S/C, either for testing purposes or to be used in the attitude control system.

The computed attitude can also be corrected for the precession and the nutation before being output. The corrections, that are important for accurate Earth pointing, can be enabled/disabled at any time by TC.

3.4 Software Description

The ASC operates as a pipe-lined instrument. This means that it is based on a FIFO command structure as illustrated in Figure 2. In the centre of the figure the command queue is displayed. The command executer (to the right) pops one command at a time and executes it. The command executer has interaction with the hardware, reads from the star catalogue and the star database, submits data to the transmission queue and is able to issue new commands onto the command queue. Also the CCD camera, the timer and the satellite on-board computer are allowed to put commands on the queue.

3.4.1 Software Structure

The software consists of several modules and a small Boot Prom loader, capable of loading the software from the Boot Prom and to upload/download the Flash Ram. The chart in Figure 3 shows a structural diagram of the software.

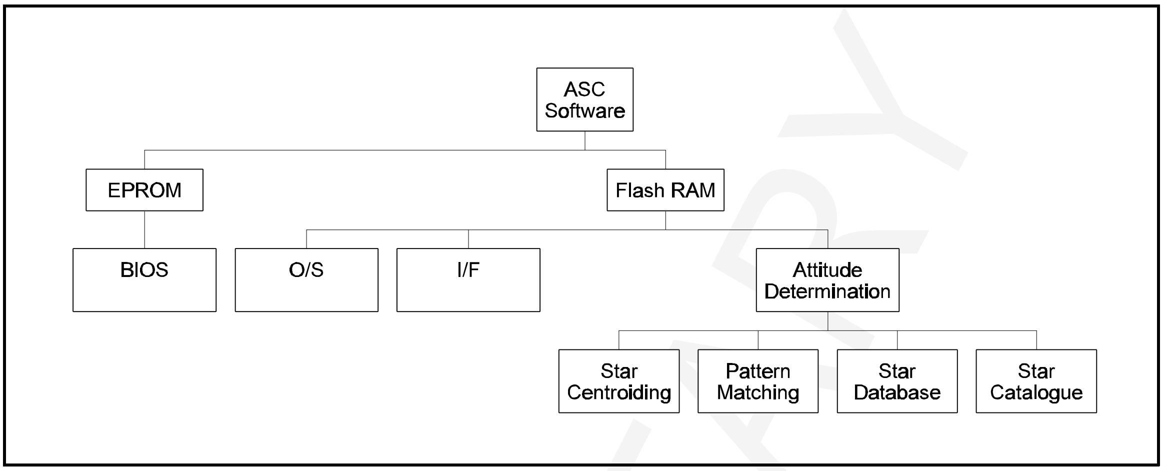

Figure 3 *ASC SW structural diagram.*

3.4.1.1 Star catalogue

The star catalogue is a data module. It contains approximately the 12,000 brightest stars. The magnitude of the stars is spectrally corrected to the CCD sensitivity. It is based on the Hipparcos catalogue supplemented by the Tycho II catalog.

3.4.1.2 Star database

The star database is a data module. The star database is a pre-compiled version of the distances between the stars. This is used by the procedure that performs the initial attitude acquisition. It contains approximately the 4000 brightest stars.

3.4.1.3 Pattern recognition

This module contains the actual algorithms that perform the pattern recognition of the star constellations and the least squares fit in the tracking mode. The algorithms are written in GNU-C.

3.4.1.4 Star centroiding

This module is the program that calculates the centroid of the stars from an image. The program also performs various lens distortion corrections. The program is written in GNU-C.

3.4.1.5 Command execution

This is the command scheduler that receives and interprets the commands, executes them and puts the output in the transmission queue. The code is written in GNU-C.

3.4.1.6 Operating system

The operating system is the program that initializes the instrument and contains all interrupt-driven procedures (transmit data, receive data, police program, keep the watch-dog alive, etc.) The program is written in assembler.

3.4.1.7 Organization in files

Figure 4 shows a modular diagram of the files in the software. The parts of the ASC software described in the previous sections are implemented in the files described below.

KERNEL.BIN	: ~20KB, Operating System
TOPS	: ~20KB, Star Centroiding
MAXIHOP	: ~450KB, Command execution, star catalogue, pattern recognition
TR_DB.O1	: ~670KB, Star Database
SYSVAR.DAT	: ~400B, Table of system parameters
RBN.DAT	: 4B, Checksum related pattern used with system parameters

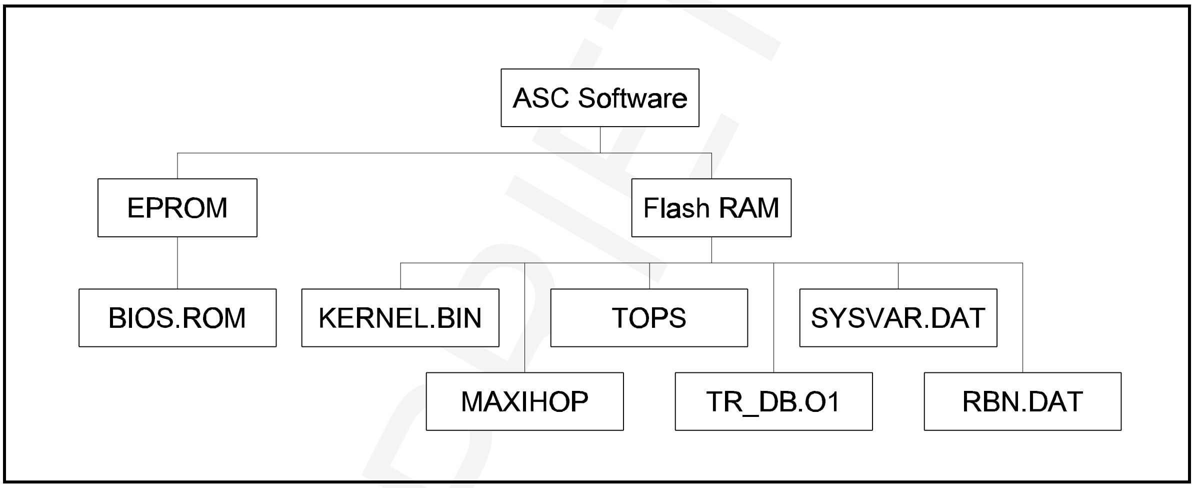

Figure 4 *ASC SW modular diagram.*

3.4.2 Miscellaneous Software Features

The mass-storage is Hamming-code protected against double faults using *bit wash* at software settable intervals.

Any part of the flight SW is uploadable except for the small boot strap part. The loaded SW can be downloaded on request.

The centroid determination algorithm and the attitude determination SW have been designed to accept substantial *motion smear* and *attitude rate*.

The attitude determination SW is able to handle a substantial number of anomalies, like hot spots, missing stars or the presence in the image of several non-stellar objects. Upon request, the position of the non-stellar objects can be reported to the S/C or to ground thus enabling to track them. The presence of distant planets in the field of view of the CHU does not reduce the performance of the ASC.

Error messages are sent if TC's are not completely received or are not executed, or if anomalies are detected during operations.

During power up, the computer performs an extensive integrity check up. This test includes RAM and ROM checks, SW integrity, CHU temperature, dark current, gain and fixed-pattern-noise, register, interrupt and discrete command status. The system-health is written up in the power-on report package.

If any anomaly is detected during the power-on cycle, the SW either reboots the instrument or goes automatically in safe mode. In case the anomaly is persistent and the instrument is continuously re-booting, it can be forced into safe-mode by sending a specific pattern during the power-on cycle.

Once in safe mode, the on-board SW can be uploaded. Usually, this procedure is sufficient to restore nominal operations. Should the anomaly persists, then the User is invited to contact DTU.

3.5 Functionality and Operations

3.5.1 Functional Characteristics

The ASC is a very versatile instrument, which offers several functions to the user:

- Autonomous solution of the *lost in space* problem in less than 300 msec;
- Accurate attitude determination;
- Possibility to output the attitude w.r.t. a user defined reference frame;
- Acquisition and transmission of images using different compression methods;
- Use of standard telemetry packets;
- Very sophisticated autonomy, including protection mechanisms and auto system gain setting;
- Fast autonomous recovery from optical overloading;
- Possibility to override all the autonomy, or part of it, by TC either from the spacecraft or from ground;
- Monitoring of the full status of the instrument;
- Possibility of adjusting all the on-board parameters during flight. This can be done autonomously or from ground;
- Possibility to re-program the whole instrument during flight from ground;
- Autonomous single-multiple CHU operation switching;
- Autonomous detection of and recovery from SEU, SEL, program flow or stuck operations;
- Possibility to correct the measured attitude to compensate the relativistic aberration;
- Redundancy.

3.5.2 ASC Modes

- **Stand-by mode**: this mode permits to check the health of the instrument (house-keeping) to modify parameters, and upload the SW. In this mode, the ASC does not perform star attitude measurements, whereas the cameras can be either on or off;
- **Attitude mode**. In this mode the ASC is able to perform acquisition (lost in space) and tracking. It delivers attitude data.

  While in attitude mode, images can be acquired, stored and transmitted without any loss of performance;
- **Safe boot up**. This mode is used only if it is forced into it by sending the proper TC when booting the DPU or if a failure boots the ASC and detects an error in the flash memory.

  In this mode, only the core functionality is loaded. This mode offers a simple way to upload/download software and parameters and perform health check of the instrument.
- **Simulation mode**: in this mode, the ASC is able to deliver attitude quaternion based on attitude indications provided by the test computer. This mode is active only on ground.
- **Test image mode**: this mode is used for ground testing of the ASC. By uploading a previously recorded image to the DPU, this image can be used for attitude determination instead of the images from the CHU's.

The state diagram (modes and condition for transition) is shown in Figure 5.

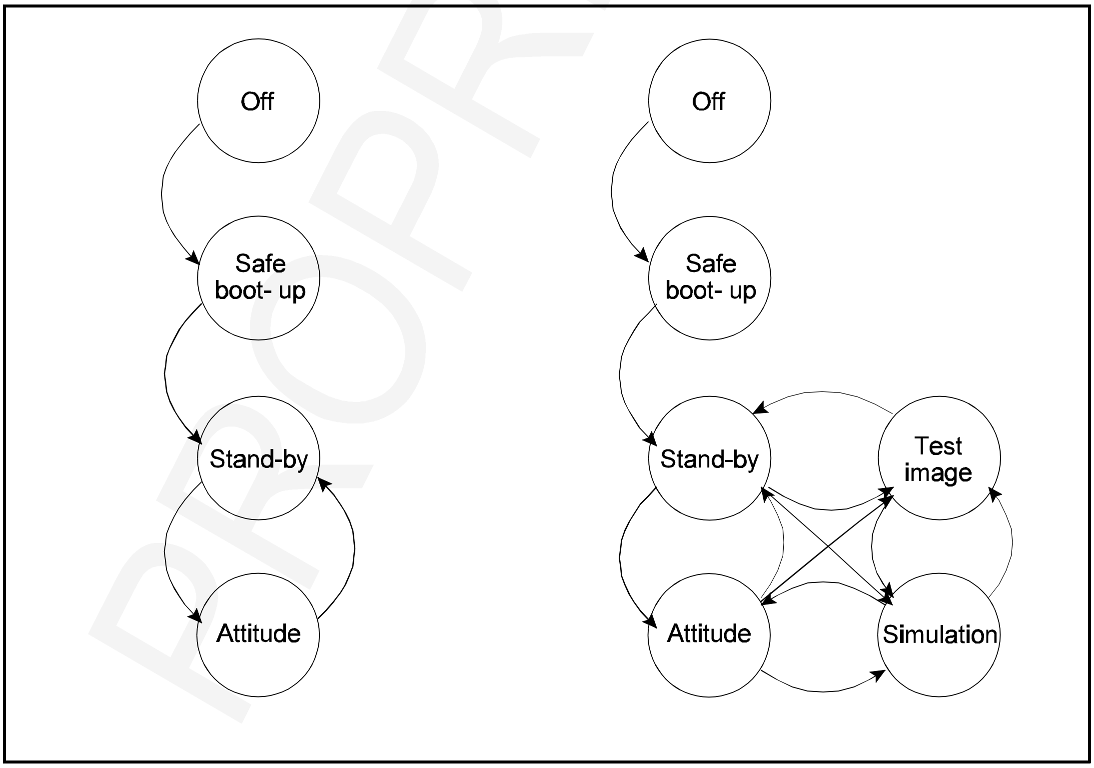

Figure 5 *ASC state diagram.*

3.5.3 Sun Exposure

Because most spacecrafts cannot guarantee that the star tracker is pointed away from the Sun at all times, it is important that the tracker is capable of handling direct Sun exposure without being permanently damaged. Therefore, the ASC optics and CCD assembly is designed in such a way, that direct solar illumination, even for extended times does not damage the unit. The way solar illumination immunity is achieved, is by assuring that the incident solar power is less than the maximum rating of the CCD, by including an IR and UV block in the lens coating, and by controlling the point spread function of the lens in such a way, that the power density in the solar spot is so low, that no local excessive heating takes place.

Obviously, star tracking with the Sun inside or near the Field Of View will preclude proper operation of the tracker, because the CCD will be brought into saturation. Also, the solar power dissipated in the CCD will give rise to a heating of the entire chip. This heating can, if the exposure is of a very long period of time (e.g. days), bring the CCD temperature above the maximum limit for full operation, and a cooling time may be planned for in these cases. Otherwise, a couple of integration cycles, i.e. 0.5s with an integration time of 0.25s, are sufficient to recover nominal operations after the optical overload.

Proper operation of this design has been verified both by the Ørsted and the CHAMP cameras. The Ørsted camera has, intermittently, been directly Sun pointing for more than 2 month in flight. The CHAMP cameras are, periodically, directly Sun pointing for more than a week at a time.

The presence of the Sun in the avoidance cone is signalled by increasing values of the AGC and video voltage in the HK telemetry of the camera and the “big bright object” flag in the attitude telemetry.

3.5.4 Earth and Moon Exposure

The ASC is quite robust against the Earth and the Moon, however, both objects may cause attitude update loss if they come within a certain distance from the optical axis of the ASC.

The general problem with bright objects in or close to the FOV is, that the handling of light in the optical systems as well as in the CCD structure, has a limited capacity. Due to the high contrast level between starlight and Bright Earth or Moon, the system may get saturated. The ASC is designed to operate with more than 30% of the FOV saturated and with more than 50% of the FOV obscured.

Theoretically, the bright Earth may come as close as 2 degrees to the FOV. The dark Earth may cover as much as 50%. In practice, small mis-adjustments or contamination of the baffle system may lead to slightly less performance. However, in-flight tests on e.g. the ESA mission PROBA has proved, that the performance is even better than expected. Typically, the boresight can go as low as 2 degrees below the horizon of the dark Earth before attitude update is impaired. Likewise the midday Earth may get as close as the actual rim of the FOV. In this respect, it is worth noting, that PROBA is equipped with a baffle of only 140mm

The effect from Moon intrusion strongly depends on the lunar phase. Due to the non-linear dependency of the moonlight radiance with the illumination area, the illuminated area is used below. As long as the Moon is less than 50% full, i.e. from last to first quarter, no performance degradation is measurable. For intrusion by a Moon between 50% and 75% an attitude update may be invalidated by the increased processor load caused by the straylight. Still an attitude availability above 95% is expected. For intrusion of a Moon between 75% and full, the effect depends on where the Moon is in the FOV. Generally the availability will drop with increasing percentage and decreasing distance to the boresight. E.g. The full Moon will cause the loss of attitude update when closer than 8 degrees from the boresight.

The ASC will keep sending attitude updates during a bright object intrusion. When the stray-light becomes too strong, the attitude is flagged invalid, and the optical overload may be verified both by checking the video-voltage of that CHU in the HK package and by verifying that the number of stars detected is above maximum (i.e. 200).

In the cases where an attitude update is dropped due to processor overload, the corresponding attitude package will flag invalid AND the number of stars detected will be 0.

Finally, to enable the user to know when a bright object intrusion is approaching, the ASC will flag that a bright object or stray light is intruding the FOV, by setting the Big Bright Object (BBO) flag in the corresponding attitude packages. Note, that this applies to any attitude package disregarding its state of validity. High performance users may use this flag as a warning of potential upcoming performance degradation.

3.5.5 Maximum Angular Rate for Acquisition and Tracking

The maximum allowable angular rate for the ASC depends on the required accuracy, integration time and axis of rotation. Also the change from tracking mode to Lost In Space (LIS) mode depends on the integration time. The allowable angular rates are summarized in Table 1.

Table 1: *Accepted angular rates for various integration times*

Description	**Direction**	**Update rate**		
		0.25 s	**0.5 s**	**1.0 s**
Limit for high accuracy (< 5") [deg/s]	Across Boresight	0.05	0.025	0.0125
	Around Boresight	0.5	0.25	0.125
Limit for switch from tracking to LIS mode [deg/s]	Across Boresight	0.8	0.4	0.2
	Around Boresight	8	4	2
Operational limit for low accuracy (> 5") [deg/s] (*)	Across Boresight	4.2	2.1	1.1
	Around Boresight	-	-	-
Max Acceleration [deg/s*s]	Across Boresight	5.3	2.6(**)	1.3(**)
	Around Boresight	-	-	-
Max d(Acc)/dt [deg/s*s*s]	Across Boresight	10.8	5.4(**)	2.7(**)
	Around Boresight	-	-	-

(*) The operational was tested on-ground using a guided telescope. The max rate of this telescope was 4.2 deg/s.

(**) Estimates

3.5.6 Detection Limit

The detection limit is set to m_v = 6.5 and for normal operations should not be changed. However, it can be set by the user up to $m_v \approx 9$.

3.6 Definition of the ASC CHU Reference Frame and Attitude

Figure 6 shows the definition of the camera axes relative to the firmament, i.e. the camera x_{cam}, y_{cam} and z_{cam} triad relative to the J2000.0 heliocentric inertial equatorial reference frame (x_{hc}, y_{hc}, z_{hc} triad), referred also as *VSN* (Vernal, Summer, North).

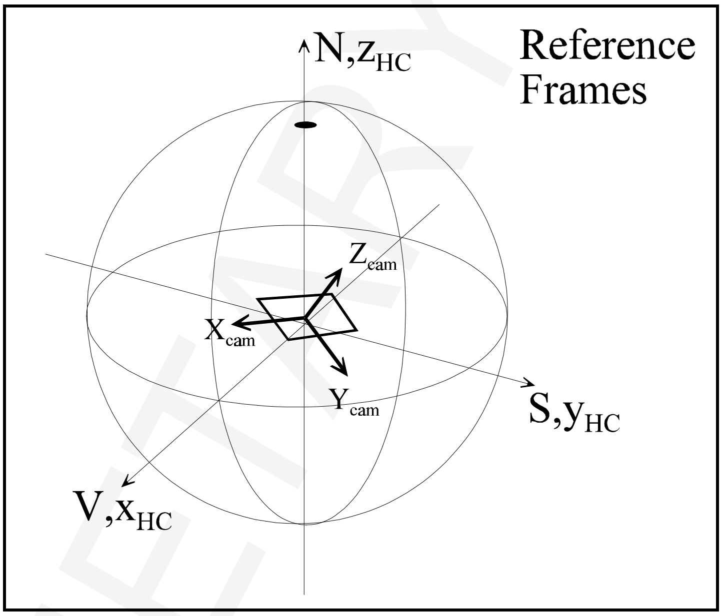

Figure 6 *Reference frame definition.*

The origin is the intersection of the CCD plane with the optical axis of the camera. The camera z axis points along the boresight, the x axis is in the CCD plane along the long side of the CCD pointing to the right of the image and the y axis completes the right-handed triad.

The heliocentric inertial equatorial reference frame is the J2000.0 system. Typically, for mission lasting few years, the epoch of the catalogue is set to the satellite mid-life epoch so to minimize the proper motion effects. However, a star catalogue referring to a different epoch can be generated and uploaded at any time during the mission.

The unity rotation, i.e., no rotation of the camera system relative to the VSN system is given by the quaternion: Q_u = (q1, q2, q3, q4) = (0, 0, 0, 1) and shown in Figure 7.

Unless otherwise specified, the output quaternion defines the attitude of the CHU w.r.t. the VSN. I.e. $x_{chu} = M(Q)_{chu,hc} * x_{hc}$, where $M(Q)_{chu,hc}$ is the rotation matrix associated with the output quaternion.

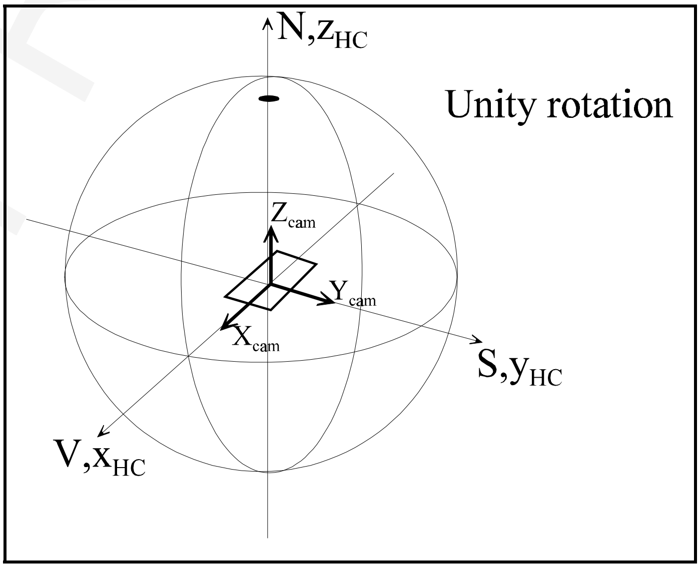

Figure 7 *Unity rotation.*

3.7 Quaternion Notation

Letting e_x, e_y, e_z denote the direction cosines of the rotation axis and φ the rotation angle, the following quaternion notation is used and assumed:

$$q_1 = e_x \cdot \sin\frac{j}{2}$$

$$q_2 = e_y \cdot \sin\frac{j}{2}$$

$$q_3 = e_z \cdot \sin\frac{j}{2}$$

$$q_4 = \cos\frac{j}{2}$$

3.8 Timing and Latency

The computer has an internal timer, that can be synchronized with the on-board SC time. It has a resolution on 0.5 µs.

The timing of the attitude data is ensured by the attachment of a time stamp to each attitude package. To assess the average latency of the data, the following shall be considered. The centroiding algorithm finds the average position of each star during integration. The attitude thus refers to the midpoint of the integration interval. With an integration time of 0.25 sec, the attitude refers to 0.125 sec before end of integration. After integration the image is transferred to the CPU D-RAM (Read Out) to compute the centroids. It is not possible to define precisely this computation time because it depends on the complexity of the image: e.g. how many stars, hot spots, presence in the field of view of very bright or large objects. Also of importance to the time latency is weather the Lost In Space (LIS) has to be performed before the fine tuning of the attitude is performed. The timing diagrams for three configurations are shown in Figures 8 to 10.

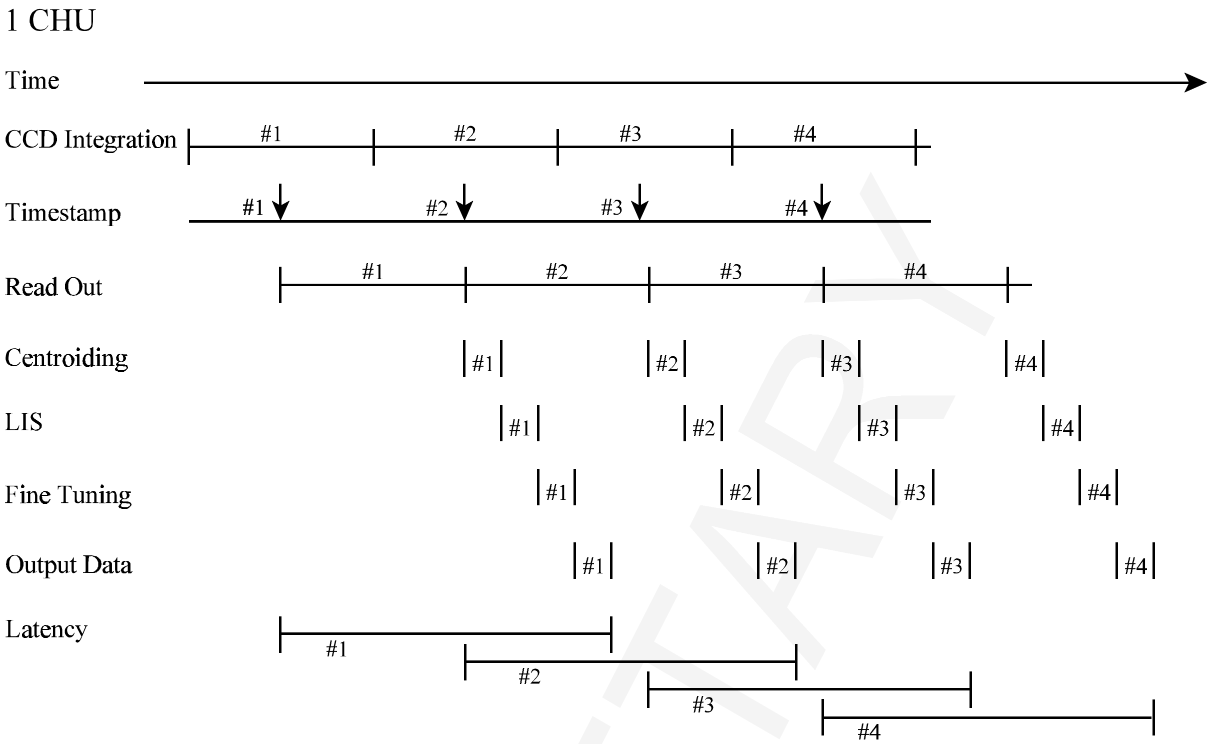

Figure 8 *Timing diagram for one CHU*.

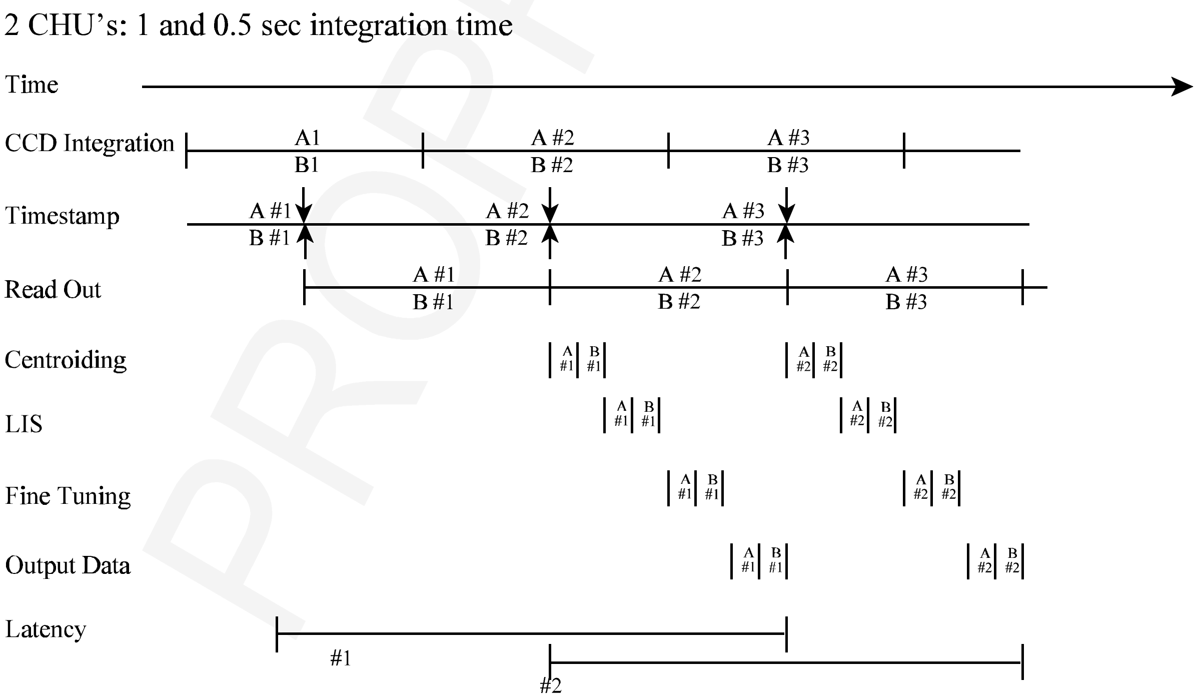

Figure 9*Timing for two CHU, 1 and 0.25 sec integration time.*

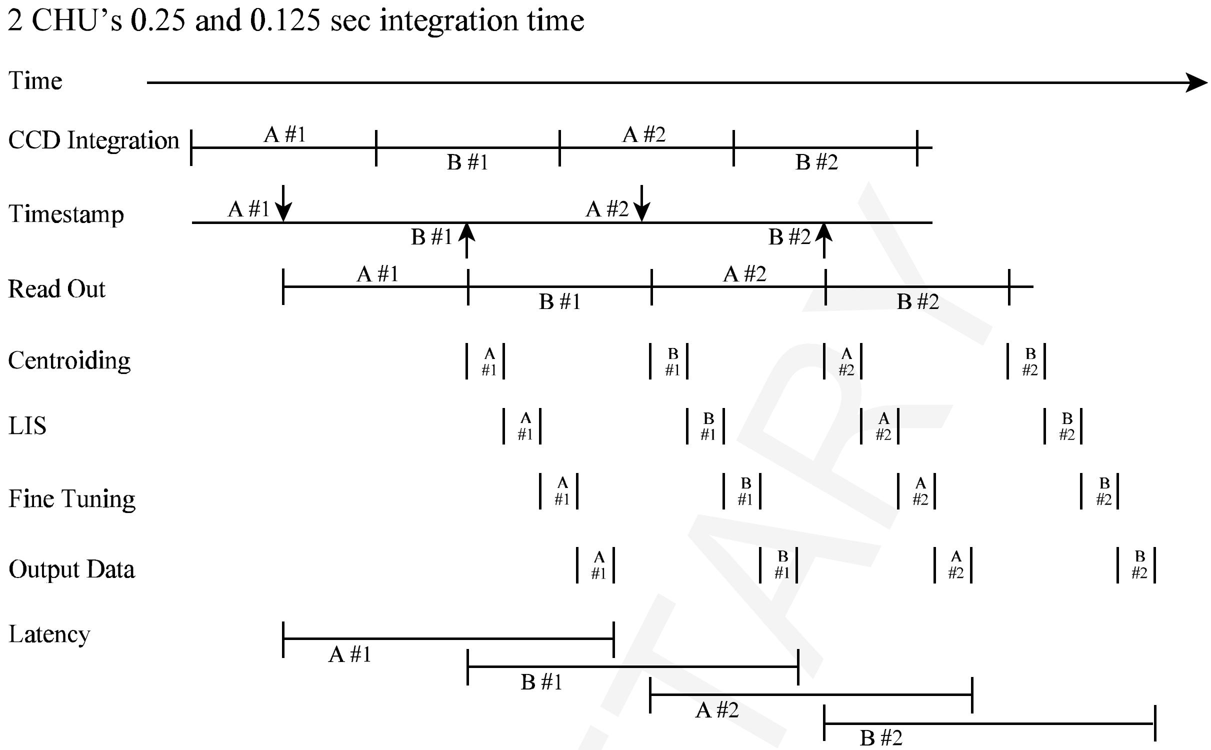

Figure 10 *Timing Diagram for two CHU, 0.25 and 0.125 sec integration time.*

3.9 Protection Mechanisms

3.9.1 Latch -Up Protection

Due to radiation etc. a circuit may experience a Single Event Latch-up (SEL). This means that the circuit enters an undefined mode, where it is not operating properly. In the worst case, a condition, including internal contingency in the circuit, may arise. This consumes an extraordinary amount of power, and the circuit is destroyed if not switched off immediately.

Typically, if a SEL has happened to a circuit, the current increases. The ASC is split into different current circuits, which are monitored continuously. If one of the monitored currents rises 180% above the nominal current for more than 1 msec, the entire ASC is switched off for a short while, and turned on again automatically. In this way, it is assured that a SEL does not destroy any components.

Due to the different voltages and currents, the camera, the DPU and the Grabber boards are split into 6 functional groups, each of which is individually latch-up protected. The DPU board is split into two separate circuits, the 3.3V for the DPU itself and 5V for the rest of the DPU board; the grabber board has one single 5V circuit, whereas each camera has three power lines (5V, 10V, 15V). Hereby an efficient latch-up protection of the low power chips is achieved.

3.9.2 Hamming Coded Memory

Apart from a radiation tolerant boot EPROM, the program code and database are stored in a FLASH type memory. To suppress the eventual occurrence of bitflips, the Flash RAM is protected with Hamming coding. Hamming code means that the contents of the Flash RAM is redundant, i.e. if a bit is flipped it is possible to reconstruct the original contents anyway. A coding scheme called 2 bits detection, 1 bit correction is used. This means that 1 bit flip per 16 bits can be corrected and 2 bit flips per 16 bits can be detected.

3.9.3 Bit Wash

Bit flips in Flash RAM can be corrected because the Flash RAM is Hamming coded. As time goes by, more and more bits might flip. If more than one bit, in a 16 bit word, has flipped then corrections are no longer possible. In order to prevent this situation, the ASC is equipped with a mechanism called *bit wash*. The Flash memory is separated in a number of banks. At regular intervals the program reads all bytes in the bank and check that the checksums are ok. Should one or several bit flips have occurred, the entire bank is copied into another bank, whereby the Hamming code protection mechanism ensures that the bit flips are corrected, and the new bank is renamed to the old bank name. In this way the code always stays original.

This process is safe (because the old records are kept until the new ones are generated) and transparent to the user, i.e. the user shall note take any action or set the ASC in any specific mode.

It should be noted that no bitflips in the Flash RAM have been detected in flight in more than ten equivalent years. Therefore, it is advisable not to perform any automatic periodic bit wash.

3.9.4 Police Program

This is a software protection mechanism to prevent program anomaly due to bitflips in the RAM. A command scheduler controls the overall program execution. The command scheduler issues the different commands like acquire image, calculate attitude, transmit attitude etc. None of the commands is allowed to take more than a specified time. If the command is not completed within its allowed time interval, the ASC is re-booted.

3.9.5 Protected Mode

One of the inherent features of the 486 microprocessor is the protected mode. This allows the different processes (procedures) to have allocated their own part of memory in which they reside. Should the process, due to a bit-flip, try to access memory outside its own part, protection violation exception is generated and the ASC is re-booted.

3.9.6 False Star Detection and Discrimination

When other satellites, comets, asteroids etc. come into FOV, they are detected as false stars. This situation has been investigated and simulated thoroughly. The algorithms are designed to handle this problem and it does not induce any performance degradation.

The processing of the false stars objects is transparent to the user and the presence of such objects is not reported to the user. However, upon command, a list of such objects is compiled and sent to the user. The list contains the CCD position and magnitude.

3.9.7 Hot Spot Rejection

Throughout the mission radiation will hit the CCD chip. This typically generates bright spots on the image, that will look like a star and be detected by the centroiding algorithm as such. The hot spots remains at the same place (same pixel) in the image. Therefore, the ASC carries a hot spots rejection filter, which eliminates them before the pattern recognition is performed.

The operations of the hot spot rejection filter are completely transparent to the user and the presence of hot spots in the images is not repported.

In order to evaluate the health status of the CCD and to assess the number of hot spots, it is recommended to download an uncompressed image periodically, e.g. once per month.

Part II
Ground Support Equipment

4 Electrical Ground Support Equipment - EGSE

The EGSE program supports the full tele-command and telemetry structure of the ASC and it may used for a variety of purposes such as:

- Familiarization with the command structure of the ASC.
- Support for checkout of the ASC functionality.
- Support for real sky verification and performance envelope tests of the instrument.
- Support for closed loop testing.
- Generation of upload commands.
- Upload of software updates.
- Upload of new parameter values.
- Debug dump device during system integration.
- Off-line operation of the instrument.
- Support for internal calibration measurements.
- Support for inter-calibration measurements.
- SCOE.

Even though the EGSE serves a great variety of functions, the program is quite simple to use and the operations of the complex ASC instrument are relatively easy. Indeed, emphasis has been put on a logical structure and grouping of the commands, the program provides bounds for critical parameters, and potential hazardous commands are double prompted.

In order to use the EGSE efficiently, a basic knowledge to the command structure is recommended. This is given in the TM/TC ICD (RD 4).

4.1 Copyright

The EGSE program and all of it's components are protected by copyright and may not be disclosed, distributed, modified or rewritten without written approval by MIS Ørsted•DTU.

4.2 System Requirements

The following hardware is required to run the EGSE properly:

- 200 MHz Pentium or compatible.
- 32 MB Ram
- 10 MB of free hard-disk space
- SVGA with 800x600 screen resolution in 256 colors
- CD-Rom drive for copying the program files
- 1 (or 2) free serial COM ports
- 1 PS/2 connector for power-supply
- Microsoft Windows 98

4.3 SW Installation

Copy all files from the CD-Rom to a user specified and created directory on the hard-disk, e.g. `C:\ASC\EGSE`. (`“egse_home”`).

Verify that the following directories are present in the EGSE home directory as it is important, that the directory structure is maintained:

- `“egse_home”\Download`
- `“egse_home”\Spool`
- `“egse_home”\Upload`

The program is started using the file

`> EGSE.EXE`

A shortcut to the program either on the desktop or in the start-menu can be created using the Windows commands.

4.4 Graphic User Interface (GUI) Description

When the program starts, the following display appears:

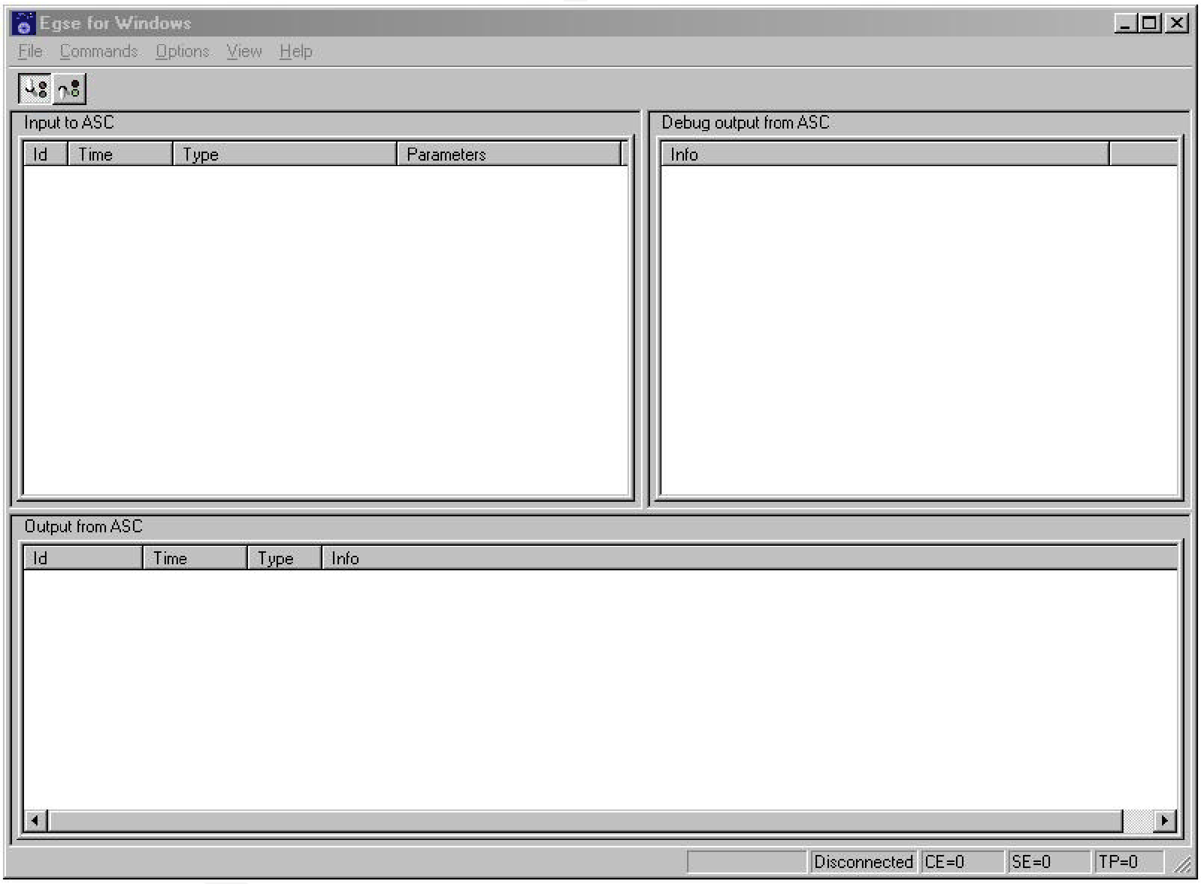

Figure 11 *EGSE main window*.

The display consist of

- a menu (for interaction with the program)
- a toolbar (for quick interaction)
- a statusbar (for user-information)
- an input window (upper left: for information on telecommands sent to the ASC)
- an output window (lower: for information on telemetry received from the ASC)
- a debug window (upper right: displays debug info received via the debug line)

4.5 Hardware Setup

Figure 12 sketches the ASC-EGSE test setup. As the details about the time synchronization are peculiar of each project, the synchronization line is ignored. The shown setup is for the most used configuration, i.e. a DPU with two CHU's.

The setup for a single camera configuration is identical but without CHU2.

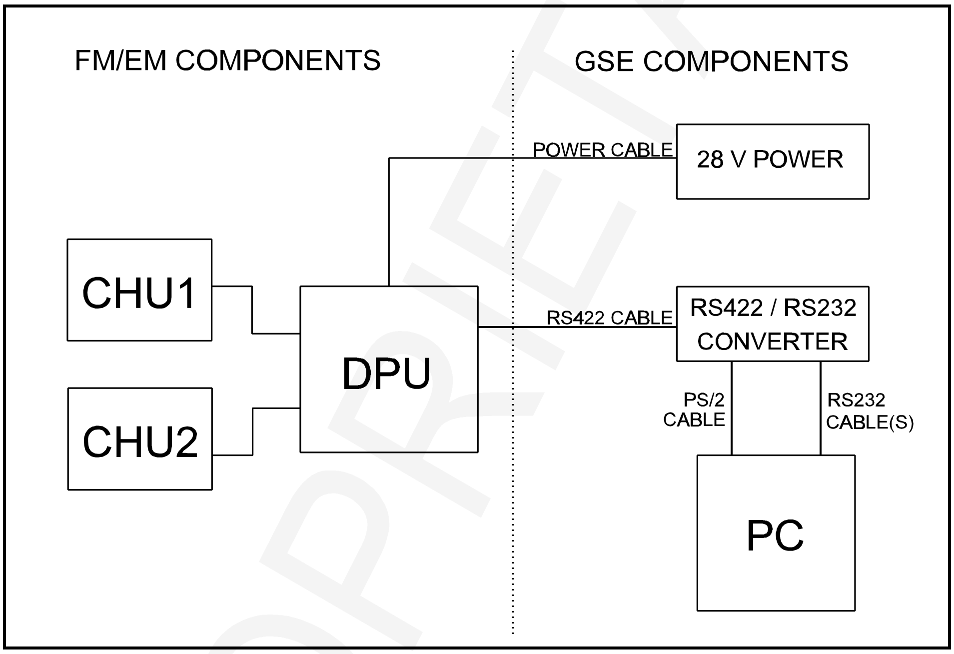

Figure 12 *ASC & EGSE test setup.*

The components are:

CHU	Camera Head Units (EM/FM)
DPU	Data Processing Unit (EM/FM)
POWER	Power Source DC 28V (This is not delivered by DTU). **The power supply must be grounded to protect electronics**.
RS CONVERTER	Converts the RS422 output from the DPU to RS232. The internal electronics are powered by the power line in the PS/2 cable. This method 'saves' a power supply.
PC	A conventional IBM compatible computer with Microsoft Windows 98. The PC must be grounded to protect electronics.

The cables are

POWER CABLE	Connects the power input on the DPU (DB-9 female) to a power source (2 x 4mm test plug). The DB-9 pin assignment is described in RD 3 (Electrical Interface Control Document).
RS 422 CABLE	This cable deals with the communication protocol to and from the DPU. In the DPU end of the cable is a DB-25 female and in the other end a DB-25 male. The male connector is connected to the converter.
PS/2 CABLE	A conventional PS/2 cable with male connectors in both ends.
RS232 CABLE	A conventional RS232 cable with male in the converter end and female in the PC end. All lines must reside in the cable, i.e. no shortened flow-control. No wire crossings.

4.5.1 Communication Setup

When the EGSE has been installed, the communication channels can be setup.

The commands are in the Options menu under “Data Port Settings...” and “Debug Port Settings...”.

In the “Data Port Settings...” the user sets the values for the "Data Port" that is normally used to connect the DPU to the spacecraft on-board computer or data handling system. Therefore, these values shall be the ones specified in RD 3 (Electrical Interface Control Document).

The instrument settings are given in Appendix B.

In the “Debug Port Settings...” the user sets the values for the "Debug Port" that, normally, is disconnected from the spacecraft and inactive during flight but that is connected to an EGSE computer during unit or system testing and checkout on ground.

The settings can be different between the two ports and, indeed, usually the baud rate of the debug port is set to the maximum rate.

Typical settings for the debug port are given in Appendix B.

The Connect/Disconnect feature opens/closes the communication ports. This feature makes it possible to perform the modifications to communication setup.

When an item is selected, a dialogue box appears.

For the Data port it will look as displayed in Figure 13.

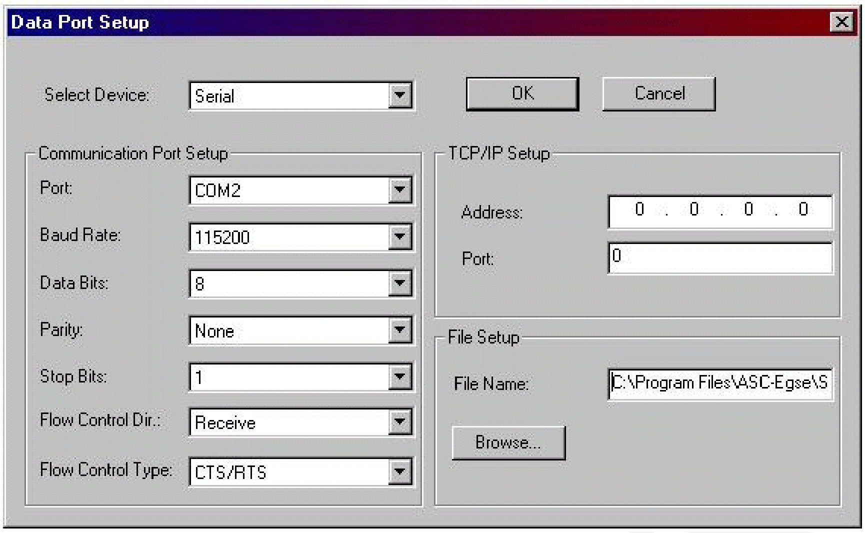

Figure 13 *EGSE Data Port setup.*

In the “Select Device” combo box, the following devices can be specified:

Serial — The input data are collected from one of the COM ports. It is possible to choose between COM1 to COM8. The communication protocol is specified in the “Communication Port Setup” field with respect to Communication port, baud-rate, number of data-bits and stop-bits, parity and flow control.

The instrument serial settings are specified in Appendix B.

TCP/IP — The input can also be collected via the Internet. If this option is selected, the EGSE-computer will act as a client computer, which has to hook up to a host computer. The IP address of the host computer is specified under “TCP/IP Setup” and the “Port” must match the port, that the host computer are listening to. Be aware, that if the host computer and the EGSE computer are at different local area networks, these networks might be separated by firewalls, proxy servers or the like. The EGSE is not configured to handle such situations.

File — If a file is selected for input, the location and name of the file must be setup in the “File Setup” field. When the EGSE is connected and running, all input tele-metry are retrieved from this file.

Disabled — This choice disables the port. At connect, the EGSE will not connect to any devices if this is selected.

If only one serial or TCP/IP input port is available, and it is required to switch between the data and debug output from the DPU, the port settings can be toggled using the command “Exchange Data and Debug” from the “Options” menu.

4.5.2 Default Settings

The EGSE is delivered with the settings according to the settings specified by the mission. However, it is a good practice to inspect the correctness of the settings when the EGSE is installed and before starting any test.

The data port is by default set to be attached to COM1.

The debug port is by default disabled. If more than one serial port is present at the EGSE-PC, it is recommended to install both links.

All changes made to the serial communication setup is saved in the files: RS232.INI and GESH.INI at program exit (or by selecting: "Options -> Save Settings..."). The settings can at all times be reset to their default values, by deleting these two files from the "\ASC\EGSE\" home directory.

The (default) instrument settings are given in Appendix B.

4.6 Accelerators

In order to access the most common commands more quickly, some keyboard shortcuts have been created. These shortcuts can be found by selecting “Accelerators...” in the “Help” menu.

5 Optical Stimulator

The optical stimulator or Star Field Simulator (SFS) is a device designed to test the quality and the performance of the CHU after integration in the spacecraft and when real-sky tests are no longer possible.

It allows polarity checks, attitude measurements, image quality assessment and end-to-end tests of the ASC. Also it supports closed loop AOCS operation tests.

The stimulator is made up from a section of a sphere of steel on which three collimators and a laser-finder are mounted. The spherical shape of the metal frame ensures a very high mechanical stability, while maintaining a low mass. All materials of the stimulators are selected such that they allow for operations under extreme conditions, e.g. in a thermal vacuum or on a stand during vibration tests. The allowable temperature ranges from -85 deg/C to +120 deg/C. The only requirement is, that the illumination of the test volume between the stimulator and the CHU can be dimmed to an extent that allows for star tracking (i.e. 0.001lux or less).

Each of the auto-collimators transforms a specific star pattern from image space to phase-space, i.e. to an collimated beam. In order to facilitate the localisation of the point of intersection of the beams from the collimators, the laser-finder may be used. The laser-finder is adjusted such that it passes through the aforementioned intersection.

5.1 General Information

The Star Field Simulator (SFS) is a fully integrated system which provides, high precision collimated visual light beams for the ASC. The system utilizes a reinforced spherical cap shell with collimators and power converter.

5.2 Specifications

The specifications for the three versions of the SFS are summarized in Table 2.

Table 2: *Star Field Simulator specifications.*

	SFS1	SFS2	SFS3
Electrical			
Input to fixed voltage regulator [V DC]	8-20	8-20	8-20
Length of power cable [mm]	1500	1500	1500
Mechanical			
Ø [mm]	500	160	325
H [mm]	140	70	130
LASER			
Class	0.125	0.125	0.125
Power [mW]	< 3	< 3	< 3
Wavelength [nm]	630-680	630-680	630-680

5.2.1 Electrical Interface

The system uses a 5V (output) fixed voltage regulator.

The SFS operates on 8-20 V DC input.

The only electrical interface is the power cable. The standard length is 1500 mm. This can be changed by customer request.

5.2.2 Thermal Interface

If the thermal limits are exceeded, degradation may occur due to mechanical deformation. The stimulator has been tested to operate from -85°C to +120°C.

The operator may have to reinitialize the ASC stimulator update function, if the mechanical deformation becomes excessive.

5.2.3 Mechanical Interface

The overall dimension of the SFS are given in Table 2. The mechanical drawing, showing the mounting interface, is given in appendix H.

5.2.4 Laser

Class 3A.

Power: < 3mw.

Wavelength: 630-680nm

5.3 Safety

The following are safety precautions that the personnel shall understand and follow when using or servicing this product.

To prevent personnel injury, adhere to safety guidelines in accordance with:

- ANSIZ 136. 1 *STANDARD FOR SAFE USE OF LASERS*

Since laser beams can be harmful to the human eyes, avoid direct eye exposure.

Do not look directly into the laser beam output aperture during operation.

Be aware that laser light reflected from a mirror-like surface, can be dangerous as well.

5.4 Setup

To setup the SFS:

1. Unpack the stimulator and store the shipping container in a convenient location. These containers can be reused to prevent damage if you store or ship the system.
2. Mount the stimulator in a secure way, in front of the ASC lens aperture.
3. Adjust the distance from the centre of the front lens to the inner surface of the stimulator. The distance must match the distance given below.

   Distance from lens to stimulator: 600mm +900/-300 mm.

4. When stimulator is properly located, remove the protection tape from one of the two inspection holes.
5. Press the red button on the guidance laser. The red spot can be observed through the inspection hole .
6. Adjust the laser spot to point at the centre of the lens.

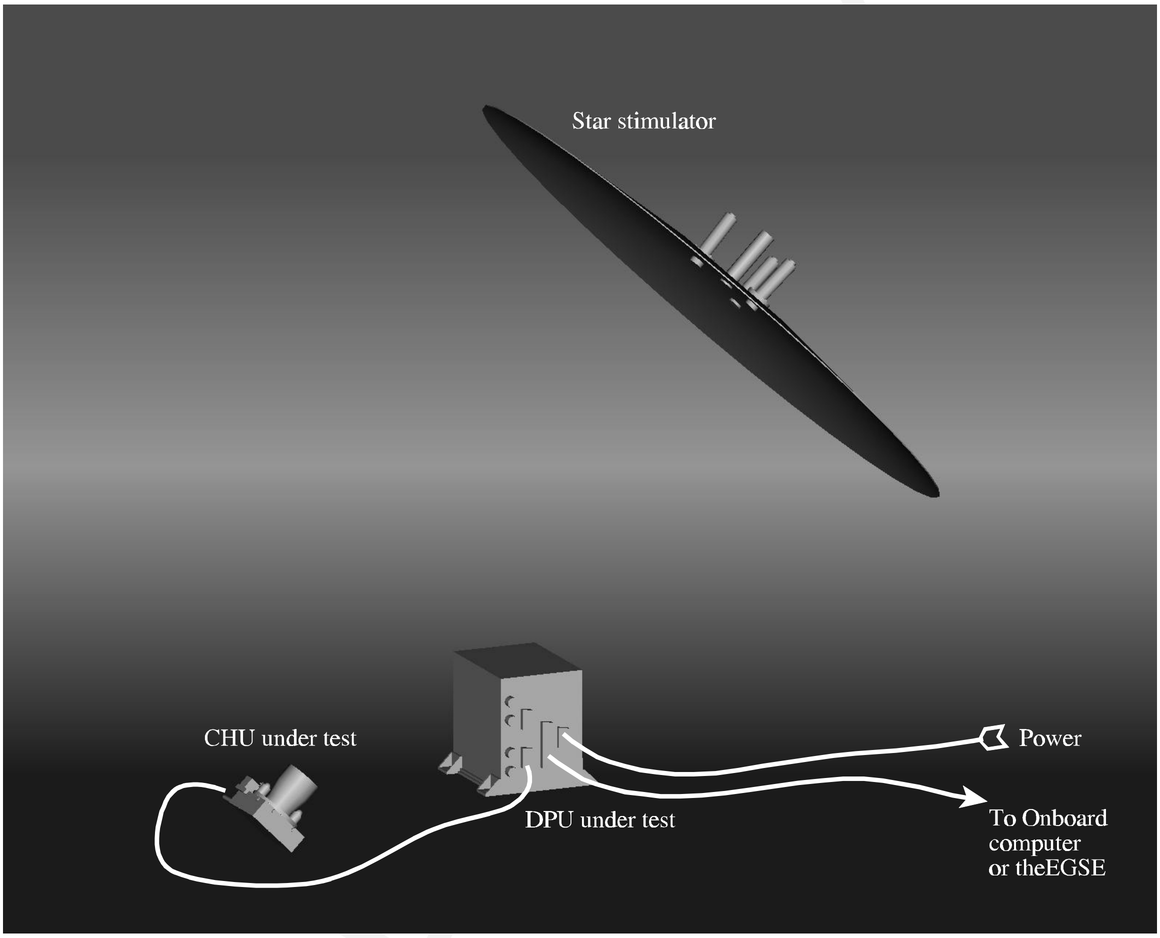

Figure 14: Sketch of the optical stimulator in front of the CHU. In the background, the DPU and the connections

5.4.1 System Power Up

1. Connect the two power lines to a DC power supply. Adjust the voltage to the voltage specified in Table 2.
2. Adjust the collimator intensity level using the control button on the box at the top of the stimulator.
3. The intensity level should be such that all nine "stars" are detected by the ASC. This adjustment can be carried out using the autoimaging function in centroiding mode. Intensity levels should be in the range 1000-2500 on the centroiding readout.

5.5 Operation

When the optical stimulator has been positioned, so that all “stars” are visible with the camera, the data processing unit (DPU) must be told to recognize the artificial star pattern.

This is achieved by inserting the star positions from the optical stimulator into the star database and the star catalogue of the DPU and by using the “AscStimulatorUpdateTC” command to specify the found pointing to be towards the Vernal Equinox i.e. 0˚ right-ascension, 0˚ declination and 0˚ rotation.

When the stars are observed in the subsequent images, the star pattern is matched in the database, and the calculated direction will be found close to the initial direction. When the optical stimulator is rotated, the magnitude of the rotation can be monitored in the rotation parameter. Similarly, when the optical stimulator is translated, the right-ascension and declination parameters will be affected.

To insert the position of the “stars” of the stimulator into the star database and catalogue and to set the initial value, the “AscStimulatorUpdateTC” shall be issued. Since this command is not relevant to the flight operations, it has not been described in the interface control document (RD 4). The format of the command is described below:

Header	Function ID 0x0188	DataLength 0
5 bytes	2 bytes	2 bytes

The header being the standard one used for telecommands (see RD 4).

The command can be issued from the EGSE by selecting "AscStimulatorUpdate (U)" from the "Miscellaneous (5)" menu.

5.5.1 TC Description

The “AscStimulatorUpdateTC” command forces the DPU to insert the centroids from the current image into the star catalogue in RAM. This command is used in conjunction with the ASC Optical Stimulator, and should only be issued during ground testing. The star catalogue will be restored after next re-boot. The ASC should generally be booted between each update of the star catalogue, otherwise it will become sub-optimal due to the repeated insertions of approximately the same stimulator stars.

5.6 Corrective Maintenance

If the stimulator needs to be adjusted in order to make all stars visible, use the following guidelines:

- Dismount the stimulator from the setup. Place the stimulator on a test stand pointing on a white piece of paper.
- The distance from the stimulator to the paper, must match the distance given in section 5.4.
- Press the red button on the ref. laser and mark the spot on the paper.
- Remove the dust shielding on the top of the collimator and carefully remove the light emitting diode.

- Use another pointing laser to point through the hole where the light emitting diode was located and watch the artificial star pattern on the paper underneath the stimulator. The direction of the laser beam must be strictly parallel to the envelope of the collimator.
- At this point it should be easy to see if the artificial star pattern from the stimulator is projected close to the ref. spot mark, (at least within the radius of the camera lens aperture .

  If not, align the collimator by adjusting the 3 hex nut screws on the bottom flange of the collimator.

6 SimASC

6.1 Introduction

The SimASC program is a piece of C-code, that simulates the behaviour of the Advanced Stellar Compass (ASC). The program simulates the behaviour of the ASC and can be interfaced with CAD tools, e.g. Matlab, and SW system simulators.

The program simulates several effects like time delays (offset, exit, process), noise contributions (NEA, residuals) and the attitude dropouts (process timeout, Sun blinding).

The use of the SimASC shall be envisaged only at the very early stage of the development or when HW in the loop is not possible.

6.2 Copyright Notice

The SimASC program and it's components are protected by copyright law and may not be disclosed, distributed, modified or reproduced without written approval from the MIS Ørsted•DTU.

6.3 Program Package

The program consist of the following files:

- ATTITUDE.H/ATTITUDE.C: A DTU developed library of functions used in the SimASC program;
- SIMASC.C: Implementation of the SimASC function

The program is developed for a DJGPP Gnu C compiler in ANSI C.

6.4 Input and Output

Input and output of the SimASC are collected in two structures in order to minimize the number of calling arguments.

6.4.1 Input

The input structure has the following declaration:

```
struct INPUTVARS
{
  struct QUATERNION q;
  double            time;
  struct EULER_ANGLE     sun;
  double            integrationTime;
  BOOL              fTimeOffset;
  BOOL              fTimeExit;
  BOOL              fTimeProcess;
```

```
    BOOL            fNoiseNEA;
    BOOL            fNoiseRes;
    BOOL            fDropoutTime;
    BOOL            fDropoutSun;
};
```

Where:

q	The input quaternion. The output quaternion is the input quaternion plus noise. See declaration of the structure QUATERNION in the ATTITUDE.H file for a description of the structure.
time	A timestamp for the start of the integration of the image. The time must be in seconds
sun	The apparent position of the Sun in pointing angles declination and right ascension. This position is used if the program shall simulate Sun blinding. Please refer to the ATTITUDE.H file for a description of the structure.
integrationTime	The integration time of the camera measured in seconds. This parameter is used to calculate the time delay from start of integration to the actual output.
fTimeOffset	Flag used to signal, that the time offset from start of integration (SOI) of the camera to start of attitude determination should be added to the time output.
fTimeExit	Flag used to signal, that the time spent on exiting existing processes before the actual attitude determination can start should be added to the time output.
fTimeProcess	Flag used to signal, that the time used on the attitude determination process should be added to the time output.
fNoiseNEA	Flag used to signal, that NEA noise should be added to the quaternion output.
fNoiseRes	Flag used to signal, that bias type noise originating from mechanical structure changes in the satellite due to temperature changes should be added to the quaternion output
fDropoutTime	Flag used to signal, that if a process is too time consuming, the valid flag should be set to FALSE
fDropoutSun	Flag used to signal, that the valid flag should be set to FALSE on Sun blinding

6.4.2 Output

The output of the function is declared in the following structure:

```
struct OUTPUTVARS
{
    struct QUATERNION q;
```

```
    double                  time;
    BOOL                    Fvalid;
};
```

Where:

q	The output quaternion
time	The output time
fValid	A flag to signal the validity of the attitude

6.5 Time Delays

6.5.1 Time Offset

This time delay describes the amount of time used for the actual image acquisition. It is measured from the start of integration of the camera until the DPU is ready to do the actual image processing. This time delay has a deterministic value dependent on the integration period.

6.5.2 Time Exit

The data processing unit (DPU) may be occupied by performing other tasks. This time delay simulates the time used for the DPU to finish such tasks and is implemented by a positive Gaussian distribution with a standard deviation (SD) of 1 ms.

6.5.3 Time Process

The DPU is now ready to perform the actual attitude determination. This time delay is used to simulate the time spent on this task and is implemented by a positive Gaussian distribution with a SD of 200 ms plus a constant time offset on 50 ms.

6.6 Noise Contributions

6.6.1 NEA Type Noise

This is the NEA (Noise Equivalent Angle) noise, that is added to the attitude output. The noise is simulated by a Gaussian distribution with a σ of 0.6'' in pointing (declination and right ascension) and a σ of 5.0'' in rotation.

6.6.2 Calibration Residual Noise

This noise contribution originates from mis-calibrations between the ASC boresight and the boresight of the satellite (or the onboard scientific instruments). This mis-calibration might either be a constant angle or it might be varying slowly over time due to mechanical changes in the satellite structure caused by temperature variations. The noise is simulated by two sines as function of input time with different period length. Please note, that this noise estimation is not necessarily representative for the actual calibration residual noise.

6.7 Dropout Conditions

6.7.1 Process Time Dropout

The processing of a star field image is set to time out if the process is too time consuming. This feature is simulated by this dropout type. If processing of the image is above a certain constant value, the validity flag is set to false.

6.7.2 Sun Blinding Dropout

Obviously, the ASC is not able to operate, when the Sun is in the field of view. This situation is simulated by the Sun blinding dropout. The Sun blinding is characterized by a certain exclusion angle. If the angle between the direction to the Sun and boresight is below the exclusion angle, the ASC will not be able to operate. If the angle between boresight and the Sun is close to the exclusion angle, the ASC will sometimes be able to operate. This is simulated by two different exclusion angles: A1 and A2 (A1 < A2). Attitudes with Sun-boresight angles below A1 are invalidated, the probability of valid attitudes at angles between A1 and A2 increases linearly from 0% at A1 to 100% at A2. Attitudes with angles above A2 are all validated. The apparent direction of the Sun can be set by the Sun variable in the INPUTVARS structure.

Part III
Ground operations

7 Stand-Alone Operations

7.1 Main Goals

The main objectives in operating the ASC as a stand-alone unit are:

- To get acquainted with the instrument, typically by "trying things out" using an engineering model;
- To check out the instrument health upon reception and to perform the FM incoming acceptance tests, e.g. a functional test.

This is achieved by connecting the instrument directly to the EGSE (see the setup described in §4.5 and (Figure 12), by running the EGSE to communicate with the ASC and by monitoring the output through the data and/or debug ports.

7.2 Telecommands

The ASC is controlled by telecommands (TC). The telecommands are used to change mode, to request information, to make memory dumps etc. The C-declaration of the telecommand structure is given in Appendix C. The TC's are fully described in RD 4.

All telecommands are implemented in the EGSE in the "Commands" menu.

7.2.1 Telecommands Functional Description

7.2.1.1 Standby Mode

By issuing the "Standby Mode" (1), the ASC is forced into standby mode, i.e. no image processing is performed.

7.2.1.2 Attitude Mode

Nominal operations are achieved in attitude mode, in which the ASC acquires and processes star images. This mode starts by issuing the "Attitude Mode" (2) command or by setting the parameter defining the standard mode entered after power up.

7.2.1.3 Simulation Mode

The "Simulation Mode" command invokes the simulation mode of the ASC for open/closed loop testing. It is fully described in §9 and it shall be used only on ground.

When this command is issued, the dialogue shown in the Figure below pops up requesting the initial pointing direction - right ascension, declination and rotation - and the rotation rates around the three axes.

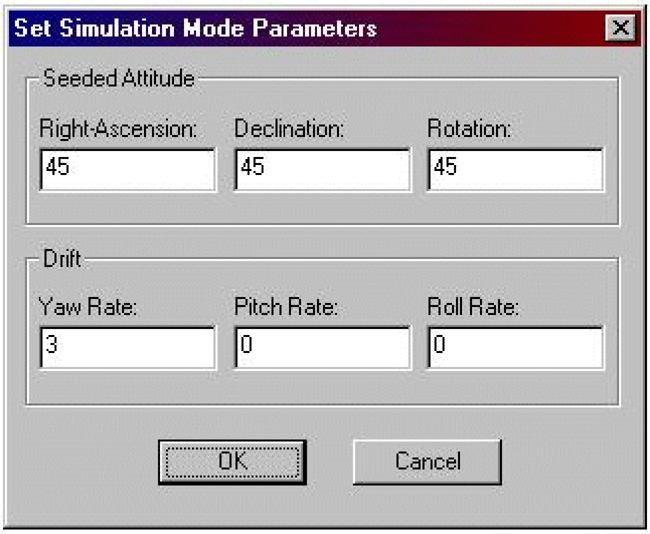

Figure 15 *Set Simulation Mode Parameters*.

7.2.1.4 Store Image

Issuing the “Store Image” (3) , will cause the dialogue shown in the Figure below to pop up. The operator shall select the compression mode and, if applicable, the camera.

The ASC must be in attitude mode in order to store images. However, it shall be pointed out that this command shall only be used to store an image in the buffer prior to downloading it. This command shall not be issue to acquire the images to compute the attitude.

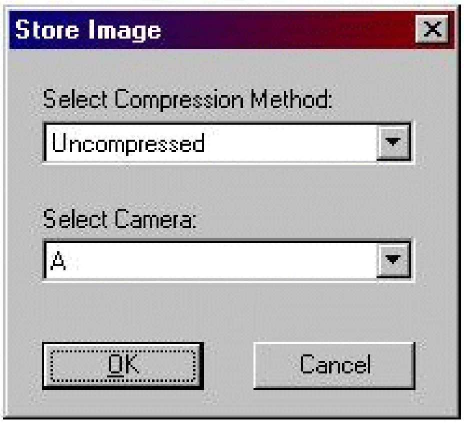

Figure 16 *Store Image*.

Select uncompressed to store an unprocessed image, centroids to save the centroids list, false stars to save a list of non-stellar objects, ROI to store regions of interest around, say, bright objects, and JPEG to compress the image in JPEG format. The compression rate for the latter three formats depends on the parameters set for each format.

The size of the centroid list depends on the number of stars in the field of view and the current setting of the centroid-function setting “threshold”. The size of a ROI-compressed image is determined by the ROI size parameter.

The size of a JPEG compressed image are determined by the JPEG compression factor parameter and the complexity of the image. For star images a compression factor of 75% typically gives a compression rate of 10.

7.2.1.5 Send Image

After an image is stored, it may be transmitted at a later time by sending the “Send Image“(4) command. The image packages will, at lowest priority, fill up the TM bandwidth.

7.2.1.6 Boot ASC

The “Boot ASC”(5) command will perform a warm-boot of the instrument, i.e. reloading all SW and resetting parameters to their initial values.

7.2.1.7 Prevent Flash Boot

“Prevent Flash Boot“ causes the EGSE to send a specific bit pattern repeatedly. During power up, the ASC checks its communication line for this pattern. If it is received, the ASC will terminate the boot sequence before the programs, stored in the FLASH-memory, are loaded.

This feature enables the user to start up the instrument in a safe mode and to upload new code, in case the software stored in the FLASH-memory is corrupted.

7.2.1.8 Send Test Image

The test image mode uploads a previously acquired image to the ASC, and forces the ASC to process this image instead of the ones taken by the CHU. The “Send Test Image” command is used to upload the required image.

7.2.1.9 Test Image Mode

The test image mode uploads a previously acquired image to the ASC, and forces the ASC to process this image instead of the images of the CHU. The "Test Image Mode" command starts the mode after a test image has been uploaded.

7.2.1.10 Stimulator Update

The optical stimulator projects an artificial star-field onto the CCD. It is used for polarity tests of the ASC on the satellite, end to end tests of the attitude and orbit control system, stability tests of the ASC, etc.

When issuing the “Stimulator Update” command, the stars from the stimulator are added to the star database in the ASC. The star pattern is now recognized as being in the direction right ascension 0°, declination 0° and rotation 0°.

§5 describes the use of the stimulator hardware and software.

7.2.1.11 Clear Bank

The command “Clear Bank (0)” is used to erase portions of the FLASH-memory. The user is prompted for the FLASH-bank to erase. The erasure takes from 1 to 11 sec.

7.2.1.12 Upload Memory

The Figure below shows the sub-menu associated with the “Upload Memory” command. As seen from the sub-menu, code, parameters and data may be uploaded in four different ways.

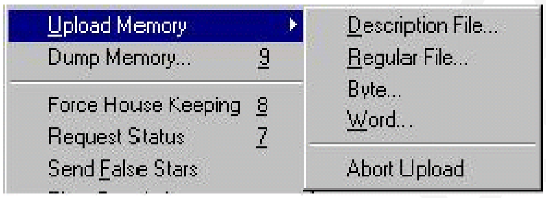

Figure 17 *Uploading memory.*

It is strongly recommended, that the user uses a description file for the uploading operations.

A single data word (two bytes in little endian) may be uploaded to the ASC by selecting Word (W). The user will then be prompted for the physical address and the data word. Similarly for the upload of a single byte (“Byte”).

The content of a file can be uploaded to the ASC by choosing “regular file (R)”. The user will be prompted for the filename and the physical location in the ASC ram, that the file is uploaded to.

Finally, to upload new releases of SW or to reload existing SW select the upload by description file, as shown in the Figure below.

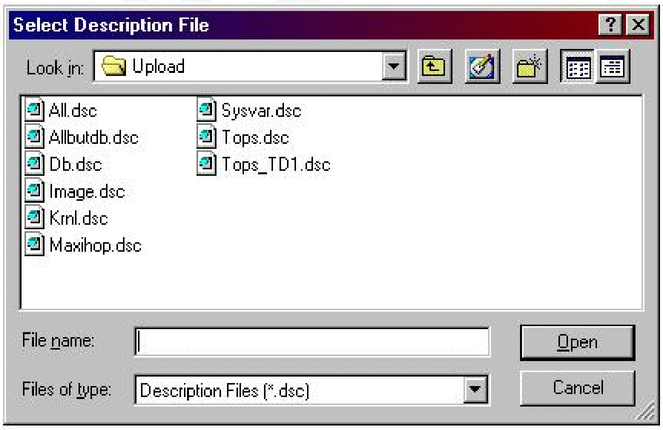

Figure 18 *Selecting a description (.dsc) file.*

After selection of the appropriate description file, the user must confirm the selected action. Because the FLASH-memory must be erased to make room for the new code, the user is now prompted whether the erasure should be done automatically or should be confirmed by the user.

The EGSE will wait for the acknowledge of a successful completion of the previous packet before a new packet is transmitted.

7.2.1.13 Dump Memory

In the case that a certain part of memory or FLASH-memory is to be downloaded the command "Dump Memory (9)" can be used. The command prompts the user for the address range to be downloaded, and the data is stored in a predefined file.

7.2.1.14 Force House Keeping

The "Force House Keeping (8)" command forces the ASC to issue an "AscHKTM".

7.2.1.15 Request Status

In order to inspect the current parameter setting of the ASC, the parameters stored in the FLASH-memory of the ASC must first be downloaded. This is achieved with the command "Request Status (7)". After this command has been issued, the parameters might be inspected or modified by issuing a "System Variables (6)" command or one of the Camera X Variables commands.

7.2.1.16 Synchronize Time

The "Synchronize Time" is used to synchronize the ASC internal clock with the timing of the system. The timing is thoroughly described in the Interface Control Document. Here follows a brief description:

With a given frequency, a PPS pulse is sent to the ASC. The internal ASC time is stored, when this pulse is received. An "AscSyncTimeTC" is then sent to the ASC with the spacecraft on-board time for the pulse. The ASC copies this timestamp and its own stored timestamp to an "AscSyncTimeTM", which is returned. If no PPS pulse has been received, the time for the last PPS pulse is returned.

7.2.2 System Variables

A system variables table has been implemented in order to be able to change one or more of the roughly 200 system variables during runtime. This gives the opportunity to change the program behaviour without uploading new software to the ASC. The system variables can be monitored and modified using the dialogues in the "System Variables" menu, showed on the Figure below.

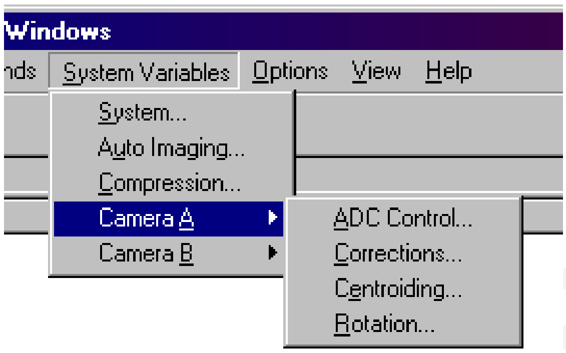

Figure 19 *Setting system variables.*

7.2.2.1 System

In the "System" menu, variables referring to the operating system can be changed. When selected the menu showed below will pop up. A description of the most common variables is given in Appendix D. The current settings can be monitored by sending the "Request Status" command. If the command has not been issued, the fields will remain blank.

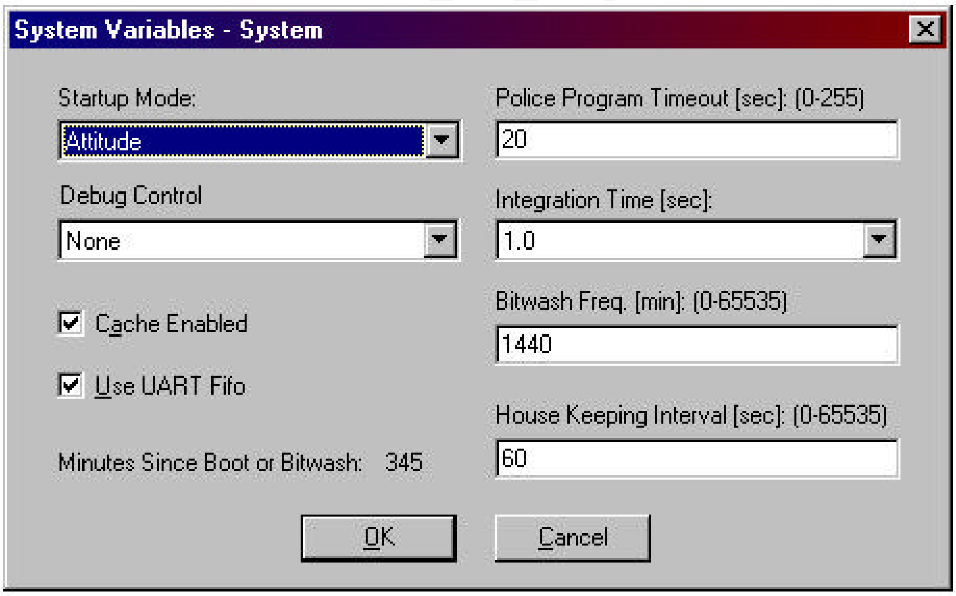

Figure 20 *System variable setup.*

7.2.2.2 Auto Imaging

When selecting "Auto Imaging..." the dialogue shown below appears.

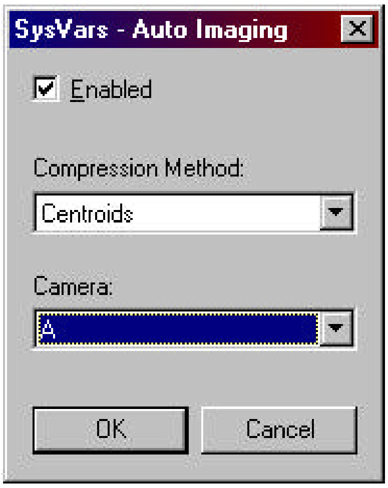

Figure 21 *Auto imaging.*

Using this dialogue, the ASC can be set to store and send images continuously in any of the three supported formats: uncompressed, JPEG or centroids. Please notice that the implemented JPEG compression algorithm doesn't follow the standard and it can only be viewed with the EGSE.

In the "camera" field, the ASC is told which camera to acquire the image from.

7.2.2.3 Compression

When selecting "Compression..." from the menu, the dialogue below appears:

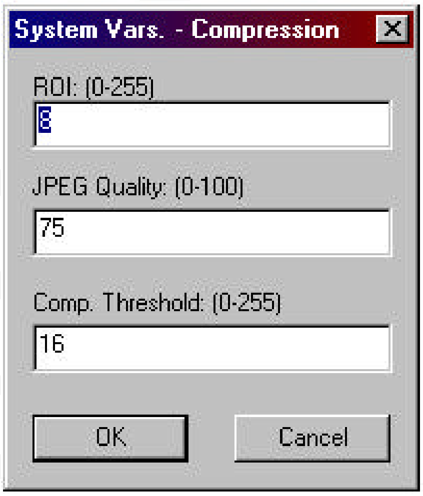

Figure 22 *Compression.*

This dialogue is used to set the parameters used for image storing.

7.2.2.4 ADC Control

When selecting “ADC Control...” from any of the “Camera X” submenu, the dialogue below appears:

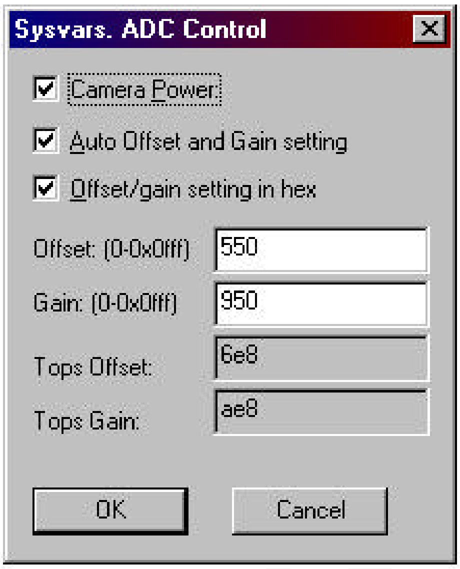

Figure 23 *ADC control.*

The fields from this dialogue can be used to control the AD conversion of the video signals from either of the cameras. The power to the camera can be toggled, auto gain setting can be enabled/disabled, and the ADC reference values can be entered manually. The values can be operated in either decimal or hexadecimal.

7.2.2.5 Attitude corrections

When “Corrections...” is selected from any of the “Camera X” submenus, the dialogue below appears:

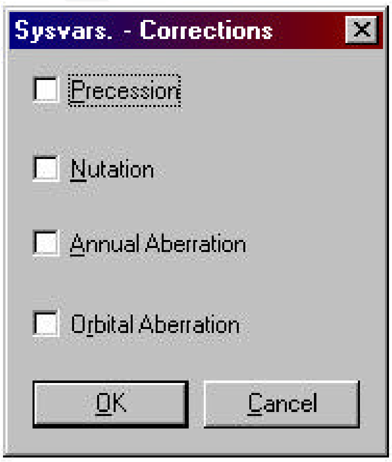

Figure 24 *Corrections.*

This dialogue can be used to enable/disable the supported types of attitude correction.

7.2.2.6 Centroiding

When "Centroiding..." is selected from any of the "Camera X" submenus, the dialogue below appears:

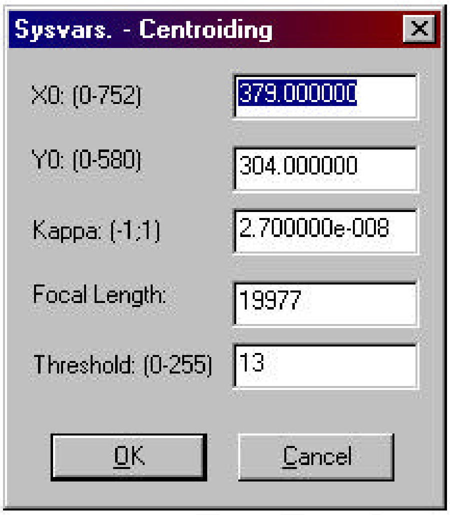

Figure 25 *Centroiding parameters.*

This dialogue can be used to modify the camera dependent parameters used for the centroiding. X0 and Y0 are the coordinates of the intersection of the optical axis and the CCD plane, Kappa is a factor to correct the field distortion and Focal Length is self explaining.

For standard values of the parameters, please refer to Appendix D.

7.2.2.7 Rotation

When "Rotation..." is selected from any of the "Camera X" submenus, the dialogue below appears:

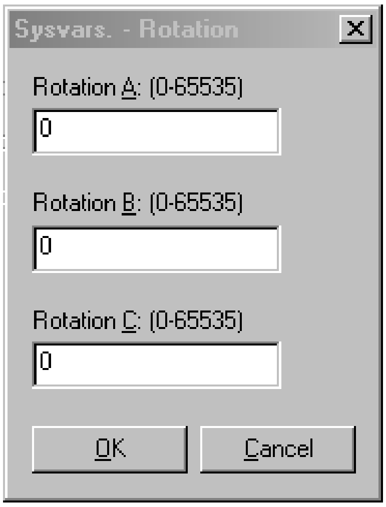

Figure 26 *Specifying a fixed rotation.*

By using this set of parameters, it is possible to change the reference frame of the attitude output. This can be used to issue directly the attitude of the satellite reference frame instead of the camera one. The rotations are:

- Rotation A: an initial rotation about the Z axis
- Rotation B: a rotation about the new X axis
- Rotation C: a rotation about the resulting Z axis

The units of the rotation are measured in 10,000th of a radian (i.e. a rotation of 31415 is a rotation of pi = 180˚).

7.3 EGSE additional Features

7.3.1 Telemetry Spool

All the telemetry can be directed to text files if specified. By issuing the “Select Spool Objects” from the “Options” menu, it is possible to setup what telemetry is to be spooled. This can be used, e.g., to monitor the house-keeping data during a test phase.

Figure 27 *Image viewer.*

7.3.2 Image Viewer

When images have been downloaded using the "Store Image" and "Send Image" commands, the contents of the images can be visualized using the "Downloaded Image..." and "Last Downloaded image" from the "View" menu. The "Downloaded image..." option lets the user select the image from a conventional file dialogue. The "Last Downloaded image" automatically selects the most recent downloaded image.

Figure 27 shows a jpeg image. On the image, nine stars from three different constellations can be observed. The image is acquired from an Optical Stimulator, i.e. it is an artificial star-field.

In the Image Information field, information about the image can be studied. Faint object can be studied be adjusting the offset and the gain.

The Image Information can be hidden/restored be checking the Info check box. It is possible to zoom in on interesting areas on the image. This can be accomplished be left clicking on the image area one or several times. The image will be restored be right clicking one or several times.

If the image is stored and downloaded as a centroid list or false stars list, the image viewer looks like Figure 28.

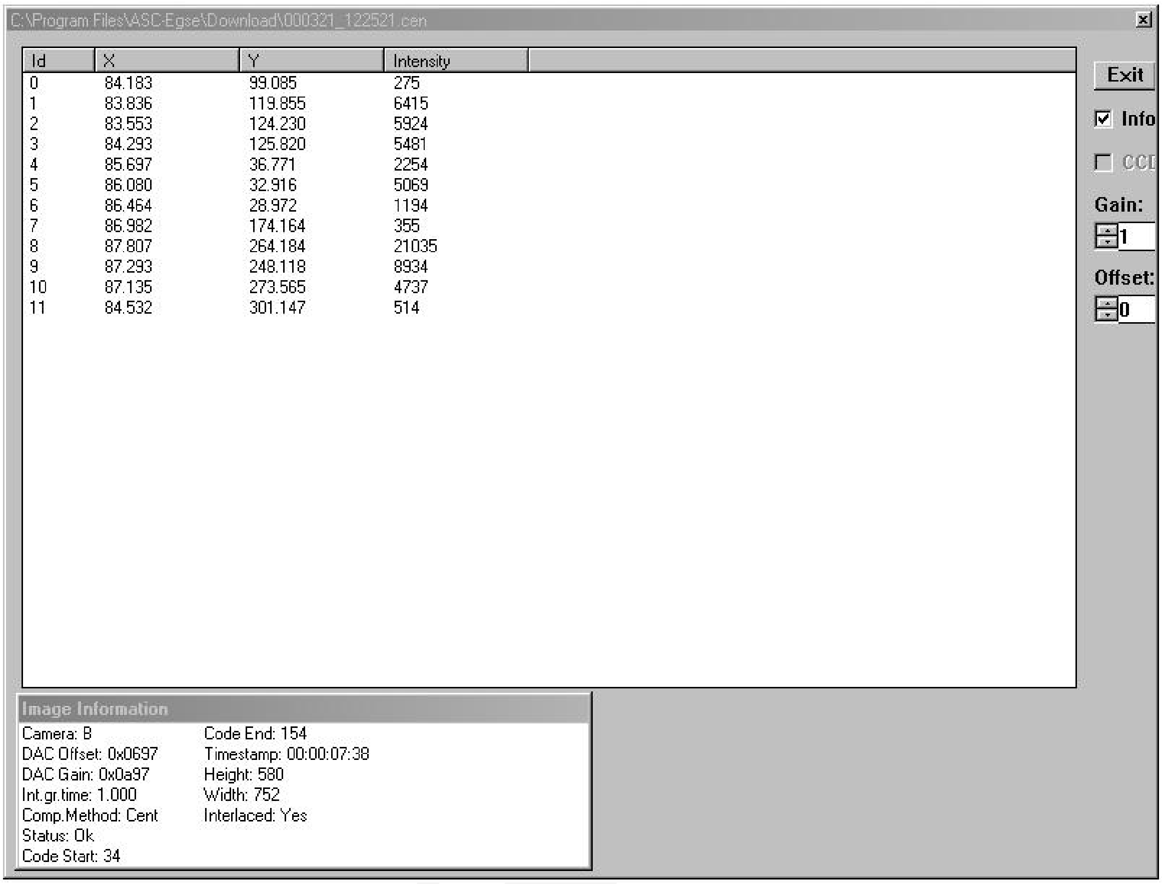

Figure 28 *List of centroids*.

If the ASC is set to auto-imaging (continuously storing and downloading images) and “Last Downloaded Image” has been selected from the “View” menu, the image will be updated each time a new image is downloaded.

All open images can be closed by selecting the “Close All Images” option from the “View” menu or by hitting the <ESC> key.

7.3.3 Output Conversion

Normally, the ASC outputs the attitude as a quaternion. Though this format is well suitable for the AOCS, it is less understandable to the human operator. To make it easier for the operator to monitor the performance of the ASC, the attitude can be output as three Euler angles, right-ascension, declination and rotation, by un-checking the “Quaternions” in the “View” menu.

7.3.4 Temporarily Disable Output

The output can be temporarily disabled by selecting the “Pause (Pause)” field in the “View” menu. The same effect can be achieved by hitting the <Pause> key. The output is re-enabled by selecting the “Pause” field again or by hitting the <Pause> key.

7.4 Get Acquainted: How-To Guide

7.4.1 Start-up

- Connect the ASC to the EGSE and power supply as described in §4.5;
- Power up the ASC, within 5-7sec the power-up packet is displayed on the EGSE TM window.

7.4.2 Set the Instrument in Stand-by or Attitude Mode

Depending on the status of the system variables, after being powered, the ASC enters automatically in stand-by or attitude mode.

If the ASC starts in attitude mode and no CHU is connected to the DPU or the camera(s) operates in a lab without the optical stimulator, then the attitude measurements are all reported as invalid and they are visible in the EGSE output window.

To set the ASC in stand-by mode, the operator shall send a “Stand-by Mode” (1) command from the “Command” menu.

When in stand-by mode, the attitude is not measured and not transmitted. Hence, no attitude packets are visualized in the output window.

To set the ASC in attitude mode, the operator shall send a “Attitude Mode” (2) command from the “Command” menu.

7.4.3 Re-boot

A reboot command is issued by selecting "Commands -> Boot ASC". For comfort reasons, before transmitting the telecommand the EGSE will prompt for a confirmation.

7.4.4 Re-boot in Safe Mode

Dependent on the mission requirements, the ASC can be setup to boot in either safe mode (microhop/ eprom mode) or in autonomous normal operational mode (maxihop/attitude/standby mode. The start up mode is specified in the system parameters table.

If the system is setup to boot in safe mode, normal operational mode is entered by issuing an “AscAttitudeMode” ("Commands -> Attitude Mode").

If the system is setup to boot in normal operational mode (attitude or standby), this autonomy can be overruled by continuously transmitting the characters 0xAA and 0x55 referred to as "PreventFlashBootPattern" during boot-up of the instrument. Transmission of this sequence is initiated by selecting "Commands -> Prevent Flash Boot". The transmissions ends either when the EGSE receives the confirmation telemetry or when the user stops it by pressing "Stop".

7.4.5 Dump the Memory

All parts of the memory (RAM as well as FLASH) can be downloaded using the “AscLoadMemoryTC” telecommand. The RAM area has the logical start address 0x00000000 and the FLASH area has the logical start address 0x01000000. The command is found in the EGSE under "Commands -> Dump Memory..." or by pressing 9.

The EPROM is copied to the RAM area as part of the boot-up. This software can be downloaded e.g. in order to investigate the date-code (date of compilation) of the EPROM by downloading 64KB starting from logical address 0x000D0000. The date-code is located almost in the end of the file.

7.4.6 Clear Memory

The FLASH memory of the ASC is divided into 64 banks each of 64KB (including hamming code protection). These flash banks can be erased individually by sending the “AscClearBankTC”. ***Since this command erases parts of the ASC memory, it should be used with extreme caution.*** The command is found under "Commands -> Clear Bank...".

The bank containing the system parameters are (at instrument delivery) located in bank 63. This bank can be erased by specifying 63 in the bank prompt. When the instrument is re-booted, it will start up in safe mode, since it is not able to find the system parameters pattern. Operation of the instruments is recovered by uploading the system parameters using the SYSVAR.DSC description file (see next section). Notice, that changes made to the system parameters will be reset by this procedure.

7.4.7 Upload Memory/Code

The software onboard on the ASC can be updated at any time, either on ground or in flight, with the “AscLoadMemoryTC” command.

This command requires five different parameters:

- UseFAT a flag for using the FAT (File Allocation Table)
- EraseFlash a flag for erasing the Flash Memory
- NumberOfBytes the number of bytes to upload
- Base the absolute starting address in which to store the first byte
- Data the new code

The format and order of the parameters are described in the TM/TC Interface Document.

In the EGSE, this command is used in four different ways, which makes it possible to upload:

- a byte
- a word (2 bytes)
- the content of a file
- controlled by a description file

The commands are located in the “Commands -> Upload Memory -> X”, where ‘X’ is either “Byte”, “word”, “Regular File” or “Description File”.

When uploading a byte or a word, the decimal value to upload and the physical address to upload to in the ASC memory must be entered. When uploading a file, the filename is typed into the “Upload File Name” field. If the file is not located in the working directory, the full path must be entered. The file can be located using the “Browse...” button as well. Notice that the flash cannot be set to erase from within the three above mentioned uploading techniques. This must be erased manually using the “Erase Flash...” command.

Finally, it is possible to have the code upload controlled by a description file. This is the most commonly used form. When selecting the command from the menu, the following dialogue appears:

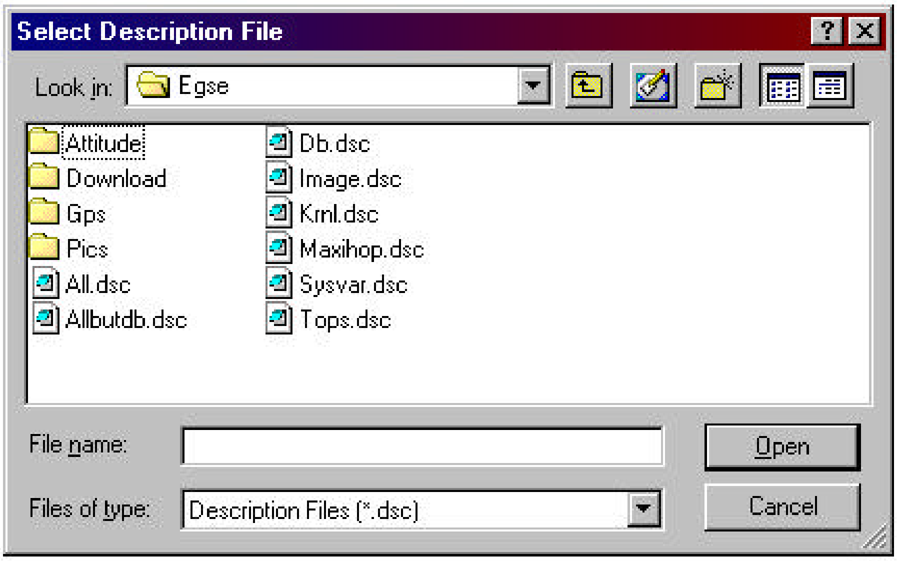

Figure 29 *Select description file.*

The required description file can be selected from the dialogue. Before the actual uploading starts, the user is requested to confirm the upload. When the upload is confirmed, the user is asked, whether flash banks should be erased automatically or if the erasure should be confirmed each time. Normally, the flash should be set to erase automatically.

The content of a description file is, e.g.:

```
INPUT_FILE=C:\EGSE\TOPS\TOPS 0x0100a800 USE_FAT=Yes ERASE_FLASH=Yes
```

In the example, the content of the file “C:\EGSE\TOPS\TOPS” is uploaded to the physical address “0x0100a800". The FAT is used and the flash should be erased before upload.

It is possible to specify several files in each description file. The following description files are provided with the ASC:

- TOPS.DSC: A piece of the software
- SYSVAR.DSC: The system variables table
- MAXIHOP.DSC: A piece of the software
- KRNL.DSC: A piece of the software
- IMAGE.DSC: To upload an image
- DB.DSC: The star database
- ALL.DSC: All files mentioned above
- ALLBUTDB.DSC: Same as ALL.DSC except the star database

It is possible to upload to the flash in all the modes of the ASC. However, the transfer will be fastest when the ASC is set to standby mode using the “`Command -> Standby Mode`”.

Since the files are uploaded to the flash ram, the ASC must be re-booted (using “`Commands -> Boot ASC`” or by switching the power off and on) before the new uploaded software will be used.

If the paths in the description file doesn’t match the present file locations, the EGSE will not be able to locate the software. Either the software must be moved to the right location or the description files must be changed.

7.4.8 Acquiring and Downloading Images

The images used for attitude determination can be downloaded to ground by command.

To acquire and store an image, the ASC shall be in attitude mode. The images are automatically acquired and processed at the rate set by the integration time (“`System Variables -> System -> Integration Time`”). However, they are immediately discarded if not commanded to be stored (buffered) by issuing an “Asc`StoreImage`TC”.

When the image is stored, it must be downloaded using the “Asc`SendImage`TC”

Since the packet length of the telemetry is lower than the image size, the image is divided into a number of packets, each marked with an offset and the packets are sent automatically with low priority, filling up the available bandwidth. The latter process is completely transparent to the user and handled by the ASC SW based on the available bandwidth and maximum allowed packet length.

It is important to note that only one image can be stored at any time.

Hence, any stored image shall be downloaded before another image can be buffered. If a new image is saved before the old one is downloaded, the new one overwrite the old one which is, consequently, lost.

If a sequence of images is required, in order to avoid the risk to overwrite the images and to loose data, the use of the autoimaging feature is to be preferred. Indeed, in autoimaging a new image is stored as soon as the buffer has been emptied.

7.4.9 Set the Detection Limit

The detection limit is a measure for, how bright an object should be to be detected by the centroiding algorithm. By making this parameter an adjustable system parameter, it is possible to tune the ASC in flight to give the highest performance wrt. accuracy and time latency.

Since the analogue electrical chain varies marginally for each piece of hardware, a detection threshold parameter has been implemented for each CHU. The system impact can easily be verified by changing this threshold while observing the night-sky. A higher value will result in lesser star detected by the ASC, whereas a lower value will result in more stars.

The detection threshold for CHU A is adjusted by selecting "System Variables -> Camera A -> Centroiding" and change the "Threshold" field. For ground based observations, the optimal value should be close to 17, whereas for space based observations, the optimal value should be around 27. This difference in optimal values is due to atmospheric effects.

7.4.10 Inspect and Change the System Variables

More than 200 system variables are used by the ASC SW to control the proper operations of the instrument and to guarantee a graceful degradation while avoiding to upload new software.

All system variables can be changed by the user. However, only a subset of these variables is meant to be accessed directly by the user. These variables are described in RD 4.

The remaining variables are meant to be a tool for specialised personnel to intervene remotely especially when the upload of new software may be not recommended, e.g. due to very slow baud rate.

The user is welcome "to try things out" and to change the variables during the ground testing especially when the instrument is directly available. However, before starting to use the ASC integrated with other instruments, we recommend to reload a fresh copy of the software to safely restore all the settings.

Furthermore:

We strongly recommended not to change the variables not described in Appendix D in flight, unless the user is fully aware of the consequence of the modifications.

To check the value of the system variables, the first step is to download them. This is done by sending a "`Request Status`" command from the "`Command`" menu.

7.4.11 Upload a Test Image

The ASC offers the opportunity to perform attitude determination on a previously acquired image. Prior to perform this operation, an uncompressed "test image" must by uploaded to the ASC using "AscSendTestImageTC"'s. This command is found in the "Commands -> Send Test Image...".

Since such images are far larger the telecommand structure, it is split into several packets by the EGSE. The image is only uploaded to RAM wherefore an image must be uploaded each time the ASC has been booted.

When the test image has been successfully uploaded, the test image mode is initiated by sending an "AscTestImageModeTC" ("Commands -> Test Image Mode"). Notice, that the CHU specific parameters set up in the system parameters MUST match the parameters for the CHU, that originally acquired the image.

7.4.12 Overrule the Autonomy

The ASC offers a variety of autonomous functions. Some of these functions can be overruled.

<u>House Keeping Conversion</u>

The ASC can autonomously perform housekeeping conversion at a frequency according the setting in the system parameters. This setting is available through "Sysvar Variables -> "System" field House Keeping Interval. The autonomy is overruled by uploading specific requests for housekeeping conversions using "Commands -> Force HK".

<u>Startup Mode</u>

During in flight operation, it is beneficial to have the ASC starting up automatically in attitude mode, such that no commands should be sent to the instrument after power-up. This autonomous operation can be overruled by continuously sending a "Prevent Flash Boot Pattern" as described in the "Re-boot in safe mode" section.

Automatic Gain

During a satellite orbit, the CHU will be exposed to different levels of background illumination. When the boresight is close to bright objects e.g. the Moon, the background illumination level will increase substantially. This varying level is autonomously tracked by the software, such that the optimal performance is ensured at any given time.

The AGC-s for the different CHU-s can be "frozen" individually, by unchecking e.g. "System Variables -> Camera A -> ADC Control -> Auto Offset and Gain Setting" for CHU A. The levels can then be set manually in the "Gain" and "Offset" fields.

7.4.13 Check the SW Version

To check the SW version, an “AscDumpMemoryTC” shall be issued.

Using the EGSE, this can be done with the command “Dump Memory (9)”.

The command prompts the user for the range and the address to be downloaded and the data is stored in a predefined file.

Ranges and typical start addresses are: :

- EPROM 30 bytes @ 0X100497B
- KERNEL 17 bytes @ 0X100FA00
- TOPS 17 bytes @ 0X1082E00
- MAXIHOP 17 bytes @ 0X113B124

The exact start addresses are found in Appendix I.

8 Optical Stimulator

In the basic test setup, the stimulator is placed at a pre-specified distance from the lens of the CHU under test. This distance is typically 600mm but may be as large as 1500mm. When the proper distance has been verified, the laser-finder may be used to adjust the stimulator relative to the lens of the CHU. i.e. the stimulator is turned such that the beam of the laser-finder hits the centre of the lens (see §5 for the detailed instructions about the stimulator setup).

Now, the DPU may be turned on and, after entering attitude mode, the number of stars is verified.

Because the star pattern of the stimulator is unknown to the ASC, the star pattern will not be recognized. In order to inject the actual star pattern of the stimulator in the star catalogue of the ASC, the "AscStimulatorUpdate (U)" from the "Miscellaneous (5)" menu (see §5.5 for the details) shall be sent to the ASC.

The centroids, detected in the next image by the ASC, are now used to update the star catalogue.

It is important to note, that it is only the runtime versions of the star catalogue that is updated, wherefore a correct version of the catalogue is obtained after power cycling.

After this update, the ASC will recognize the star pattern of the stimulator, and the stimulator may be moved according to the test in progress. E.g. if a polarity test is called for, the stimulator may be turned relative to the spacecraft, successively, in each of the three degrees of freedom of the attitude.

The mechanical and optical stability of the stimulator is excellent, and biases less than 1 arcsecond are achievable over a time-span of tens of hours.

9 Simulation Mode

Complex instruments like the ASC may be quite difficult to test in closed loops. This problem is augmented by the fact, that it is not possible to perform a direct stimulation of the CHU that will render the full performance, noise-spectrum and real-timeliness with high fidelity.

In order to circumvent this impasse, the AscSimulationMode command has been added to the ASC command structure.

Basically, the AscSimulationMode command upload a desired attitude to the ASC that the ASC then processes and in turn output to the data channel.

Upon receipt of the command, the ASC stores the desired attitude, flags simulate mode in the system status, and, forces the instrument into attitude mode. Upon integration of the next image from the CHU, a normal attitude process is initiated with a single additional step.

Firstly, the image is sifted for stars, resulting in a centroid list.

Then the additional step is taken. The attitude requested by the simulate-command is passed to an algorithm that searches the star-catalogue for the stars, that should be visible, had the field of view of the CHU been pointing at the required attitude. Each star position and magnitude is perturbed slightly to simulate the photon, readout and system noise of a real star image. The resulting centroid list is added to the centroid list from the camera. This extra step takes 5msec on average ensuring the real-timeliness of the overall process.

The combined centroid list is then forwarded to the normal star recognition algorithms, i.e., the previous attitude, if existing, is used to seed a least square fit between the catalogue stars and the centroid list. If no match is found, the lost-in-space algorithm is initiated.

The attitude, based on the combined centroids list, is then output through the DATA communication line as a standard attitude package, and the attitude is stored internally for use by the next simulation step.

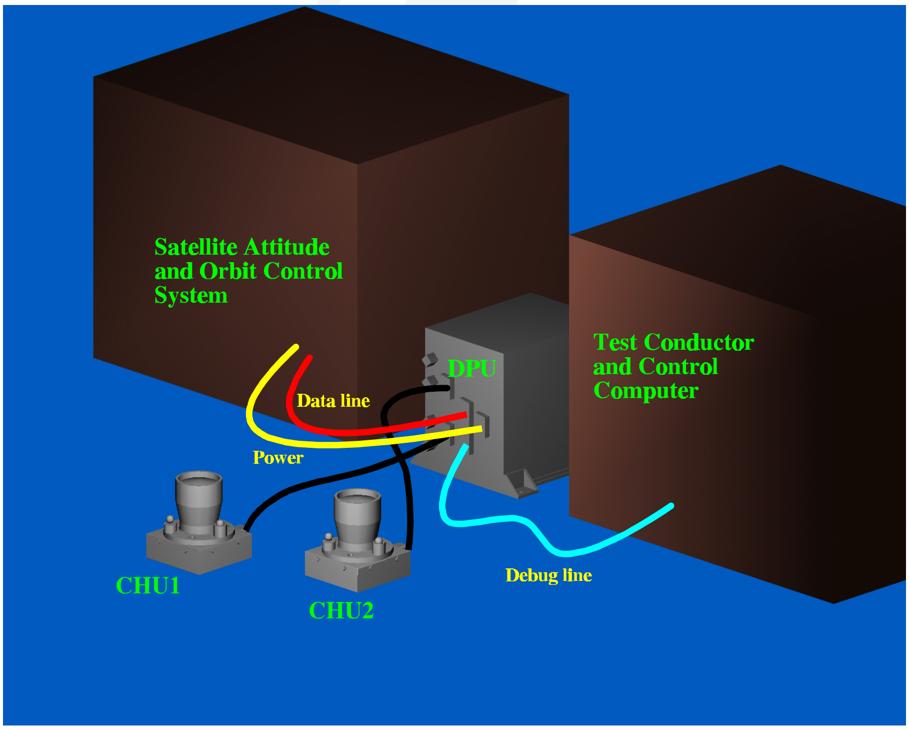

Figure 30 *A typical closed loop test-setup.*

9.1 Using the Simulation Mode

The simulation mode of the ASC is specifically designed to facilitate testing of the instrument in closed loop in conjunction with e.g. AOCS. As shown on Figure 30, the ASC is typically connected via the "data" communication line to the on-board computer, and via the "debug" communication line to a dedicated test-computer.

All communication via the "data" line is exactly as in-flight. The simulation mode may be controlled by either communication line, but will in closed loop tests entirely be controlled via the "debug" line.

The test computer may then, at any time, command the ASC into simulation mode, simply by issuing the "AscSimulationMode" command. The CHU's of the ASC must be blind-folded so that only dark images is generated, because the simulate mode uses the noise of the image to generate realistic output attitude jitter.

To enable an easy setup of virtually any attitude scenario, AscSimulationMode takes a direction cosine matrix in J2000.0 and the rate of change in the three camera-axes as parameters.

To avoid problems with realtime clock skewing, the rates of change are given as change per update. Hence, the actual rate will change if the integration time is changed during simulation. E.g. Say the ASC is commanded to 2 Hz update-rate and to simulate a drift-rate of 0.01° per update, this will result in a simulated drift-rate of 0.02° per second.

The AscSimulationMode may be uploaded anew at any point in time, but the new parameters will only take effect after the end of the next integration time of the CHU's.

9.2 Modality

The user may choose to control the simulated motion in three different ways:

1. Full user-control. The attitude and apparent drift are directly controlled via the test-computer that uploads a new attitude, say, once per update. I.e. A direction-cosines representing the desired attitude is sent once per update. The uploaded rates-of-changes may then be set to zero.

   Because a new attitude is present each time a new image is ready for processing, the previous attitude is overridden. The user may let the attitude shift any amount between updates, hence forcing the lost-in-space algorithms to be activated constantly. Or, the user may choose a small attitude rate, in which case, the least square fit algorithm will suffice.

   This mode is intended for verifying complex manoeuvres, and for checking the real-timeliness and the attitude flags.

2. Pointing user-control. The pointing direction and a drift rate are uploaded to the ASC. When the next image ready for processing, an attitude simulation process, as described above, will take place.

   After outputting the simulated attitude, the result is stored, and a new simulation step is spawned. This procedure results in constant rate-of-change, at the rate set in the last AscSimulationMode, and about an axis defined by the uploaded rate-of-changes.

   This simulation will proceed until a new simulation command is issued.

   This mode is intended to verify AOCS actuator signal sign and size.

3. Relative user-control. To forward the latest attitude package to the simulation control computer and for that computer to calculate the next desired attitude in time to be used by the ASC in the next simulation step might prove difficult. Hence, the following mode has been included.

   To seed the ASC with an initial pointing direction, the user may issue an AscSimulationMode command, containing the desired pointing direction and rates of change values.

   All subsequent AscSimulationMode commands may then have a ZERO direction cosine, i.e. an invalid rotation matrix, but valid rate-of-change values.

   The ASC will then automatically use the latest calculated value of the attitude to seed the next simulation step.

   This mode is intended for closed loop simulations, simulating real attitude manoeuvres and control. The effect of new values of disturbances and torques on the spacecraft, may be used by the simulation control computer to calculate the resulting drift-rates which in turn are uploaded to the ASC.

9.3 Conventions and Examples

Attitudes uploaded to the ASC in simulation mode are all given in equinox J2000.0, i.e. the direction cosine gives the relation between J2000.0 and the ASC reference system, as depicted in Figure 31. The ASC may rotate its output to a user specified coordinate system, typically the

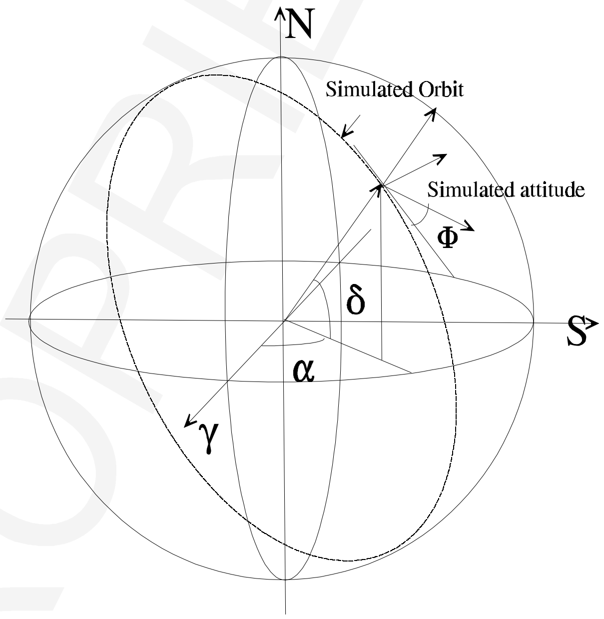

Figure 31, The relationship between J2000.0, Spacecraft coordinate systems, and the angles α, δ and ϕ.

spacecraft reference system (SCRS). The direction cosine to be uploaded is defined as the direction cosine that rotates SCRS coordinates to J2000.0. Assuming that the ASC reference system is the SCRS this means that the direction cosine gives the SC coordinates as seen in the J2000.0 frame. As an example case B below illustrates the convention.

In order to ease operation in multi-CHU systems, the input and output reference frame of the ASC are kept identical in simulation mode. This results in, that at a given uploaded attitude, two identical (except for noise) attitudes are output in a dual-CHU system. This means, that the reference system of the simulation should not be perceived as the boresight but rather the spacecraft reference frame.

As reference axes for the rotations the camera axes are used, i.e. the rates refer to rate-of-change of the SCRS frame. This is illustrated in the examples below from case D. In multi-CHU systems each CHU will deliver approximately identical attitudes, allowing for noise, for each simulation step. Please note, that these rotations do NOT commutate, and, that the order of rotation used to propagate the attitude is: Y,X,Z for pitch, yaw and roll respectively.

The following examples disregard the noise impact on the simulation. Right Ascensions are denoted α, Declinations δ and Rotations ϕ.

9.3.1 Example 1: Full User-Control

A) The user uploads an attitude matrix Aa, and a rotation rate vector Ar:

$$Aa = \begin{vmatrix} 1.0 & 0.0 & 0.0 \\ 0.0 & 0.1 & 0.0 \\ 0.0 & 0.0 & 1.0 \end{vmatrix} \quad Ar = \begin{vmatrix} 0.0 \\ 0.0 \\ 0.0 \end{vmatrix}$$

The attitude output will then be:

$QA = (0.0, 0.0, 0.0, 1.0)^T$ equal to $(\alpha,\delta,\phi) = (0,90,0)$. The rotation matrix propagated to the next simulation step is then:

$$Aa_1 = \begin{vmatrix} 1.0 & 0.0 & 0.0 \\ 0.0 & 0.1 & 0.0 \\ 0.0 & 0.0 & 1.0 \end{vmatrix}$$

I.e. The attitude remains, except for noise, the same over time.

---------o0o---------

B) The user uploads an attitude matrix Ba, and a rotation rate vector Br:

$$Ba = \begin{vmatrix} 0.0 & 0.0 & 1.0 \\ 0.0 & 0.1 & 0.0 \\ -1.0 & 0.0 & 0.0 \end{vmatrix} \quad Br = \begin{vmatrix} 0.0 \\ 0.0 \\ 0.0 \end{vmatrix}$$

The attitude output will then be:

QB = (0.0, 0.707107, 0.0, 0.707107)^T equal to (α,δ,ϕ) = (0,0,0). The rotation matrix propagated to the next simulation step is then:

$$Ba_1 = \begin{vmatrix} 0.0 & 0.0 & 1.0 \\ 0.0 & 0.1 & 0.0 \\ -1.0 & 0.0 & 0.0 \end{vmatrix}$$

I.e. the attitude remains, except for noise, the same over time.

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C) The user uploads an attitude matrix Ca, and a rotation rate vector Cr:

$$Ca = \begin{vmatrix} 0.500000 & -0.500000 & 0.707107 \\ 0.707107 & 0.707107 & 0.000000 \\ -0.500000 & 0.500000 & 0.707107 \end{vmatrix} \quad Cr = \begin{vmatrix} 0.0 \\ 0.0 \\ 0.0 \end{vmatrix}$$

The attitude output will then be:

QC = (0.146447, 0.353553, 0.353553,, 0.853553)^T equal to (α,δ,ϕ) = (0.0, 45.0, 45.0). The rotation matrix propagated to the next simulation step is then:

$$Ca_1 = \begin{vmatrix} 0.500000 & -0.500000 & 0.707107 \\ 0.707107 & 0.707107 & 0.000000 \\ -0.500000 & 0.500000 & 0.707107 \end{vmatrix}$$

I.e. The attitude remains, except for noise, the same over time.

---------o0o---------

9.3.2 Example 2: Pointing User-Control

D) The user uploads an attitude matrix Da, and a rotation rate vector Dr:

$$Da = \begin{vmatrix} 0.0 & 0.0 & 1.0 \\ 0.0 & 1.0 & 0.0 \\ -1.0 & 0.0 & 0.0 \end{vmatrix} \quad Dr = \begin{vmatrix} 0.01 \\ 0.02 \\ 0.03 \end{vmatrix}$$

The attitude output will then be:

QD = (0.604495, 0.006436, 0.428356, 0.671607)^T equal to (α,δ,ϕ) = (303.139964, 15.610005, 121.920045). The rotation matrix propagated to the next simulation step is then:

$$Da_1= \begin{vmatrix} 0.632941 & -0.567592 & 0.526522 \\ 0.583154 & -0.097806 & -0.806453 \\ 0.509233 & 0.817480 & 0.269088 \end{vmatrix}$$

The next three simulation steps will then result in an attitude of:

QD_1 = (0.603694, 0.006269, 0.444286, 0.661910)^T equal to

(α,δ,ϕ) = (304.465141, 15.725540, 123.275299)

QD_2 = (0.602682, 0.006099, 0.460062, 0.651983) ^{T} equal to

(α,δ,ϕ) = (305.787961, 15.871196, 124.628288)

QD_3 = (0.601459, 0.005928, 0.475677, 0.641828)^T equal to

(α,δ,ϕ) = (307.107895, 16.046837, 125.978503)

---------o0o---------

E) The user uploads an attitude matrix Ea, and a rotation rate vector Er:

$$Ea = \begin{vmatrix} 0.632941 & -0.567592 & 0.526522 \\ 0.583154 & -0.097806 & -0.806453 \\ 0.509233 & 0.817480 & 0.269088 \end{vmatrix} \quad Er = \begin{vmatrix} 0.01 \\ 0.02 \\ 0.03 \end{vmatrix}$$

The attitude output will then be:

QE = (0.604495, 0.006436, 0.428356, 0.671607)^T equal to (α,δ,ϕ) = (303.139964, 15.610005, 121.920045). The rotation matrix propagated to the next simulation step is then:

$$Ea_1= \begin{vmatrix} 0.632941 & -0.567592 & 0.526522 \\ 0.583154 & -0.097806 & -0.806453 \\ 0.509233 & 0.817480 & 0.269088 \end{vmatrix}$$

The next three simulation steps will then result in an attitude of:

QE_1 = (0.603694, 0.006269, 0.444286, 0.661910)^T equal to

(α,δ,ϕ) = (304.465141, 15.725540, 123.275299)

QE_2 = (0.602682, 0.006099, 0.460062, 0.651983) ^{T} equal to

(α,δ,ϕ) = (305.787961, 15.871196, 124.628288)

$QE_3 = (0.601459, 0.005928, 0.475677, 0.641828)^T$ equal to

$(\alpha,\delta,\phi) = (307.107895, 16.046837, 125.978503)$

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9.3.3 Example 3: Relative User-Control

F) The user uploads an attitude matrix Fa, and a rotation rate vector Fr:

$$Fa = \begin{vmatrix} 0.0 & 0.0 & 1.0 \\ 0.0 & 0.1 & 0.0 \\ -1.0 & 0.0 & 0.0 \end{vmatrix} \qquad Fr = \begin{vmatrix} -0.523598776 \\ 0.0 \\ 0.0 \end{vmatrix}$$

(30deg/update about -X (SCRS) or Z (IRF)).

The attitude output will then be:

QF = (0.0, 0.707107, 0.0, 0.707107)^T equal to (α,δ,ϕ) = (0,0,0). The rotation matrix propagated to the next simulation step is then:

$$Fa_1 = \begin{vmatrix} 0.0 & -0.500000 & 0.866025 \\ 0.0 & 0.866025 & 0.500000 \\ -1.0 & 0.000000 & 0.000000 \end{vmatrix}$$

The next three simulation steps will then result in an attitude of:

QF_1 = (-0.183013, 0.683013, 0.183013, 0.683013)^T equal to

(α,δ,ϕ) = (30.0, 0.0, 0.0)

QF_2 = (-0.353553, 0.612372, 0.353553, 0.612372) ^{T} equal to

(α,δ,ϕ) = (60.0, 0.0, 0.0)

QF_3 = (0.5, -0.5, -0.5, -0.5)^T equal to

(α,δ,ϕ) = (90.0, 0.0, 0.0)

Now assume that, before the calculation of QF_4 starts, a new simulation command is uploaded with the following parameters:

$$Fa_4 = \begin{vmatrix} 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 \end{vmatrix} \qquad Fr_4 = \begin{vmatrix} 0.0 \\ -0.174532925 \\ 0.0 \end{vmatrix}$$

(10deg/update about -Y (SCRS) or X (IRF)).

The next three simulation steps will then result in an attitude of:

QF_4 = (-0.454519, 0.454519, 0.541675, 0.541675)^T equal to

(α,δ,ϕ) = (90.0, 10.0, 0.0)

QF_5 = (-0.405580, 0.405580, 0.579228, 0.579228) ^{T} equal to

$(\alpha,\delta,\phi) = (90.0, 20.0, 0.0)$

$QF_6 = (-0.353553, 0.353553, 0.612372, 0.612372)^T$ equal to

$(\alpha,\delta,\phi) = (90.0, 30.0, 0.0)$

Again assume that, before the calculation of QF_7 starts, a new simulation command is uploaded with the following parameters:

$$Fa_7 = \begin{vmatrix} 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 \end{vmatrix} \quad Fr_7 = \begin{vmatrix} 0.0 \\ 0.0 \\ 0.122173048 \end{vmatrix}$$

(7deg/update about Z (SCRS) or about (0.0, 0.866, 0.5) (IRF)).

The next three simulation steps will then result in an attitude of:

$QF_7 = (-0.331310, 0.374478, 0.648615, 0.573864)^T$ equal to

$(\alpha,\delta,\phi) = (90.0, 30.0, 7.0)$

$QF_8 = (-0.307831, 0.394005, 0.682437, 0.533178)^T$ equal to

$(\alpha,\delta,\phi) = (90.0, 30.0, 14.0)$

$QF_9 = (-0.283203, 0.412063, 0.713714, 0.490522)^T$ equal to

$(\alpha,\delta,\phi) = (90.0, 30.0, 21.0)$

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10 Integrated Operations

10.1 Main Goals

The main objectives in operating the ASC as an integrated unit are:

1. to verify that the ASC is correctly integrated in the test bench / spacecraft;
2. to check out the communication between the ASC and the spacecraft computer;
3. to test the integrated operations and performance of the ASC and of the test bench / SC as a whole;
4. to perform open/closed loop simulations in particular of the attitude control system;
5. to train the personnel for the flight operations.

To achieve these goals, the setup is shown in Figure 32 shall be used:

1. the ASC shall be connected to the test bench / OB computer.
2. the ASC shall be controlled by/via the on-board computer, i.e. all the commands shall issued by it or be sent via it.
3. using a split-up cable, the data output shall be connected to the on-board computer whereas the debug channel can be connected and monitored directly by the EGSE.

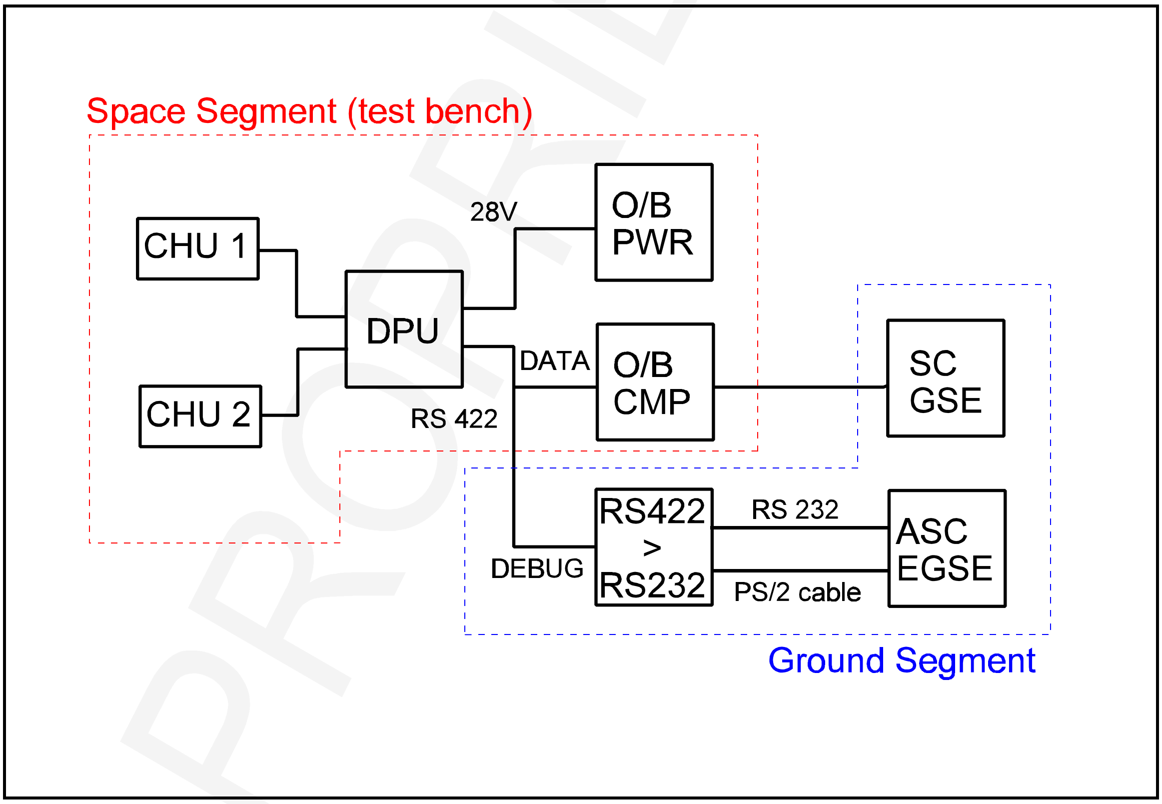

Figure 32 *Integrated test setup.*

10.2 Telecommands

The ASC is controlled by telecommands (TC). The telecommands are used to change mode, to request information, to make memory dumps etc. The TC-declaration of the telecommand structure is given in Appendix F. The TC's are fully described in RD 4. Telecommands can be generated and stored as binary files by the EGSE. For a description of this see section 11.4.1.

10.3 How-to

This section describes various operations which can be performed to practice and verify the integrated operations . These are very similar to what is described in section 7.4. For integrated operations however the interaction with the ASC is done via the on-board computer instead of the EGSE.

10.3.1 Start-up

1. Connect the ASC data port to the on-board computer and power supply and connect the ASC debug port to the EGSE computer as shown in Figure 32;
2. Power up the ASC, within 5-7sec the power-up packet should be received by the on-board computer.

10.3.2 Set the Instrument in Stand-by or Attitude Mode

Depending on the status of the system variables, after being powered, the ASC enters automatically in stand-by or attitude mode.

If the ASC starts in attitude mode and no CHU is connected to the DPU or the camera(s) operates in a lab without the optical stimulator, then the attitude measurements are all reported as invalid.

To set the ASC in stand-by mode, the operator shall send an "AscStandByModeTC" command via the on-board computer.

When in stand-by mode, the attitude is not measured and not transmitted. Hence, no attitude packets will be received.

To set the ASC in attitude mode, the operator shall send an "AscAttitudeModeTC" command via the on-board computer

10.3.3 Re-boot

A reboot command is issued by sending the "AscBootTC" command. See the TM/TC ICD for the full description.

10.3.4 Re-boot in Safe Mode

Dependent on the mission requirements, the ASC can be setup to boot in either safe mode (microhop/ eprom mode) or in autonomous normal operational mode (maxihop/attitude/standby mode. The start up mode is specified in the system parameters table.

If the system is setup to boot in safe mode, normal operational mode is entered by issuing an "AscAttitudeModeTC".

If the system is setup to boot in normal operational mode (attitude or standby), this autonomy can be overruled by continuously transmitting the characters 0xAA and 0x55 referred to as "PreventFlashBootPattern" during boot-up of the instrument and following the procedure described in RD 4.

10.3.5 Dump the Memory

All parts of the memory (RAM as well as FLASH) can be downloaded using the “AscLoadMemoryTC” telecommand. The RAM area has the logical start address 0x00000000 and the FLASH area has the logical start address 0x01000000.

The EPROM is copied to the RAM area as part of the boot-up. This software can be downloaded e.g. in order to investigate the date-code (date of compilation) of the EPROM by downloading 64KB starting from logical address 0x000D0000. The date-code is located almost in the end of the file.

10.3.6 Clear Memory

The FLASH memory of the ASC is divided into 64 banks each of 64KB (including hamming code protection). These flash banks can be erased individually by sending the "AscClearBankTC". ***Since this command erases parts of the ASC memory, it should be used with extreme caution.***

The bank containing the system parameters are (at instrument delivery) located in bank 63. This bank can be erased by specifying 63 in the bank prompt. When the instrument is re-booted, it will start up in safe mode, since it is not able to find the system parameters pattern. Operation of the instruments is recovered by uploading the system parameters using the SYSVAR.DSC description file (see: next section). Notice, that changes made to the system parameters will be reset by this procedure.

10.3.7 Upload Memory/Code

The software onboard on the ASC can be updated at any time, either on ground or in flight, with the “AscLoadMemoryTC” command.

This command requires five different parameters:

- UseFAT — a flag for using the FAT (File Allocation Table)
- EraseFlash — a flag for erasing the Flash Memory
- NumberOfBytes — the number of bytes to upload
- Base — the absolute starting address in which to store the first byte
- Data — the new code

The format and order of the parameters are described in the TM/TC Interface Document (RD 4).

It is possible to upload to the flash in all the modes of the ASC. However, the transfer will be fastest when the ASC is set to standby mode.

Since the files are uploaded to the flash ram, the ASC must be re-booted (using “AscBootTC or by switching the power off and on) before the new uploaded software will be used.

10.3.8 Acquiring and Downloading Images

The images used for attitude determination can be downloaded to ground by command.

To acquire and store an image, the ASC shall be in attitude mode. The images are automatically acquired and processed at the rate set by the integration time. However, they are immediately discarded if not commanded to be stored (buffered) by issuing an "AscStoreImageTC". This command is fully described in the TM/TC Interface Document (RD 4).

When the image is stored, it must be downloaded using the "AscSendImageTC" (also described in the TM/TC Interface Document, RD 4).

Since the packet length of the telemetry is lower than the image size, the image is divided into a number of packets, each marked with an offset and the packets are sent automatically with low priority, filling up the available bandwidth. The latter process is completely transparent to the user and handled by the ASC SW based on the available bandwidth and maximum allowed packet length.

It is important to note that only one image can be stored at any time.

Hence, any stored image shall be downloaded before another image can be buffered. If a new image is saved before the old one is downloaded, the new one overwrite the old one which is, consequently, lost.

10.3.9 Set the Detection Limit

The detection limit is a measure for, how bright an object should be to be detected by the centroiding algorithm. By making this parameter an adjustable system parameter, it is possible to tune the ASC in flight to give the highest performance wrt. accuracy and time latency.

Since the analogue electrical chain varies marginally for each piece of hardware, a detection threshold parameter has been implemented for each CHU. The system impact can easily be verified by changing this threshold while observing the night-sky. A higher value will result in lesser star detected by the ASC, whereas a lower value will result in more stars.

The detection threshold for the CHU is adjusted by uploading the parameter with the correct offset using "AscLoadParameterTC" as described in the TM/TC ICD (RD 4). For ground based observations, the optimal value should be close to 17, whereas for space based observations, the optimal value should be around 27. This difference in optimal values is due to atmospheric effects.

10.3.10 Inspect and Change the System Variables

More than 200 system variables are used by the ASC SW to control the proper operations of the instrument and to guarantee a graceful degradation while avoiding to upload new software.

All system variables can be changed by the user. However, only a subset of these variables is meant to be accessed directly by the user. These variables are described in RD 4.

The remaining variables are meant to be a tool for specialised personnel to intervene remotely especially when the upload of new software may be not recommended, e.g. due to very slow baud rate.

The user is welcome "to try things out" and to change the variables during the ground testing especially when the instrument is directly available. However, before starting to use the ASC integrated with other instruments, we recommend to reload a fresh copy of the software to safely restore all the settings.

Furthermore:

We strongly recommended not to change the variables not described in Appendix D in flight, unless the user is fully aware of the consequence of the modifications.

To check the value of the system variables, the first step is to download them. This is done by issuing a “AscRequestStatusTC” command.

10.3.11 Upload a Test Image

The ASC offers the opportunity to perform attitude determination on a previously acquired image. Prior to perform this operation, an uncompressed "test image" must by uploaded to the ASC using “AscSendTestImageTC”.

The image is only uploaded to RAM wherefore an image must be uploaded each time the ASC has been booted.

When the test image has been successfully uploaded, the test image mode is initiated by sending an “AscTestImageModeTC”. Notice, that the CHU specific parameters set up in the system parameters MUST match the parameters for the CHU, that originally acquired the image.

10.3.12 Overrule the Autonomy

The ASC offers a variety of autonomous functions. Some of these functions can be overruled.

House Keeping Conversion

The ASC will autonomously perform housekeeping conversion at a frequency according the setting in the system parameters. The autonomy is overruled by uploading specific requests for housekeeping conversions using "AscHKForceTC".

Startup Mode

During in-flight operations, it is beneficial to have the ASC starting up automatically in attitude mode, so that no commands should be sent to the instrument after power-up. This autonomous operation can be overruled by continuously sending a "Prevent Flash Boot Pattern" as described in the "Re-boot in safe mode" section.

Automatic Gain

During a satellite orbit, the CHU will be exposed to different levels of background illumination. When the boresight is close to bright objects e.g. the Moon, the background illumination level will increase substantially. This varying level is autonomously tracked by the software, such that the optimal performance is ensured at any given time.

The AGCs for the different CHUs can be "frozen" individually, by uploading a parameter with the correct offset, as described in the TM/TC ICD (RD 4) under "System Oriented Parameters".

10.3.13 Check the SW Version

To check the SW version, a “AscDumpMemoryTC” shall be issued.

The command prompts the user for the range and the address to be downloaded and the data is stored in a predefined file.

Ranges and typical start addresses are: :

- EPROM 30 bytes @ 0X100497B
- KERNEL 17 bytes @ 0X100FA00
- TOPS 17 bytes @ 0X1082E00
- MAXIHOP 17 bytes @ 0X113B124

The exact start addresses are found in Appendix I.

Part IV
Flight Operations

11 Flight Operations

11.1 Main Goals

The main objectives in controlling the ASC in flight are:

- to check out that the instrument is operating nominally;
- to monitor the performance and the aging of the instrument;
- to be able to change the settings if the satellite or the instrument is working in non-nominal conditions;
- to be able to upload new software or parts of it;
- to be able to overrule the autonomy.

In order to ensure nominal operations during flight, a number of operational are considered in the following section.

11.2 Operational Constraints

In spite of the high agility of the ASC, some operational constraints do exist. These are caused by disturbing light sources. In the following the operational constraints imposed by the Sun, Earth and Moon and the measures taken to minimize these constraints are described.

11.2.1 Sun exposure

The design of the ASC guarantees that the ASC can be exposed to direct sunlight for any desired span of time. The effect from the Sun exposure is that the CCD, lens and baffle structure will absorb the sunlight, and due to the primary function of these components only reflecting back a few percent. The absorbed energy will give rise to an increase of the temperature of the absorbing elements. Since the elements have all been optimized for high thermal radiative surfaces, the temperature rise will be moderate. For the CCD itself, the temperature may rise above the full operations limit, but even indefinite exposure will not rise the temperature above the CHU maximum limit at 1AU distance to the Sun. To assess the thermal impact from Sun exposure consider the following figures: The lens entrance pupil is 620mm^2, which at 1AU will result in 0.85W optical power entering the lens. The incident power on the CCD is therefore 0.75W. The thermal capacity of the CCD/support structure is approximately 450J/K. Therefore the initial temperature rise over time will be about 0.0017K/sec, or 6K/hour.

The ASC will keep outputting attitudes, but since the CCD is saturated with light, the attitude is flagged not valid, the quaternion is 0,0,0,1, and, the number of detected objects is maximum 200.

11.2.2 Sun avoidance angle

To enable operations with the boresight of a CHU close to the Sun, each CHU is equipped with a high performance straylight suppression baffle system. The baffle system is optimized towards the operational envelope of the spacecraft and the available space. Generally, the longer and more symmetrical the baffle is, the better straylight suppression. The baffle designed for your spacecraft has been analysed and tested, so as to assess the in-flight expected tolerance towards sunlight, i.e. how close to the Sun the system may be expected to operate nominally. The result of this analysis is the minimum angle, from boresight to the direction to the Sun centre, where full operations is still maintainable. This angle is referred to as the Sun avoidance angle. Because the baffle system usually is asymmetrical, the Sun avoidance angle will vary with the azimuth angle about the boresight, to the Sun. Detailed numbers for any given azimuth angle is found in the Baffle simulation report in the ABL.

When the Sun passes the Sun avoidance angle, the performance rapidly degrade, due to the system saturates with light. The actual degradation depends on the azimuth angle, and have been found from space, to be variable. The typical behaviour is, that when the Sun enters the Sun exclusion angle, the validity percent drops off from 100 to zero over a few degrees. The valid updates will be interspersed with an increasing amount of non-valid stamped updates with a quaternion of 0,0,0,1. The number of stars will either be 0, indicating a processor overload due to a complex straylight image, or, 200, if the straylight becomes excessive.

When the Sun leaves the Sun exclusion angle, the Automatic Gain Controls will use a few updates to settle to the new operating conditions. The number of updates thus lost, will vary with the time spent staring at the Sun, and, on the temperature environment, but typically full operations are restored after 5-10 updates. The performance envelope, entering and leaving a solar blinding is therefore slightly asymmetric.

11.2.3 Earth limb

Similarly to Sun intrusion, the bright Earth will flood the CCD with light, if directly in view. Also here, the baffle system does a good job minimizing the impact with the bright Earth outside the FOV. All baffle systems having an outer baffle stage, will therefore be able to operate nominally, as long as the bright Earth stays outside the Field Of View. Bright Earth is here understood as anywhere on the day side of the Earth, as viewed from LEO. It is important to note, that the radius of the Earth to be used for assessing the performance, is not the radius of the physical Earth, rather the Earth limb, which is typically found at the 1 pascal limit of the atmosphere, i.e. R_j' = 6460Km.

If bright Earth comes within the FOV, operations rapidly degrades. The size where the bright Earth has to be kept outside for nominal operations is given in the Baffle simulation report in the ABL.

The effect of the dark side of the Earth is less detrimental. The full dark Earth limb, may come as close as to the actual boresight, before operations are impacted. From space, it is found, nominal operations is typically maintained, until the Earth limb is 2-3 degrees across the boresight, i.e. until less than 1/3 of the FOV is still viewing stars. It shall be noted, that the effect that eventually ceases the operations is lights from the cities below, that are confused for star like objects.

11.2.4 Moon limb

The Moon, as described below, is understood as the Moon as seen from LEO, and the phase angle, is the illuminated fraction of the area. It is important to use the correct lunar phase angle, because the moonlight irradiation is highly nonlinear with the lunar phases.

The ASC is optimized towards handling luminous objects, as the Moon in the FOV. Therefore, no performance degradation is to be expected for a up to 50 % phase Moon anywhere in the FOV. Obviously, the Moon will remove a few stars from the attitude estimate, but since the typical number of stars used is in the range from 25 to 80, the impact on the accuracy is marginal.

From 50% to 75% lunar phase, the straylight impact increases. Therefore, and since the process of detecting/removing the straylight from the images is quite demanding, the validity percentage may drop from 100% to some 98% with the Moon in the FOV close to the boresight. The increased processor load will be reflected in an odd non-valid attitude update, quaternion

0,0,0,1, and 0 stars detected, between the valid updates. The removal of stray infested image areas is important, since such areas otherwise could lead to offsets in the attitudes.

When the Moon phase is higher than 75%, performance degrades fast with the Moon in the centre of the FOV. At 85% the validity percentage is close to zero. This is caused by the massive optical overload. However, as the Moon moves away from the boresight operations recover fast. with a 98% validity percent with the Moon, more than 7 degrees from the boresight.

11.2.5 Attitude rates

A rate of change in the attitude will lead to the stars, as seen by the ASC, are smeared out, i.e. motion smeared. Such smearing will have two detrimental effects on the operations of star trackers. Firstly, since the starlight is smeared over a larger error, more pixels must be taken into account to perform the centroiding. This will increase the noise, while the signal is constant. Secondly, the smear will cause some stars to be lost for the matching process, either because they move outside the FOV during the integration time, or because their signal to noise ratio drops below the threshold set. Therefore, the accuracy will drop with increasing rate.

The ASC star position finder, the centroider, has been optimized so as to allow for high attitude rate of change, while maintaining high accuracy, so that operations are essentially limited by the laws of physics. The rate handling is strongly dependent on the selected integration time. Since the ASC is photon noise limited, the accuracy is also dependent on the selected integration time, with a decrease in attitude noise of approximately sqrt(2) for every time the integration time doubles. Conversely, the rate handling capacity roughly doubles, as the integration time is halved.

At low attitude rates, the ASC is optimized to render the maximum accuracy, and at high rates the ASC is optimized towards maximizing the validity percentage at the expense of accuracy. The transition between optimal processing towards accuracy and rate performance occurs at 15% of the maximum rate.

When the rate increases, the accuracy performance therefore essentially will remain constant at rates between 0 and 15% of the maximum rate. For rates between 15% and 25% the accuracy will degrade a factor 2. For rates between 25 and 100%, the accuracy will degrade to the limiting accuracy, i.e. some 15" pointing.

Also the validity percentage will drop with increasing rate of change of the attitude. Typically 100% validity is obtained up to 30% of the maximum rate of change. 75% valid updates is maintained at 50%, whereas only 10% valid updates are found at full speed. The valid updates will be interspersed with non valid attitude updates, quaternion 0,0,0,1, and 0 stars indicating the processor overload from retrieving the faint, smeared star patterns.

The rate performance may be increased substantially, if the detection threshold is decreased a few DN's. Typically, the validity percent at full rate may be doubled this way.

11.2.6 Radiation

At times with elevated radiation impacts, i.e. when passing through the Van Allen proton belts, or, during a massive solar mass ejection, the CCD will be penetrated by an increased number of protons. Such a passing proton will cause an ionization trail to from, which will be seen appear as a light speckle on the CCD image.

Even though the ASC is optimized to handle the extra load from these protons, the performance may degrade under such conditions. The performance loss is roughly proportional to the number of piercing protons. Under normal conditions, i.e. in the South Atlantic Anomaly, in the Van Allen electron belts, outside the radiation belts, and during moderate solar mass ejections, the ASC anti proton filter mechanism will efficiently remove all effects, so that full performance is achieved. But as the proton flux increases, the load on the filtering increases, so that a few attitude updates may be lost due to processor overload. This will result in interspersed non-valid updates, quaternion 0,0,0,1, and 0 stars in the update stream.

The user may decrease the processor load by increasing the star detection threshold 5-10 DN, during massive solar storms. This will lead to a slight drop in accuracy, but increase the validity percent towards 100.

11.2.7 Temperature

The operational temperature span of the CHU' s is mainly set by thermally generated noise. Therefore, the CHU's shall always be operated as cold as possible/permissible.

The thermally generated noise comes from two sources. Firstly, the dark current noise of the CCD increases exponentially with temperature. This effect is dominant at BOL, where the CHU's will still deliver full performance at 60C CCD temperature. Operations will be degrade towards zero at 85C on the CCD.

Secondly, the pixel to pixel background level variations, which at BOL is virtually zero, will build up with the total dose received from piercing baryons. The dominant source is protons for all orbits considered until now. The passage of such a particle will adversely affect the pixel pierced by generating trapped surface charges, and/or lattice defects. At elevated temperatures, the non uniformity from some of these impacts will actually saturate the pixel, resulting in a white spot on the image, wherefore these has been given the name Hot-spots. Since the effect decreases exponentially with temperature, the effect is minimised by keeping the CCD cold during operations. The temperature dependence is such, that no radiation damages are measurable at -10C, even the CCD has received 10 times the lifetime dose.

The actual operations temperature of the CHU for this mission is calculated based on the mission profile and the requested RDM, and is found in the Thermal ICD in the ABL.

It is important to note, that the above mentioned temperature is the measured temperature of the CCD, not to be confused with the reference temperature of the CHU mounting. Since the CHU adopts a passive radiation cooling scheme, the reference temperature span is somewhat higher. The reference point temperature is also found in the Thermal ICD.

11.3 Telecommands

The ASC is controlled by telecommands (TC) issued by the on-board computer or by a human operator at the ground station. The TC is sent to the instrument via the spacecraft TM/TC subsystem.

The TC’s are fully described in RD 4.

A simple, efficient, thoroughly tested and reliable way to generate the telecommands is to use the EGSE command "dump" feature. By doing so, the EGSE generates and stores the binary files associated to each command in the proper format and size.

These files are then readily available to be sent by the ground control station, command DB or command stack.

It is important to note, that no command or sequence of command can lead to permanent damages or malfunctions of the instrument, i.e. a safe recovery procedure exists from any command or sequence. Obviously, the instrument configuration or the onboard SW may be changed or erased, whereby proper operations are excluded, but an easy recovery to normal conditions exists. To familiarize the user with this procedure, she is encouraged to try and test all command and foreseen sequences, during instrument checkout and integration.

11.4 How-to Guide

11.4.1 Generate the Telecommands Using the EGSE

As long as the EGSE is connected to a serial port, the full telemetry is stored in a spool file, so that all data can be restored and regenerated. In order to avoid data-loss, this spooling is not an option.

In addition to spooling the telemetry, the EGSE can be set up to spool all telecommands. This is a very efficient way to generate telecommands in the correct format and checksum. The TC spooling is per default disabled, but can be enabled by checking "Options -> Select Spool Objects -> Commands". The spooled commands will be located in the file: "CMDyyMMdd_hhmmsshh.bin" in the "ASC\EGSE\SPOOL" folder. There will be a file for each EGSE connection session.

11.4.2 Upload System Variables and Software

The modifiable ASC software consist of two classes: System variables and software modules. The system variables are a set of parameters, that can easily be adjusted, whereas a software module is a software recompilation issued by MIS DTU.

The system variables can be modified by uploading an “AscLoadParameterTC” that contains information of which parameter to modify and the new value. This TC can be generated by the EGSE by using the following procedure:

- Download the system variable table (to the EGSE) using "Commands -> Request Status".
- Check the "Command" option in the "Option -> Select Spool Object" dialog.
- Find and modify the parameter in the "System Variable" menus.
- Uncheck the "Command" option again
- The “AscLoadParameterTC” is now available in the file "ASC\EGSE\SPOOL\CMDyyMMdd_hhmmssHH.BIN", which shall be sent to the ASC through the OBDH.

The ASC software can be uploaded using the “AscLoadMemoryTC” that contains information of which address range of memory to modify, the new software, plus flags indicating whether to erase the existing memory and whether to use the FAT to locate the memory. The packetizing can be handled by the EGSE by using the following procedure:

- Check the "Command" option in the "Option -> Select Spool Object" dialog.
- Use "Commands -> Upload Memory -> Description File" to select which module to upload. A series of packets containing the software is now sent from the EGSE. Please note, that a DPU must be attached to the line, since the EGSE requires the verification telemetry as trigger for the preceding packets.
- When the upload is done, the TC spool is disabled by unchecking "Command" option from the "Option -> Select Spool Object" dialog.

- The “AscLoadMemoryTC”'s are now available in the file "ASC\EGSE\SPOOL\CMDyyMMdd_hhmmssHH.BIN", which shall be sent to the ASC through the OBDH.

11.4.3 Overrule the Autonomy

The ASC offers a variety of autonomous functions. Some of these functions can be overruled. For a description of the possibilities of overruling the autonomy see section 10.3.12

11.4.4 Correct for the Relativistic Aberration

The ASC offers the possibility of automatically correcting for the relativistic aberration.

The aberration correction is split in two components: one to compensate for the motion of the Earth/Moon system about the Sun (annual aberration) and the second to compensate for the orbital motion of the S/C (diurnal aberration). For the first correction, only the date is needed and the updates do not need to be frequent. The second correction is performed by an on-board orbit model requiring in input the S/C state vector, inertial position and velocity, and the time. The filter update rate depends on the required accuracy and the perturbations affecting the orbit and it can vary from minutes to hours or even days. By request, the orbit model output can be routed to the S/C, either for testing purposes or to be used in the attitude control system.

The two corrections can be turned on and off individually by uploading parameters using the "AscLoadParameterTC" command, with specific offsets as described in the TM/TC ICD (RD 4.)

11.4.5 Correct for Nutation and Precession

The computed attitude can also be corrected for the precession and the nutation before being output. These corrections are important for accurate Earth pointing. They can be enabled/disabled at any time uploading parameters using the "AscLoadParameterTC" command, with specific offsets as described in the TM/TC ICD (RD 4.)

11.4.6 Monitor the ASC Performance

Because of the high level of autonomy of the ASC in-flight operations are usually limited to monitoring a few key parameters. However, since the ASC delivers absolute attitude information, mission control may find it useful to show the measured quantities graphically, as shown in Figure 33. The primary objective of these plots are typically to monitor or improve mission performance, but they also provide an excellent tool for anomaly trapping, investigation and analysis.

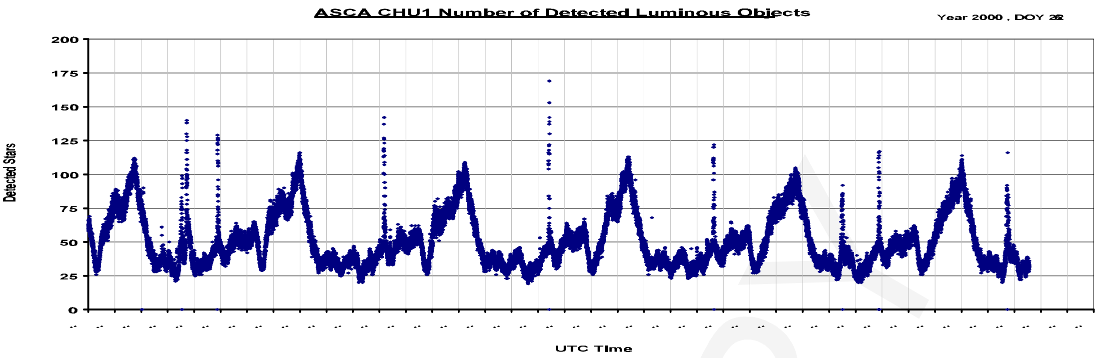

Figure 33 *The measured number of luminous objects vs time. Rich and meagre star field variation over orbit is clearly visible. The distinct spikes are symptomatic for grazing Sun intrusions.*

It is proposed, that the HouseKeeping information collected from the ASC is displayed as a time sequence. The examples below are from the LEOP phase of a mission CHAMP/GFZ.

It is recommended that all HK parameters are plotted for monitoring use in this fashion.

From attitude information dumped to ground, a very useful tool is a world-plot, as shown in Figure 34. The world plot show the trace of the pointing direction over the orbits. It is useful both as a tool for assessing Moon and Sun rejection performance, and for assessing AOCS control and isolating any anomalies in the operations of this system.

Monitoring the accuracy of the ASC is inherently a rather complex procedure, because of the extreme performance of the ASC. Even minute variations in platform stability, AOCS dead-banding, pointing noise or external forces will impact the assessment procedure. For two or more CHU missions, a simple and reliable assessment may be obtained by calculating the

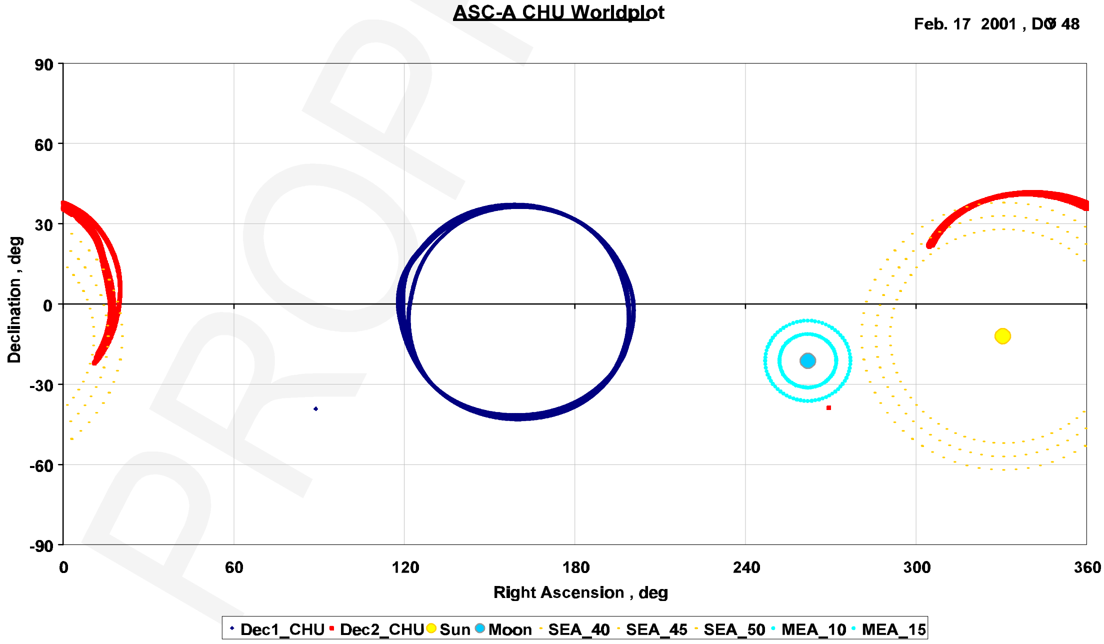

Figure 34 *Pointing direction (Dec vs RA) for the left and right hand camera.*

measured angle between the boresights. Assuming a stable platform, this will lead to an independent assessment of the pointing accuracy as shown in Figure 35.

For single CHU missions, only two possibilities exists. Either the ASC attitude must be compared to another attitude source, e.g. telescope pointing noise during imaging, or, by analysing the spectral noise density of attitude time series, if feasible after subtraction of a fit polynomia to take out AOCS induced variations

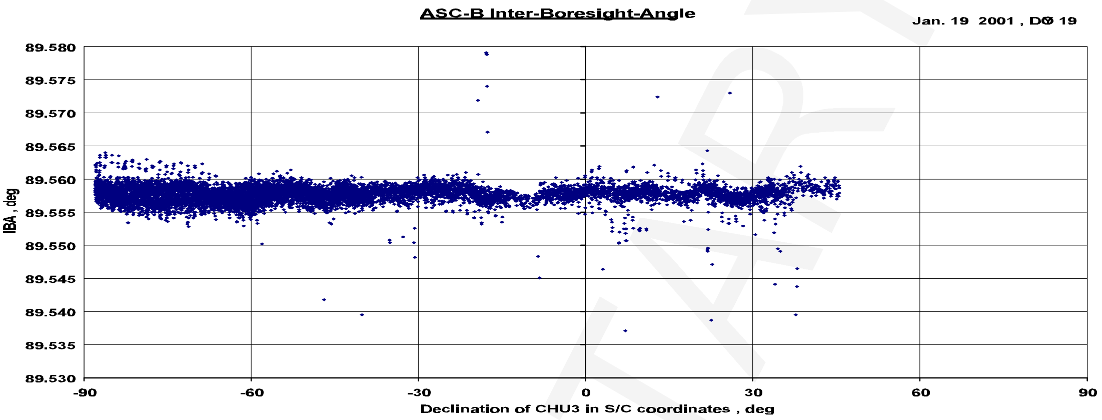

Figure 35 *Measured angle between boresights of two CHU's as a function of declination (orbital latitude).*

11.4.7 Monitor the CHU Aging

The major impact on the performance of the ASC is ageing of the CCD and surrounding systems. Two major ageing mechanisms are of importance.

1) As the CCD ages, the analog signal chain, from photons entering the lens until A/D conversion must maintain a specific amplification at all times. Lens darkening as a function of total ionizing dose received, is not an issue for the totally RAD-hard lens system of the ASC (>5 MRad tolerance). The microlenses of the CCD however, slightly darkens as a function of time spent, at temperatures above 80C. Furthermore, the amplification of the line amplifiers of the chain will degrade with received total dose. These effects are both eliminated by design, by ensuring ample amplification margin in the feed back loops. From a user perspective, the analog system gain will remain constant over the lifespan of the instrument. This has been verified from all missions in orbit.

Should the user anyway chose to monitor the analog system gain, direct star photometry is used. Apart from being simple, this also has the benefit of being the primary objective for keeping the gain constant. Depending on the orbit of the mission, the user may either monitor the measured intensity of a specific stars, or set of stars, or the user may plot the measured number of luminous objects detected, which is strictly a monotone function of system gain. To obtain the measured luminosity, the user must issue a image TC, with compression standard set to centroids. To assess system gain via number of objects detected, a statistical comparison of the time variation of "number of stars" from attitudes from the same star field is easily achieved.

2) The second ageing mechanism is the accumulation of radiation damages to the CCD itself. This task is by a specialist task, and its execution is offered to the mission, by the MIS. MIS has a set of SW tools that, based on raw images from space, extracts the accumulated radiation

damage level. Based on this measurement, MIS will issue an advise for action should an excessive damage level be approached. E.g. for the Ørsted satellite, the mission lifetime have been extended substantially. Based on this decision, MIS developed an action plan for the operations, that has resulted in an improved performance level at 3 times design EOL.

The user may indirectly monitor the radiation damage level, through monitoring the number of luminous objects detected. Should an excessive accumulated radiation dose be approached, the "number of stars" from the attitude packages will increase above the nominal level at times with high CCD temperatures.

It is important to note, that neither of the above effects will have any effect measurable on the attitude accuracy. E.g. The CCD in the Oersted ASC unit, has now passed 2.5kRads total dose, primarily from protons, i.e. more than 5 times the design EOL dose. The impact on the accuracy is an increase in the NEA of 0.2"!

11.4.8 Nominal in-flight status.

During nominal operations of the ASC, i.e. whenever the ASC is operating within its specified environment, the various ASC HK information will remain within a narrow band. Obviously, this band will depend on the mission profile, and operational state of the space segment, but to give the user an idea of what to look out for, the following HK parameter overview is given.

CPU temperature.

Nominally, this temperature will be found to follow the variation in the DPU box reference point temperature, i.e. it will be above, but follow the platform temperature. Typically the temperature span to the platform is 27C, and the in-orbit variations 2-3C. After boot from cold conditions, the CPU temperature will raise to quasi-steady state in 20-30min.

Switch Mode Power Supply temperature.

Similar behaviour to the CPU. For single CHU missions, SMPS temperature is approximately the same as that of the CPU, for dual CHU missions 3-5C above.

Video voltage.

The video voltage, monitors the analogue signal as it enters the DPU. When the CHU power is commanded off, the voltage is 0V. With power on, the voltage is 0.20V for nominal conditions. The primary use for the video voltage is to monitor optical overload conditions. E.g. when the full Moon enters the FOV, the video voltage raise above 0.2V and may get as high as 0.3V. When the bright Earth or the Sun grazes the FOV, the video voltage increases, and at full Sun intrusion reaches 1.0V.

AGC levels.

The AGC levels are monitoring the offset level and the band size of the A/D process.

The offset level will automatically adjust towards a background level of the star images of 15 DN. This means that the offset level will change with integration time setting, CCD temperature and straylight illumination level. Typically the offset level, for nominal operation conditions, will be about half way of the span, i.e. ~ 0x750. It is important to note, that this level do vary over orbit and time.

The "gain" level is set at a fixed number above the offset. I.e. it defines the full range of the A/D. When the AGC's are enabled, this number must be at the same number above the threshold value. Note, that this number do change with integration time.

Number of stars.

Even though the "number of stars field" is reported with the attitude package, it is an important piece of HK information.

The ASC require more than 5 stars to operate, and need more than 16 to guarantee full operations over the entire sky. The user is therefore encouraged to monitor the number of stars over orbit, and if needed to adjust the detection threshold parameter down, if less than ~16 stars are measured at the lowest point in the orbit.

Similarly, to avoid excessive attitude information latency, the ASC is in SW limited to process 200 luminous objects per image. Any image that exhibit more than 199 is consequently rejected, and an empty attitude package, i.e. non-valid, 0.0.0.1 quaternion, and 200 stars are reported. Therefore, if the ASC, anywhere in orbit and under nominal conditions, report blocks of attitudes of 200 stars, the star detection threshold is to be increased.

A typical value for star detection threshold is ~30, and do result in an in-orbit variation in the number of stars detected between 20 and 80. These numbers are indicative only, and do depend on orbit, manoeuvres, blinding etc.

Also, in case of blinding, e.g. Sun intrusion, the ASC will report a block of 200 star attitudes, while the blinding remains. This situation shall not lead to an adjustment of the detection threshold. Sun intrusions are easily discernible from nominal star field variations. Either the actual position of the Sun and the angular separation to the last/first valid attitude around the 200 star block is calculated (e.g .as shown in the monitoring section), or the almost instantaneous onset and departure from Sun blinding may be used as an indicator (also shown in the monitoring section).

12 Deep Space Navigation

12.1 Description of the DSN Software Module

The Deep Space Navigation (DSN) module is a software module which from observations of planets along with information about the absolute time can calculate the spacecraft position.

The DSN tool was developed for deep space missions to improve their flexibility and to reduce costs by performing on-board the navigation that so far has been performed using dedicated ground stations.

12.1.1 General operations

The DSN operates by recognizing planets as non-stellar objects and identifying them from knowledge of the absolute time. Having identified the planets the spacecraft position can be calculated by triangulation.

A filter ensures a gradual improvement in the position determination as observational data are accumulated.

If possible the CHU should be pointed so as to alternately having two different planets in its FOV. This will improve the position determination considerably.

12.2 Timing and TM/TC for the DSN module

The DSN has not yet been assigned its own TM /TC structures. Thus TM /TC for the DSN module is done as described in the following:

The timing is implemented in such a way, that the mission elapsed time (MET) is uploaded to the unit using "AscTimeTC" packets in conjunction with a timing pulse (serial break). To convert this time to Julian day, an offset between the MET and the Julian day must be known. This offset is a part of the system variable table at offset 205, size 8, data type: double. For test purposes, the easiest way is to upload the Julian day of the test day as MET offset (e.g. 2452227.5 for nov. 151 2001, UT = 0). The MET is then uploaded using an "AscTimeTC" with secs = 0 and fraction secs = 0.

When the Julian day is known to the system, a CHU is pointed to a planet. The CHU must be connected as CHU A. Integration of position data is gathered in the background, which means that there will be no output in the EGSE.

Enabling the DSN is performed by setting a flag in the system variables: offset 414, size 1, data type unsigned char. 0 means disabled, 0xAA means enabled.

The output of the DSN is collected in the image buffer. This means, that it is not possible to store an image, while it is enabled. It is also not possible to download the DSN data while DSN is enabled. The DSN function will be called each time an attitude determination is concluded. Should the image buffer run full (this will happen after approximately 30 minutes, depending on integration time), future DSN output will be lost.

To download the test data, the DSN must be disabled and an "AscSendImageTC" must be issued. This will download all the obtained data. The downloaded image has a conventional ASC 34 byte image header with compression method set to 255. The image data is ASCII and can be read in a normal text viewer when the 34 byte header has been removed. It can NOT be read in the EGSE.

Uploading of telecommands for changing system parameters can not be performed directly from within the EGSE. However, the data fields can be compiled in advance and uploaded using Commands -> Custom Command...

Procedure:

1. Connect the CHU to port A

2. Point the CHU towards a planet

3.Send an "AscLoadParamTC" with offset 205, size 8, data as day of the test in Julian day with double precision (e.g. JD = 2452227.5 (value to upload = 0x4142b581c0000000) for 11/01/2001).

4. Send a serial break

5. Send an "AscLoadParamTC" with secs = 00000000 and fraction secs = 0000 (Custom Command: ID = 0x0199, data = 000000000000)

6. Send an "AscLoadParamTC" with offset 414, size 1, data 0x55

7. Wait for X seconds (X = test time). The number of samples acquired will depend on the integration period.

8. Send an "AscLoadParamRC" with offset 414, size 1, data 0x00

9. Send an "AscSendImageTC"

10. Remove the 34 byte header and view the file in a text editor.

12.3 Format of telemetry from the DSN (TM)

To be written... (see also the above description)

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Part V
Pre-Launch Verifications & Maintenance

13 Recommended Tests to be Performed by the Customer

This section describes, which tests DTU recommends the customer to perform. At this point it should be noticed, that all delivered units have been fully performance tested at DTU.

13.1 Incoming Tests

Upon delivery, unpacking and inspection, it is recommended to perform a full functional test as described below.

13.1.1 Full Functional Test

The scope of this test is to verify that the ASC operates correctly, namely

1. to check the integrity of the harness between the ASC DPU and ASC CHU and the correctness of the connection;

2. to verify the communication, in terms of protocol and software, between the ASC DPU and SC test computer.

Therefore, the test shall comprise at least the following steps:

1. start up the instrument
2. if not by default, power the CHU and set the instrument in attitude mode
3. monitor the temperature and voltages for, say, several minutes
4. download uncompressed dark images
5. download images with little light. JPEG compressed images are sufficient. This can be achieved either by putting an artificial aperture in front of the lens, or by covering the lens with welding glass. The acquired image should be recognizable.
6. send PPS signal to the ASC
7. reboot the ASC in safe mode
8. upload SW
9. check out SW version, CHU parameters and other critical system variables

The commands and procedures to perform a full functional test are described in the previous chapters of this manual and are not repeated here.

In particular, the user shall refer to the “Part IV - Flight Operation” of the manual.

13.2 Periodically Health Checks

It is recommended, that the customer performs a dark image check of the camera(s) in the range of once pr. month while the instrument is handled on ground. When acquiring dark images please use the following procedure:

1. Cover the lens (using the supplied lens protection cap or similar non-transparent media)
2. Turn on the DPU
3. Wait half a minute

4. Acquire and download an uncompressed image

The mean of the pixels in the image should be approx. 14 and the variance between the pixels should be between 0.5 and 2.5 dependent on the integration time. The acquired images should be dated and saved for traceability.

13.3 Post-Integration & Pre-Launch Health Test

To guarantee that the ASC has been correctly integrated on the spacecraft and that it functions properly, as a minimum, a full functional test shall be performed at least soon after integration and well before launch. This procedure shall be repeated during the launch readiness check out.

Beside what has already been addressed above, the functional test after integration allows:

- to check the integrity of the harness between the ASC DPU and ASC CHU and the correctness of the connection;
- to check the integrity of the harness between the ASC DPU and SC computer and the correctness of the connection;
- to verify the communication, in terms of protocol and software, between the ASC DPU and SC computer.

13.4 End to end check

Using the optical stimulator, the user is encouraged to perform an end to end check of the ASC operations after integration. Using the stimulator, will ensure that the entire signal path from light to attitude reception and handling of the AOCS and or the OBDH is operating as expected. The actual test sequence will depend on the mission, spacecraft configuration and integration stage but shall encompass the following steps:

- Verify power up ASC
- Setup and adjustment of the stimulator (see the stimulator section).
- Issue the stimulator update command.
- Verify correct polarity for all three axes (see the stimulator manual).
- Verify correct understanding of polarity.

It is stressed, that the stimulator is designed for use in thermal vacuum, and it is encouraged, that it is used during TV and TC testing.

13.5 Light proofness test

Since the ASC cameras are extremely light sensitive, any sneak path for light may pose a threat to proper operations under all conditions. Therefore a light proofness test has to be performed. The aim of the test, is to ensure, that no light may follow a sneak path into the optical system of the ASC baffle/CHU assembly. The test shall be performed after final integration into the spacecraft, and after all ancillary components as MLI blankets and baffle supports has been mounted. The test shall encompass the following stages.

- The viewing entrance of the baffle outer stage is blinded, by means of an non-transparent cover or black light shield.

- The ASC is powered on.
- The light around the spacecraft is dimmed as much as possible.
- A raw image is acquired, and a flat field is verified. I.e. check that the image variance is within limits (< 2.4 DN^2).
- Now the light around the spacecraft is increased as much as possible.
- A raw image is acquired, and a flat field is verified. I.e. check that the image variance is within limits (< 2.4 DN^2).
- If any specific sneak paths is suspected, the above image acquisition and check is iterated by shining a strong light source at the path (e.g. orifice, slit or tube).

Under all illumination conditions, no change in the image variance must be noted apart from nominal statistical fluctuations (assessable by performing the initial reference variance measurement a few times).

13.6 Baffle alignment verification

Since the baffle alignment relative to the boresight is important to ensure proper operations close to the Sun and bright Earth, and since the baffle alignment may shift as a consequence of a temporary dismounting of any component of the CHU/baffle system, the user must perform a baffle alignment checkout, as described in the baffle alignment manual.

This check is only necessary after final assembly, but must be re-performed after any subsequent disassembly procedure.

13.7 Dust/debris check

Since dust and debris may have a detrimental effect on system performance, a check for such contaminants must be performed prior to launch. Even though the baffle protective cover has been in place during most of the integration, this test is necessary.

The effect of small amounts of dust and/or debris will be marginal during nominal operations, but may lead to severe performance degradations during periods with moderate to high levels of straylight.

The test shall encompass the following elements:

- Ensure clean environment, and that all tools are available and ready, so as allow for as short a test time as possible. The chance of entry of new contaminants are roughly proportional to the time spent without protective cover.
- Remove protective dust cover.
- Using a laser pen, examine all internal edges of the baffle system for traces of hair/particles. Pay special attention to damages to the sharp edges. If any anomaly is noted, DO NOT ATTEMPT TO ACCESS OR REMOVE the anomaly. Note its position and appearance.
- Using a strong directional light source, visually examine for dust/debris, all viewable surfaces of the baffle system.
- Using the same light source, examine the surface of the lens. DO UNDER NO CIRCUMSTANCE TRY TO REMOVE ANY CONTAMINANT. Just note its position and appearance.

Should any anomaly be detected, contact DTU for instructions for further actions.

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Appendix A FAQ

This section is meant as a help for frequently asked questions.

➢ A required dll “TVICHW32.DLL” is not found

The EGSE is making use of a non-standard dll, which cannot be linked statically to the program. This dll must be placed in the same directory as the EGSE.EXE program file.

➢ No output from the ASC

Check that the cabling of the EGSE equipment is made in accordance with the guide described elsewhere in this document.

Check that the setting in the “Options -> Data Port Settings...” dialogue corresponds to the settings required by the ASC (see Appendix B). Note that flow control usually is CTS/RTS on receive.

Check that the protocol settings in the “Options -> Setup Protocol...” dialogue corresponds to the required protocol setting (see Appendix B).

Notice, that settings are saved, when the program exits. If the program has not been exited correctly, changes in the settings will not be saved for next execution.

➢ Program stalls during connecting

Check that the folders “SPOOL” and “DOWNLOAD” is located in the EGSE working directory. If not, they should be created.

Appendix B Instrument Settings

Protocol and Port Settings

The following settings must be applied for communication to the ASC data and debug port

Data Port

Baudrate: 38400 bps

Start Bits: 1

Stop Bits: 1

Parity: None

Flow Control: RTS/CTS

Flow Control Direction: Receive

Debug Port

Baudrate: 115200

Start Bits: 1

Stop Bits: 1

Parity: None

Flow Control: RTS/CTS

Flow Control Direction: None

Appendix C Full Functional Test

The functional test is described in section 13.1.1 and is repeated here for easy reference.

The scope of this test is to verify that the ASC operates correctly, namely

- to check the integrity of the harness between the ASC DPU and ASC CHU and the correctness of the connection;
- to verify the communication, in terms of protocol and software, between the ASC DPU and SC test computer.

Therefore, the test shall comprise at least the following steps:

- start up the instrument
- if not by default, power the CHU and set the instrument in attitude mode
- monitor the temperature and voltages for, say, several minutes
- download uncompressed dark images
- download images with little light. JPEG compressed images are sufficient. This can be achieved either by putting an artificial aperture in front of the lens, or by covering the lens with welding glass. The acquired image should be recognizable.
- send PPS signal to the ASC
- reboot the ASC in safe mode
- upload SW
- check out SW version, CHU parameters and other critical system variables

The commands and procedures to perform a full functional test are described in the previous chapters of this manual and are not repeated here.

In particular, the user shall refer to the “Part IV - Flight Operation” of the manual.

Appendix D System Variables

The following settings are the default settings, that are available in the ASC at delivery. The given parameters are delivered with FM1, datecode 20011206:

```
Valid System Variables      :     0x5550  (Yes)

Startup Mode                :          0  (Microhop)
Cache Enabled               :          1  (Yes)
Bitwash Frequency           :          0  (0 min)
Police Time                 :         20  (20 sec)
Integration Time            :          1  (0.250 sec)
House keeping interval      :          1  (1 sec)
Auto UART FIFO On           :          0  (No)

ROI Size                    :          8
Jpeg Quality                :         75  (75%)
Compression Threshold       :         16
Auto Imaging                :          0  (No)
Auto Imaging Compression    :          1  (Centroids)
Auto Imaging Camera         :        170  (A)

Camera A:

DAC Offset Value            :        550
DAC Gain Value              :        950
Tops DAC Offset Value       :        3f0
Tops DAC Gain Value         :        630
Auto Offset Gain            :          1  (Yes)

Precession Correction       :          0  (No)
Nutation Correction         :          0  (No)
Annual Aber. Correction     :          1  (Yes)
Orbital Aber. Correction    :          0  (No)

X0                          :        360
```

```
Y0                          :       291
Kappa                       :  3.0e-008
Focal Length                :     20005
Threshold                   :        27

Rotation A                  :         0
Rotation B                  :         0
Rotation C                  :         0

Camera B:

DAC Offset Value            :       550
DAC Gain Value              :       950
Tops DAC Offset Value       :        d0
Tops DAC Gain Value         :       310
Auto Offset Gain            :         1  (Yes)

Precession Correction       :         0  (No)
Nutation Correction         :         0  (No)
Annual Aber. Correction     :         1  (Yes)
Orbital Aber. Correction    :         0  (No)

X0                          :       360
Y0                          :       291
Kappa                       :  3.0e-008
Focal Length                :     20005
Threshold                   :        27

Rotation A                  :         0
Rotation B                  :         0
Rotation C                  :         0
```

Appendix E ASC Image Format

Header

All acquired images downloaded from the ASC share the same 34 byte header. The format of the header is described below:

Offset	Size	Name	Description
0	2	DAC_OFFSET	The AGC floor value used for acquiring the image
2	2	DAC_GAIN	The AGC ceiling value used for acquiring the image
4	1	INTEGRATION_TIME	The integration time of the image: 0 : 1/8 s 1 : 1/4 s 2 : 0.5 s 3 : 1 s 4 : 2 s 5 : 4 s 6 : 8 s 7 : 1/16 s
5	1	COMPRESSION	0 : Uncompressed 1 : Centroids 2 : Region Of Interest (ROI) 3 : JPEG 4 : Non-Stellar Object List (False stars)
6	1	ROI	The region of interest used for the ROI compression
7	1	JPEG_QUALITY	The quality of the JPEG compression in %.
8	1	COMPRESSION_-THRESHOLD	The threshold used for the ROI compression
9	1	INFO	Various information about the image: bit 0: Time format (Synchronized/Raw) bit 2-3: Camera ID
10	2	VALID	Contains 0x5055 if the image is valid. 0x0000 otherwise
12	2	STATUS	Status of the compression
14	4	CODE_START	Offset of start of image data
18	4	CODE_END	Offset of end of image data
22	2	SUB_TIMESTAMP	Timestamp of image. 1/65536 of seconds

24	4	TIMESTAMP	Timestamp of image. Seconds.
28	2	H	Height of the image.
30	2	W	Width of the image.
32	2	IMOD	0 if image is non-interlazed. 1 if image is interlazed. The total height of the image is: H * (IMOD+1)

Uncompressed

The uncompressed images are raw bitmaps. The image data is stored row-wise from right to left with origo in the upper left corner. The pixel format is 8 bit gray-scale (1 pixel/byte). The total size of the image is: 34 + H * W * (IMOD+1) bytes.

Centroids

The centroids compression returns only the centroid positions on the CCD. One centroid is 10 bytes long, which is:

Offset	Size	Description
0	4	The X position of the centroid
4	4	The Y position of the centroid
8	2	The intensity of the centroid (0-32000)

The centroids are listed sequentially. The X and Y positions are coded as 4 byte unsigned longs. In order to convert to image coordinates, these integers must be divided by 5000000.

Region of Interest (ROI)

The region of interest compression returns a region around each centroid in uncompressed format. The image data for one centroid is:

Offset	Size	Description
0	2	The x coordinate of the upper left corner of the centroid
2	2	The y coordinate of the upper left corner of the centroid
4	2	The width of the ROI (ROI_W)
6	2	The Height of the ROI (ROI_H)
8	ROI_W * ROI_H	The image data of the ROI starting from upper left corner.

The ROI of the centroids in the image are coded sequentially in the image file.

JPEG

The JPEG compression uses a standard JPEG compression scheme, except that the standard header has been replaced with the 34 byte ASC header.

Non-Stellar Objects (False Stars)

The Non-Stellar Objects compression returns only the centroids that have not been recognized as stars. The format is the same as the centroids format.

Appendix F Telecommand Structure

This appendix gives an easy reference to ASC telecommand (TC) structure. For the full description see the TM/TC ICD (RD 4).

TC-packets

A TC-packet is generated on ground and sent to the ASC through the serial interface. The minimum packet size is 9 bytes and the maximum packet size is 2048 bytes. Since most OBC's does not support packets of length 2048 (normally used for non-fixed-length parameter fields) parameter fields at all sizes are supported. A packet consists of a header field and a data field. The header field is 5 bytes and the data field is of variable length with a minimum length of 4 bytes:

Header Field				Data Field		
DLE		Checksum	TCPacketCounter	ID	ParameterLength	Parameter
DLE1 0x81	DLE2 0xFF	8 bit XOR value	TC Packet Counter	Function ID	Bytes in Parameter Field	Different types of parameters
2 bytes unsigned short		1 byte unsigned char	bit 13 – 0 2 bytes unsigned short	2 bytes unsigned short	2 bytes unsigned short	Variable

DLE: 2 bytes of data that signals the start of a packet. The DLE is used to synchronize the start of the packet when the sync is lost. For safety reasons 2 bytes shall be used.

Checksum: Calculated as an 8-bit XOR combination of all following bytes in the packet (TCPacketCounter, ID, ParameterLength, and Parameter).

TCPacketCounter: Represents a TC packet sequence counter in the range 0 to 16383.

ID: The function ID identifying the command to be performed.

ParameterLength: Specifies the number of bytes in the following Parameter (0 to2039).

Parameter: This field contains the ASC input parameters transported by the packet. This field can be empty and may contain up to 2039 bytes.

Be aware that all data is stored in memory complying to the Little-Endian format (Intel) unless otherwise explicitly stated, e.g. a two-byte short integer is stored with LSByte in the lowest address.

For the CNES application, all TC packets must be followed by a serial break signal. This signal is defined as holding the communication line low (active) for a period of one full character (incl. start bit, stop bit and parity bits) or longer.

The TC packets available are:

Telecommand	Function ID
AscStandByModeTC	0x0100
AscAttitudeModeTC	0x0101
AscDumpMemoryTC	0x0103
AscLoadMemoryTC	0x0104
AscClearBankTC	0x0105
AscBootTC	0x0106
AscRequestStatusTC	0x0107
AscLoadParameterTC	0x0108
AscStoreImageTC	0x0109
AscSendImageTC	0x010A
AscSimulationModeTC	0x0111
AscSendTestImageTC	0x0112
AscTestImageModeTC	0x0113
AscHKForceTC	0x0114
AscSendFalseStarsTC	0x0115
AscRequestAttitudeTC	0x0180
AscSendStatusTC	0x0181
AscSendMemoryTC	0x0182
AscDumpFalseStarsTC	0x0183
AscRequestModeTC	0x0184
AscUniversalTimeTC	0x0185
AscStimulatorUpdateTC	0x0188

AscStandByModeTC

Header	FunctionID 0x0100	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscAttitudeModeTC

Header	FunctionID 0x0101	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscDumpMemoryTC

Header	FunctionID 0x0103	DataLength 8	NumberOfBytes ?	Base ?
5 bytes	2 bytes	2 bytes	4 bytes	4 bytes

Parameters:

- NumberOfBytes (4 bytes unsigned long)
- Base (4 bytes unsigned long)

AscLoadMemoryTC

Header	FunctionID 0x0104	DataLength 7+n	UseFAT + EraseFlash ? + ?	NumberOfBytes n	Base ?	Data ?
5 bytes	2 bytes	2 bytes	1 byte	2 bytes	4 bytes	n bytes

Parameters:

- UseFat + EraseFlash (1 unsigned char, UseFAT in 4 MSbits, EraseFlash in 4 LSbits)
- NumberOfBytes (2 bytes unsigned short)
- Base (4 bytes unsigned Long)
- Data (variable length)

AscClearBankTC

Header	FunctionID 0x0105	DataLength 2	1 (b_7)	Banknumber ($b_6 \ldots b_0$)	0 (b_7)	InvBanknumber ($b_6 \ldots b_0$)
5 bytes	2 bytes	2 bytes	1 byte		1 byte	

Parameters:

- BankNumber (7 bit).
- InvertBankNumber (7 bit).

AscBootTC

Header	FunctionID 0x0106	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscRequestStatusTC

Header	FunctionID 0x0107	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscLoadParameterTC

Header	FunctionID 0x0108	DataLength 3+n	ParameterOffset ?	ParameterSize n	ParameterValue
5 bytes	2 bytes	2 bytes	2 byte	1 byte	n bytes

Parameters:

- ParameterOffset (2 bytes unsigned short).
- ParameterSize (1 byte unsigned char).
- ParameterValue (n bytes).

SYSTEM ORIENTED PARAMETERS

Para-meter offset	Parameter-name	Param. size	ParameterValue-interpretation	Def. Value
66	StartUp Mode	1 byte	0: ASC startup in Safe Mode(EPROM) 1: starts in Standby Mode(FLASH) 2: starts in Attitude Mode(FLASH)	0
67	CacheStatus	1 byte (unsigned char)	0: CPU internal cache turned off 1: CPU internal cache turned on	1
68	BitWashFrequency	2 bytes (unsigned short)	[1;65535] number of minutes between a bitwash of Flash RAM. 0 disables bitwashing.	0

70	PoliceTimeOut	1 byte (unsigned char)	[1;255] number of seconds before the PoliceTimeOut (ASC reboots itself) turns in action. 0 disables PTO.	20
71	IntegrationTime	1 byte (unsigned char)	1: Integration time approx. 0.25 sec * 2.:Integration time approx. 0.5 sec 3: Integration time approx. 1sec 4: Integration time approx. 2 sec 5: Integration time approx. 4 sec 6: Integration time approx. 8 sec 7: Integration time approx. 1/16 sec * with two CHU's at 4Hz, each CHU's update rate is 2Hz	1
72	UART FIFO Auto Setting	1 byte (unsigned char)	0: UART FIFO Auto Setting turned off 1: UART FIFO Auto Setting turned on	0
79	DAC Offset CHU A	2 bytes (unsigned short)	[0000h,0FFFh] sets the DAC Offset for CHU A	
81	DAC Gain CHU A	2 bytes (unsigned short)	[0000h,0FFFh] sets the DAC Gain for CHU A	
87	Auto Set Gain & Offset CHU A	1 byte (unsigned char)	0: AGC disabled for CHU A 1: AGC enabled for CHU A	1
237	DAC Offset CHU B	2 bytes (unsigned short)	[0000h,0FFFh] sets the DAC Offset for CHU B	
239	DAC Gain CHU B	2 bytes (unsigned short)	[0000h,0FFFh] sets the DAC Gain for CHU B	
245	Auto Set Gain & Offset CHU B	1 byte (unsigned char)	0: AGC disabled for CHU B 1: AGC enabled for CHU B	1
395	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera A is rotated about the Z_{ASC} axis, where ' and " indicate the new axes resulting from the previous rotation	0
397	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera A is rotated about the X'_{ASC} axis, where ' and " indicate the new axes resulting from the previous rotation	0

399	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera A is rotated about the Z''_{ASC} axis, where ' and '' indicate the new axes resulting from the previous rotation	0
401	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera B is rotated about the Z_{ASC} axis, where ' and '' indicate the new axes resulting from the previous rotation	0
403	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera B is rotated about the X'_{ASC} axis, where ' indicate the new axes resulting from the prevous rotation	0
405	ASC attitude transformation	2 bytes (unsigned short)	The parametervalue sets the Euler angle (in 1/10000 radians) that camera B is rotated about the Z''_{ASC} axis, where ' and '' indicate the new axes resulting from the previous rotation	0
407	Camera A power	1 byte (unsigned char)	0xAA: CHU A turned on 0x00: CHU A turned off	0xAA
409	Camera B power	1 byte (unsigned char	0xAA: CHU B turned on 0x00: CHU B turned off	0x00
411	Debug Mode	1 byte (unsigned char)	0: the debug port is off, no info to the port 1: normal mode where debug info is send to the port 2: echo mode, every byte received by the DPU on the normal data line is echoed out on the debug port	0
412	HK Time Interval	2 bytes (unsigned short)	[1,65535] specifies the time interval in seconds between updating of HK TM buffer. 0 means never update	1

ATTITUDE ACQUISITION ORIENTED PARAMETERS

Para-meter offset	Parameter name	Parameter size	ParameterValue interpretation	Def.
88	Precession Correction	1 byte (unsigned char)	0: disables the Precession Correction 1: enables the Precession Correction - for CHU A	0

89	Nutation Correction	1 byte (unsigned char)	0: disables the Nutation Correction 1: enables the Nutation Correction - for CHU A	0
90	Annual Aberration Correction	1 byte (unsigned char)	0: disables the Annual Aberration Corr. 1: enables the Annual Aberration Corr. - for CHU A	1
91	Orbital Aberration Correction	1 byte (unsigned char)	0: disables the Orbital Aberration Cor. 1: enables the Orbital Aberration Corr. - for CHU A	0
246	Precession Correction	1 byte (unsigned char)	0: disables the Precession Correction 1: enables the Precession Correction - for CHU B	0
247	Nutation Correction	1 byte (unsigned char)	0: disables the Nutation Correction 1: enables the Nutation Correction - for CHU B	0
248	Annual Aberration Correction	1 byte (unsigned char)	0: disables the Annual Aberration Corr. 1: enables the Annual Aberration Corr. - for CHU B	1
249	Orbital Aberration Correction	1 byte (unsigned char)	0: disables the Orbital Aberration Corr. 1: enables the Orbital Aberration Corr. - for CHU B	0

TOPS ORIENTED PARAMETERS

Para-meter offset	Parameter name	Param. size	ParameterValue-interpretation	Def.
92	X_0 CHU A	8 bytes (double)	[0.0;752.0[. This is the X-component of the optical axis' intersection with the CCD-plane on the CHU A	360
100	Y_0 CHU A	8 bytes (double)	[0.0;580[. This is the Y-component of the optical axis' intersection with the CCD-plane on the CHU A	291
108	κ CHU A	8 bytes (double)	[-1E-01;+1E-01]. This is the lens distortion coefficient	3.0e-8
116	EFL CHU A	4 bytes (unsigned long)	The parametervalue sets the Effective Focal Length of the lens measured in µm	20005
120	Threshold CHU A	1 byte (unsigned char)	The parametervalue sets the Star Threshold	27
250	X_0 CHUB	8 bytes (double)	[0.0;752.0[. This is the X-component of the optical axis' intersection with the CCD-plane on the CHU B	360

258	Y_0 CHU B	8 bytes (double)	[0.0;580[. This is the Y-component of the optical axis' intersection with the CCD-plane on the CHU B	291
266	κ CHU B	8 bytes (double)	[-1E-01;+1E-01]. This is the lens distortion coefficient	3.0e-8
274	EFL CHU B	4 bytes (unsigned long)	The parametervalue sets the Effective Focal Length of the lens measured in µm	20005
278	Threshold CHU B	1 byte (unsigned char)	The parametervalue sets the Star Threshold	27

IMAGING PARAMETERS

Para-meter offset	Parameter name	Param. size	Parametervalue-interpretation	Def.
74	JPEG QUALITY	1 byte (unsigned char)	[1%;100%] sets JPEG quality of the image	75
76	AutoImaging	1 byte (unsigned char)	0: AutoImaging is disabled 1: AutoImaging enabled. Autoimaging continously stores and sends images.	0
77	Compression Method in Autoimaging	1 byte (unsigned char)	0: Uncompressed 1: Centroids 2: unused 3: JPEG	1
78	Imaging camera	1 byte (unsigned char)	0xAA: camera A 0x55: camera B	0xAA

AscStoreImageTC

Header	FunctionID 0x0109	DataLength 2	Compression Method ?	CameraID
5 bytes	2 bytes	2 bytes	1 byte	1 byte

Parameters:

- CompressionMethod (1 byte unsigned char).
- CameraID (1 byte) (camera A = 0xAA, camera B = 0x55)

Tells the ASC to store the next acquired image in a temporary location in RAM and which camera shall be used. The image will reside there until an AscSendImage is issued.

Five different CompressionMethods are supported:

- Not Compressed (CompressionMethod=0). The image will be stored in raw bitmap format.
- Centroids (CompressionMethod=1). Only the star-positions calculated in the internal Centroiding algorithm are stored.
- ROI (CompressionsMethod=2). A small area around each centroid is downloaded in uncompressed format.
- JPEG (CompressionMethod=3). This will store the image using a JPEG compression.
- False Stars (CompressionMethod=4). This generates a list of the centroids, that are not recognized as stars. This selection makes the AscSendFalseStarsTC, AscDumpFalseStarsTC and AscFalseStarsTM obsolete.

AscSendImageTC

Header	FunctionID 0x010A	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscSimulationModeTC

Header	FunctionID 0x0111	DataLength 48	Seed RA ?	Seed Dec ?	Seed Rot ?	YawRate ?	PitchRate ?	RollRate ?
5 bytes	2 bytes	2 bytes	8 bytes	8 bytes	8 bytes	8 bytes	8 bytes	8 bytes

Parameters:

- Seed RA (8 bytes double) [0˚..360˚]
- Seed Dec (8 bytes double) [-90˚..90˚]
- Seed Rot (8 bytes double) [0˚..360˚]
- YawRate (8 bytes double)
- PitchRate (8 bytes double)
- RollRate (8 bytes double)

AscSendTestImageTC

Header	FunctionID 0x0112	DataLength 6+n	Offset ?	Length n	Data ?
5 bytes	2 bytes	2 bytes	4 bytes	2 bytes	n bytes

AscTestImageModeTC

Header	FunctionID 0x0113	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscHKForceTC

Header	FunctionID 0x0114	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None.

AscSendFalseStarsTC

Header	FunctionID 0x0115	DataLength 1	Order Flag (b_7)	Number Of False Stars ($b_6...b_0$)
5 bytes	2 bytes	2 bytes	1 byte	

Parameters:

- Order Flag: Bit b_7 indicates whether the False Stars is ordered by magnitude (b_7=1) or ordered by the location in the acquired image (b_7=0).
- NumberOfFalseStars (7 bit: 0-127)

AscUniversalTimeTC

Header	FunctionID 0x0185	DataLength 4	Time ?
5 bytes	2 bytes	2 bytes	4 bytes

Parameters:

- Time: The universal time reference. Byte 0 = Day, Byte 1 = Month, Byte 2-3 = Year

AscRequestAttitudeTC

Header	FunctionID 0x0180	DataLength 0
5 bytes	2 bytes	2 bytes

AscSendStatusTC

Header	FunctionID 0x0181	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None

AscSendMemoryTC

Header	FunctionID 0x0182	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None

AscDumpFalseStarsTC

Header	FunctionID 0x0183	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None

AscRequestModeTC

Header	FunctionID 0x0184	DataLength 0
5 bytes	2 bytes	2 bytes

Parameters:

None

AscStimulatorUpdateTC

Header	FunctionID 0x0188	DataLength 0	InitialDirection
5 bytes	2 bytes	2 bytes	1 byte

Parameters:

InitialDirection = 1:	North Pole
InitialDirection = 2:	Vernal Point

Appendix G Telemetry Structure

This appendix gives an easy reference to ASC telemetry (TM) structure. For the full description see the TM/TC ICD (RD 4).

A TM-packet is generated by the ASC and transmitted to the on-board computer through the serial interface. The minimum packet size is 9 bytes and the maximum packet size is 82 bytes. A packet consists of a header field and a data field. The header field is 5 bytes and the data field is of variable length with a minimum length of 4 bytes:

<table>
<tr><th colspan="4">Header Field</th><th colspan="3">Data Field</th></tr>
<tr><td colspan="2">DLE</td><td>Checksum</td><td>TMPacketCounter</td><td>ID</td><td>ParameterLength</td><td>Parameter</td></tr>
<tr><td>DLE1
0x81</td><td>DLE2
0xFF</td><td>8 bit XOR value</td><td>TM Packet Counter</td><td>Report ID</td><td>Bytes in Parameter Field</td><td>Different types of arguments</td></tr>
<tr><td colspan="2">2 bytes unsigned short</td><td>1 byte unsigned char</td><td>2 bytes unsigned short</td><td>2 bytes unsigned short</td><td>2 bytes unsigned short</td><td>Variable</td></tr>
</table>

DLE: 2 bytes of data that signals the start of a packet. The DLE is used to synchronize the start of the packet if it loose the sync. To be safe 2 bytes are used instead of just 1.

Checksum: Calculated as an 8-bit XOR combination of all following bytes in the packet (TMPacketCounter, ID, ParameterLength, and Parameter).

TMPacketCounter: Represents a TM packet sequence counter in the range 0 to 16383.

ID: The report ID identifying the type of packet.

ParameterLength: Specifies the number of bytes in the following Parameter (0 to 73).

Parameter: This field contains the ASC output data transported by the packet. This field may contain up to 73 bytes.

Be aware that all data is stored in memory complying to the Little-Endian format (Intel) unless otherwise explicitly stated, e.g. a two-byte short integer is stored with LSByte in the lowest address.

The TM packets available are:

Telemetry Packet	Report ID
AscAttitudeTM	0x0200
AscPowerUpReportTM	0x0201
AscMemoryDumpTM	0x0203
AscFailureReportTM	0x0206
AscStatusReportTM	0x0207
AscImageTM	0x020A
AscFalseStarsTM	0x020B
AscHKTM	0x0210
AscSyncTimeTM	0x0216
AscModeTM	0x0280
AscTCVerTM	0x0301
AscTCBufferFullTM	0x0304

AscAttitudeTM

Header	ReportID 0x0200	DataLength 48	Quat. 1_1	Quat. 1_2	Quat. 1_3	Quat. 1_4	Info 1	Time 1
5 bytes	2 bytes	2 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes

Quat. 2_1	Quat. 2_2	Quat. 2_3	Quat. 2_4	Info 2	Time 2
4 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes

Parameters:

- Quat1_1/Quat2_1 (4 bytes signed long)
- Quat1_2/Quat2_2 (4 bytes signed long)
- Quat1_3/Quat2_3 (4 bytes signed long)
- Quat1_4/Quat2_4 (4 bytes signed long)
- Info1/Info2 (4 bytes unsigned long)
- Time1/ Time2 (4 bytes float)

The content of the Info field is the following:

INFO

Bit Numbers	Item
0	Valid
1	unused
2	Big Bright Object
3	O/B Synchronization Signal (REFT)
4	TimeSyncTC received
5	unused
6	OrbitCorrection
7	Sequence
8-15	EstimateConfidence
16-23	NumberOfLocks
24-31	NumberOfStars

- The Valid field is 1 if the current attitude is valid for use. The valid field is 0 if the attitude determination software has not been able to determine the attitude from the acquired image.
- the Big Bright Object flag indicates, that a big bright object has been detected in the image.
- The on-board Synchronization Signal is set to 1 after the ASC have received an on-board Synchronization Signal, otherwise it's 0 (reset to 0 after filled into Info field).
- The TimeSync TC is set to 1 after the ASC have received a TimeSync TC packet, otherwise it's 0 (reset to 0 after filled into Info field).
- t.b.d.
- The OrbitCorrection field is used to signal if the attitude determination software uses any kind of orbit correction (See AscLoadParameter, ParameterOffset=88-91 and 246-249). It is set to 1 if one or more of the four different corrections are on.
- The Sequence field is 0 if both an initial attitude determination and a fine-tuning are performed. If only a fine-tuning is performed this field is set to 1.
- The EstimateConfidence field contains a number between 0 and 255. The smaller the more accurate is the attitude.
- The NumberOfLocks is used only if the Sequence field is 0, and shows how many stars are used to acquire the initial attitude.
- The NumberOfStars is the actual number of stars found in the image.

AscPowerUpReportTM

Header	ReportID 0x0201	DataLength 2	Boot Source ?
5 bytes	2 bytes	2 bytes	2 bytes

Parameters:

- BootSource (2 bytes unsigned short)

AscMemoryDumpTM

Header	ReportID 0x0203	DataLength 4+n	Base ?	Data ?
5 bytes	2 bytes	2 bytes	4 bytes	n bytes

Parameters:

- Base (4 bytes unsigned Long)
- Data (size <= maximum TM size - 13 bytes)

AscFailureReportTM

Header	ReportID 0x0206	DataLength 2+n	Type	FailureText ?
5 bytes	2 bytes	2 bytes	2 bytes	n bytes

Parameters:

- Type (unsigned short)
- FailureText (n <= max TM packet size - 11)

Description:

If the ASC has detected some kind of flaw during operation, an AscFailureReport is transmitted. There are basically two classes of failure reports which is reflected through the type field. If Type equals 0x0000, a zero terminated string follows describing the failure. On the other hand, if Type is different from 0x0000 the origin of the failure can be found in the table below:

Failure Type	Failure Description
0x0101	Attempt to send sysvar before storing it
0x0102	Error in DLE field in TC packet
0x0103	Wrong length of TC packet
0x0104	Checksum error in TC packet
0x0105	Attempt to send image before storing it (or download finished)
0x0106	Attempt to send memory before storing it
0x0107	Asc is not in attitude mode
0x0108	Attempt to download falsestars before storing them
0x0109	Image data not ready yet
0x010a	Memory data not ready yet

AscStatusReportTM

Header	ReportID 0x0207	DataLength 2+n	Offset	ASC Status ?
5 bytes	2 bytes	2 bytes	2 bytes	n bytes

Parameters:

- Offset: The offset of the downloaded part
- The downloaded part

AscImageTM

Header	ReportID 0x020A	DataLength 4+n	Offset ?	Image Data ?
5 bytes	2 bytes	2 bytes	4 bytes	n bytes

Parameters:

- Offset (4 bytes unsigned long)
- ImageData (size <= maximum TM size - 13 bytes)

AscFalseStarsTM

Header	ReportID 0x020B	DataLength 2+n*10	Camera ID	Num. of False Stars n	False Stars Data ?
5 bytes	2 bytes	2 bytes	1 byte	1 byte	n*10 bytes

Parameters:

- CameraID (1 byte unsigned char)
- NumberOfFalseStars (1 byte unsigned char)
- False Stars Data (NumberOfFalseStars * 10 bytes image data [<= max TM packet size - 11 bytes)

AscHKTM

Header	ReportID 0x0210	DataLength 9	AscHKTM ?
5 bytes	2 bytes	2 bytes	9 bytes

Parameters:

- Temperature CCD A (1 byte unsigned char)
- Temperature CCD B (1 byte unsigned char)
- Temperature CPU (1 byte unsigned char)
- Temperature SMPS (1 byte unsigned char)
- Voltage (1 byte unsigned char, 4 bits for each CHU)
- AGC (autogain) A (1 byte unsigned char)

- Offset A (1 byte unsigned char)
- AGC (autogain) B (1 byte unsigned char)
- Offset B (1 byte unsigned char)

AscModeTM

Header	FunctionID 0x0280	DataLength 1	Mode ?
5 bytes	2 bytes	2 bytes	1 byte

Parameters:

- Mode = 0: Safe Mode
- Mode = 1: Standby Mode
- Mode = 2: Attitude Mode
- Mode = 3: Simulation Mode
- Mode = 4: Test Image Mode

AscTCVerTM

Header	ReportID 0x0301	DataLength 5	TCFunctionID ?	Acknowledge Type Flag (bit 15 & 14) 01	TCPacketCounter (bit 13-0)	Code 0
5 bytes	2 bytes	2 bytes	2 bytes	2 bytes		1 byte

Parameters:

- TCFunctionID (2 bytes unsigned short)
- Acknowledge Type Flag (01 -> Reception of command)
- TCPacketCounter (14 bit: 0-16383)
- Code (1 byte unsigned char)

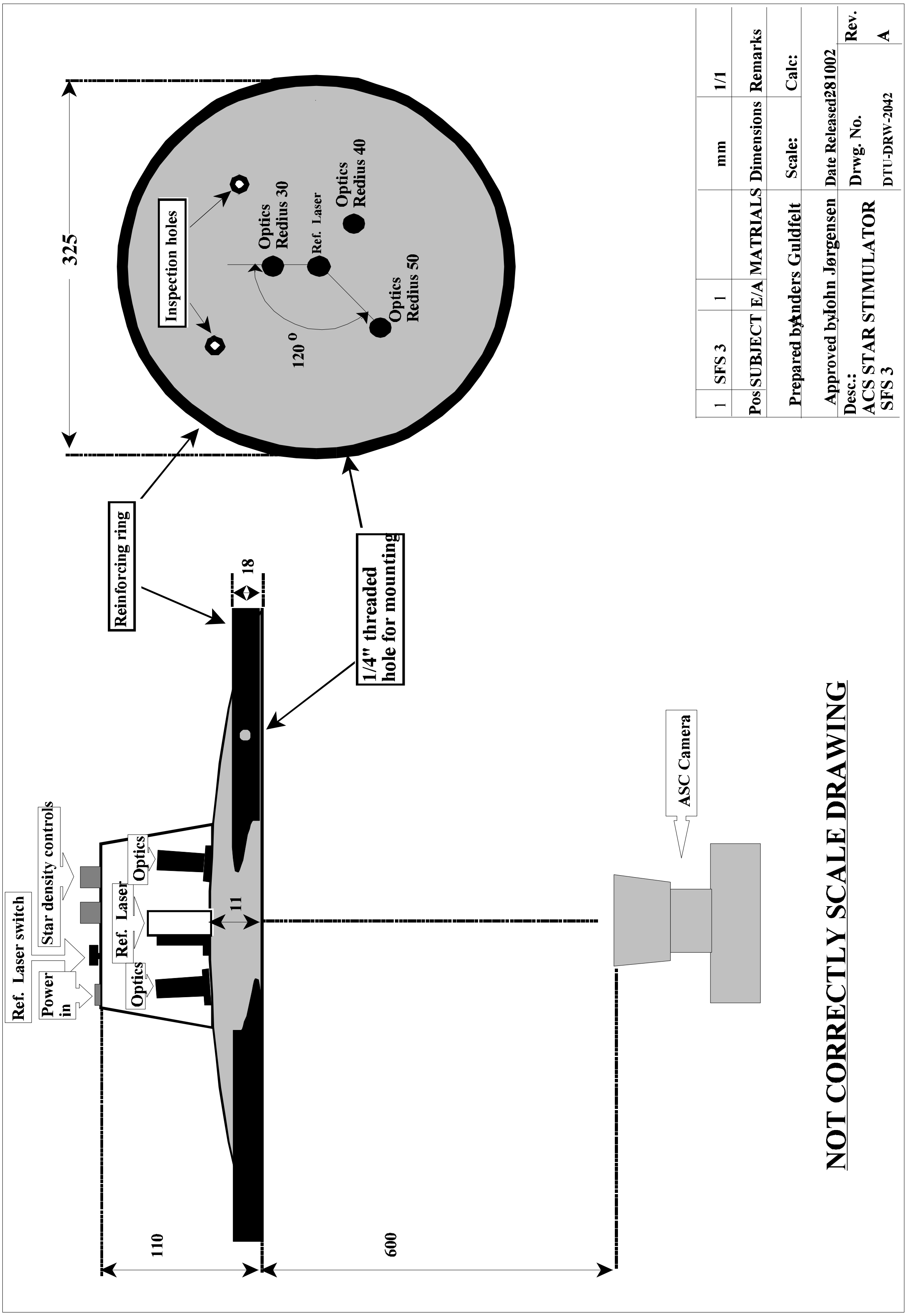
AscTCBufferFullTM

Header	ReportID 0x0304	DataLength 4	TCFunctionID ?	TCPacketCounter ?
5 bytes	2 bytes	2 bytes	2 bytes	2 bytes

Parameters:

- Function ID (2 bytes unsigned short)
- TC Packet Counter (2 bytes unsigned short)

Appendix H Optical Stimulator Mechanical Interface



Appendix I Exact Start Addresses for Various Code Elements

The following table contains the logical start addresses and address of datecodes in the ASC software modules. The given addresses are for FM1 version CN-20011119:

Software Module	Start Address	Version	Address of datecode
BIOS	0x000d0000	20010104	0x000dff4c
KERNEL	0x01000000	20011119	0x0100497b
TOPS	0x0100a800	20011119	0x0100fa00
MAXIHOP	0x01015000	20011119	0x01082e00
DATABASE	0x01093000	20011119	0x0113b124
SYSVAR	0x01295800	20011206	N/A