SUMMARY TECHNICAL DESCRIPTION OF GILLAM ALL-SKY IMAGER

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Abstract

This reports contains a technical description of the Gillam CANOPUS all-sky imager. Both hardware and software issues are addressed. Some historical background is provided as well. The last section points out some problems and deficiencies pertaining to the imager and its operation.

1 History

The original requirements for a CANOPUS imager were in part as follows:

Resolution: 20×20 km at 110 km in zenith
Dynamic range: 200 R to 300 kR in a 5-second exposure
Monochromatic filters: 4 (557.7, 391.4, 427.8, and 630.0 nm)
Imaging rate: 4 filter/sky 'maps' per minute

The original need for an ASI for the CANOPUS program envisaged an imager capable of delivering 4 low-resolution sky images in a twenty-second cycle. The original resolution specification was expressed in terms of a sky 'map' consisting of an array of 20×20 elements, each 20 km on a side, at an altitude of 110 km. What was proposed by the University of Calgary, and what was subsequently built, was an intensified CCD imager, using a 256×256 element CCD. The camera system was designed to be able to take four 256×256 all-sky images, process them into the 20×20 'maps,' and send them to Ottawa via the SkySwitch equipment.

In the final configuration, the 20×20 'maps' were changed to 16 elements east-west, and 25 elements north-south, with the center of the array being somewhat north and east of Gillam, to better correspond with the BARS radar images. These 'BARS' pixels became known as 'superpixels,' and the sky maps were known as 'barsmaps.'

Thus, in its first incarnation, the ASI was producing four barsmaps per minute. Each superpixel had an angular extent, as seen from ASI, of about 5° in the zenith. For this reason, alignment was never considered to be a critical issue; indeed, an alignment accuracy requirement was never specified.

The first significant modifications came with a refurbishment program executed in the summer of 1989. Hardware changes were made to improve CCD temperature stability and filter wheel reliability, and software changes were made to improve system operation and timing accuracy. A documentation upgrade to the original end item data package was made after the summer work was completed.

The next major changes took place in the summer of 1992, when the ASI system was converted to ‘high resolution’ mode. In this mode, images of the sky were taken at the full 256×256 resolution of the imager, and then cropped radially, compressed, and transmitted to Ottawa via a high-speed satellite link. This change involved mainly software changes, at least at the ASI end.

In vetting the design, it was discovered in the laboratory that the ASI system had sufficient processing power to render only three high resolution images per minute, and this was the scheme implemented. In the field, however, it was discovered that ASI was not able to send 3 images in 60 seconds, and the timing was set to 3 images in 70 seconds. Over time, this scheme proved inconvenient, and the timing was changed to 3 images in 75 seconds, and finally 2 images per 60 seconds. Even with this reduced data volume, ASI was at that time sometimes unable to complete transmission on time.

With the implementation of ‘high-resolution’ mode, no alignment requirements were set out. ASI internal alignment was measured in the laboratory, and ASI was carefully aligned in the field, parallel to the MSP photometer, which is adjacent. This alignment, parallel to the MSP, was an historical artifact, and had the advantage of simplifying creating ‘MSP-like’ meridian strip scans from ASI data. No improvements were at that time made to ASI to ease the task of alignment. It was deemed sufficient to level the instrument, align it azimuthally ‘close’ to some fiducial reference, and to subsequently rely on all-sky images of stars to provide accurate alignment information.

The last major upgrade to the ASI took place during the summer of 1995. The move was made away from an LSI-11 microcomputer running a Unix compliant O/S to a PC/486 running the POSIX compliant Linux O/S. Further, a DAT drive was implemented, and the old 9-track tape drive was retired. As well, the filter wheel filter retension mechanism was improved. A feasibility study was made on migrating from the Geneva mechanism to a belt-driven mechanism, but the idea was in the end abandoned. Fans in the temperature control unit and the summation memory unit were replaced. The satellite uplink was improved and the ASI has since then had no problems completing transmission of data on time. Finally, measures were introduced that greatly reduced the complexity of aligning the imager. A north-south line was established using astronomical observations. An alignment telescope mount was built onto the ASI optics module, telescope attached, aligned, locked, and removed, making alignments easier in the future.

2 System Design, Hardware

The system configuration is depicted in Figure 1. The following sections describe the various parts in somewhat more detail.

2.1 Outdoor Unit

The outdoor unit consists of the camera head, surrounding thermal/weather shroud, and thermoelectric temperature control unit (TECA). It is connected to the indoor unit by two cables: a power cable which is an SOH-type 18 AWG cable carrying two circuits (clean and raw AC), and a multiple-conductor Belden ‘Datalene’-style computer cable. Only the power cable is rated for extreme cold, the computer cable must not be flexed while frozen.

Camera Head

The camera head consists of an optics module, a detector module, an electronics module, a calibration lamp and fibreoptic, and two D.C. power supplies. The units are mechanically cascaded, and mount together in a steel frame, which is then bolted to a base plate, which is in turn bolted to the base of the weather shroud.

Optics Module

The optics module is depicted schematically in Figure 2. The optics system is comprised of the following components (top to bottom):

1. Widefield lens (180°)
2. Shutter
3. Telecentric lens
4. Interference filter
5. Field lens
6. Relay lens

The optics module consists of a pair of nested boxes, made of machined 6 mm aluminum plate, into which have been cut a number of large threaded holes. The optic axis of the instrument runs through these holes. The lenses are held in threaded holders, which are screwed in to the aforementioned holes, thus allowing each to be moved back and forth along the optical axis. The various lenses of the optical system, when taken together, form an all-sky, telecentric, monochromatic imager, delivering an 11 mm-diameter image onto the focal plane of the detector module.

The shutter is a 24-volt D.C., normally-closed electric shutter. The shutter dissipates about 6 watts when activated. It has an action time of 100-200 ms, but is not used to determine exposure time.

The four-position filter wheel sits offset from the optic axis, arranged so that one filter is always in the optic axis. The disk of the filter wheel is located between two of the lenses. The filter wheel is actuated by means of a bidirectional D.C. reduction-gear motor, and a four-position Geneva intermittent-action mechanism. The filter wheel position is sensed by means of optical (infrared) sensors, which look through coded holes in the edge of the filter wheel. The sensors are mounted on the filter wheel position sense board, which sits inside the optics module.

The electrical cabling for the filter wheel module is routed through 3 DB9 connectors, and overall cabling out of the optics module is via a single DB25 connector.

Detector module

The detector module is depicted schematically in Figure 3. The detector module consists of a metal ‘can,’ machined from heavy aluminum stock, which forms a container for the elements of the detector system, which are:

1. 25-mm Generation-II image inverter tube with an S25 photocathode and a P20 phosphor
2. 25 mm to 12 mm 2:1 reducing fibre-optic bundle
3. 385×578 element frame-transfer CCD (EEV P86000-series)
4. CCD preamp circuit board

The image formed on the intensifier input plate is reproduced in inverted form at the output plate. This 11 mm diameter image is coupled to the CCD input fibreoptic block via a 2:1 reducing fibreoptic taper. The resultant image scale on the CCD is about 5.5 mm.

The image intensifier is screwed into a holding frame, which also accommodates and localizes the reducing taper. The optical joints at both ends of the reducing taper are filled with optical joint compound to reduce losses.

The CCD is mounted on a small circuit board which is free to move along the optic axis. The bottom of the CCD is pushed against by a flexible, spring-loaded coldfinger, which performs the dual function of conducting heat away from the CCD, and maintaining physical contact between the CCD and the fibreoptic taper.

The detector module electrical connectors and gas purge valves are located on the baseplate. O-rings are fitted to the end plates so as to make the module gas tight.

Electronics Module

The electronics module consists of 3 circuit boards mounted in a Eurocard cage, which is mounted in the frame of the camera structure. The three cards communicate over a common backplane bus. The camera head electronics configuration is depicted in Figure 4.

The first card contains the interface to the host computer and the CCD readout controller. The CCD controller, a microprogrammed control unit (MCU), is essentially a small microcontroller which is downloaded with the program which controls all aspects of CCD clocking and pixel digitization. Thus, the host computer is not directly involved in CCD readout. The MCU supports a variety of readout modes, including reading out all or any part of the CCD and integer $N \times M$ binning. It is currently configured to read out the central 256×256-pixel area of the CCD in 1×1 (non-binned) mode. The system has a readout rate of 815 kpixels/s, with a readout noise level of about 100 RMS electrons (1.5 DN). The MCU supports CCD exposure times in the range 100 ms to 65.5 seconds.

The second circuit card (the ANB) contains the CCD clock drivers, and the analog signal chain, which performs correlated double-sampling on the CCD output signal, and digitizes the signal with a 12-bit A/D unit.

The last card is the auxiliary function board (AFB), which controls the shutter, filter-wheel, measures temperatures, and other housekeeping functions.

Calibration Source

The calibration source consists of a lamp-and-filter holder which is mounted to the camera frame at the front of the unit. The holder has a fibreoptic output connector to which is connected a fibreoptic cable which takes the calibration light signal up to the optics module. Lying between the optics and detector module is a purpose-built arrangement for distributing the light around the input of the image intensifier.

Weather Shroud

The weather shroud is an aluminum shell which surrounds the ASI camera head. It consists of a dome section, a main body section, and a base section. The dome section provides an 18-inch hemispherical dome under which are ambient light detectors and a thermostatically-controlled heater to keep the dome free of condensation.

The dome section clamps onto the main body, and has an access port on the north side, which allows some access to the electronics unit without shroud removal. The access port is the mounting hole for the thermoelectric temperature regulator (TECA). The TECA unit is a self-regulating cooler/heater which uses thermoelectric elements for cooling, and resistive elements for heating. It is adjusted to maintain an internal enclosure temperature of about 20±5°C.

The main body section clamps onto the base section. The base section is free to rotate in azimuth, allowing the system to be rotated about the optic axis. The base section mounts to the podium by means of 3 1-inch threaded brass rods, which can be adjusted to bring the instrument to a level condition.

2.2 Indoor Equipment

The indoor components of the ASI system are:

- Summation Memory Unit
- Intel 80486 Personal Computer (PC)
- Digital Audio Tape (4 mm DAT) drive
- 14-inch video monitor
- Computer console monitor
- Modem

These units are mounted in a full-height 19-inch rack. The console monitor sits on a table nearby.

Summation Memory

The summation memory unit (SVM) performs a number of functions. It provides the interface to the outdoor unit, interface to the PC, and storage and display of the accumulated digital image data. The unit consists of a power supply and three circuit boards mounted in a Eurocard cage. The functions of the three circuit boards are as follows:

Controller Board:

- Interface to the host computer
- Read/write interface to image memory from host computer
- Write-only interface from camera data path
- Read-only interface from memory for video refresh
- Communication with the Camera Port Board
- Control of the operating mode of the CCD readout system (continuous, single-shot, summation)
- Control of the data memory
- 8-of-16-bit data window selector
- 8-bit D/A conversion for video
- RS-170 analog video

Memory Board:

– 512 kB RAM in dual-ported configuration, arranged as 4 quadrants of 256×256 16-bit elements
– Provides three data ports: video (read-only) refresh, camera data, and host CPU access

Camera Port Board:

– Serial data channel to/from camera head for command and status
– Information and parallel data path for 16-bit image data from camera

Thus, the indoor SVM unit, and the two circuits MCU and ANB in the outdoor camera head compose the CCD readout system. These units provide a readout system which needs only triggering signals from the host computer to provide continuous, one-shot, or summation modes of CCD readout. The MCU supports a variety of readout modes, including reading out all or any part of the CCD and integer N×M binning. It is currently configured to read out the central 256×256-pixel area of the CCD in 1×1 (non-binned) mode.

Computer

The host computer is an IBM compatible 80 MHz, 80486-based Personal Computer. It is equipped with 16 MB of RAM, a 1.6 GB harddisk, 3.5-inch floppy disk, a 4 mm DAT drive, and a Cyclades serial multiport board. A purpose-built interface provides the link between the PC's AT bus and the SVM bus.

Tape Drive

The tape drive is an Archive Corporation 4 mm Digital Audio Tape (DAT), using 60-m tape, providing a storage capability of 1.3 GB. It is used primarily for calibration data recording and system backups. The camera system is capable of reading/writing image data directly from/to the tape drive. The tape drive connects to the host CPU via a SCSI interface.

Monitor

The video monitor is a monochrome, 15-inch, rackmounted, RS-170 monitor, and is used to display realtime or playback of recorded image data. The monitor connects to the Summation Memory unit via 75-ohm coax.

Console

The computer console currently consists of a PC keyboard and a SVGA monitor. It is used for local control of the host computer and camera system.

Modem

The modem is a US Robotics Sportster 14.4 Kbps error-correcting modem. Although it is used primarily for diagnostic purposes, it can be used for remote access to the host and remote control of the camera system. Due to bandwidth limits imposed by the link from site to downtown Gillam, the modem is only usable at 2,400 baud maximum.

Interfaces

The system has a purpose-built interface which interfaces the PC's AT bus to the QBUS interface required by the SVM. This is a 16-bit, parallel interface which handles all communication to/from the ASI.

Additionally, this interface has an on-board watchdog timer, which can force a PC system reboot, if not serviced within the watchdog interval. The interval is jumper-programmable, and currently set to 7 minutes.

The PC employs an 8-port async serial interface card from Cyclades Corp., to handle all the serial I/O. Ports are currently assigned to the dial-up modem, the satellite multiplexer, and the GPS time distribution.

3 ASI System Software

3.1 Operating System

The operating system used in the ASI system is Linux, a (free) reimplementation of the POSIX specification with SYSV and BSD extensions. Linux is copyrighted by Linus Torvalds and other contributors and is freely redistributable under the terms of the GNU Public License. The ASI runs Linux kernel version 2.0.0. This Unix-like O/S provides true multitasking system operation, and a C-language compiler. All of the programs used in the CANOPUS application were written in C.

In the particular application, the O/S is used only to provide inter-process communication, task-switching, and file system management. Most of the system services normally found in Unix operating systems, such as mail handling, process logging, network services, etc., have been disabled.

The CANOPUS application is operated by 6 programs which are loaded at boot time, and which remain memory-resident. These programs are launched near the end of the boot sequence from a ‘shell’ script, which the system always executes upon bootup. By changing the boot shell script, the system can be ‘booted up’ into different operating configurations.

3.2 Application Programs

3.2.1 Software Design

System operation is cyclical, with a ‘cycle length’ determined by a configuration file. A master control program simply repetitively works its way through the cycle, issuing whatever signals are designated for each second of the cycle. The application software consists of six programs which are always memory-resident. Five programs effect the realtime operations of the system, and a sixth keeps the Unix system time synchronized to the GPS clock. The software arrangement is depicted in Figure 5. The six programs are described here:

‘master’

The master control program. Running continuously, it operates once each second to dispatch whatever signals are designated for the particular second. The operating cycle of the system is defined as being some number of seconds in length (in the present case 60 seconds), and the operation is cyclic over that period. The master program uses one ancillary file, the cycle table, which contains one line for each second in the cycle. Each line of the file contains a list of up to 9 distinct signals which may be issued in the current second. It is necessary only to change the number of lines in this file to change the length of the ASI operating cycle. In the present application, which has become much simplified since the original implementation, we utilize only three seconds of the cycle, with only one signal per active second. The current organization of the cycle is as follows:

Second Number	Action
0	do nothing
1	"
2	trigger "xi" - the camera operation
3	do nothing
4	"
.	"
.	"
.	"
30	strobe watchdog timer
31	do nothing
32	"
.	"
.	"
.	"
59	trigger data transmission

Additionally, the ‘master’ program is aware of the time of day, and triggers the hourly camera operations, and triggers the daily reboot at 12:08 local time [after converting to the Linux O/S, this reboot is no longer performed], by ceasing to strobe the watchdog timer board, which subsequently forces a hard reset of the system.

‘xi’

XI is the camera control program. It understands a command set, and these commands, with associated parameters, are used to operate the camera. The ‘xi’ program employs a single ancillary file which contains a list of command sequences. Each command sequence is a ‘canned’ procedure, and is associated with a particular camera operation. Presently, six procedures are used, to effect the various camera operations currently supported. These are: idle mode, dark frame mode, calibration frame mode, starfield mode, normal datataking mode, and initialization.

The ‘xi’ program receives from the ‘master’ program both a trigger signal, and control information which determines which camera command sequence to execute. In this way, the ‘xi’ program initializes the camera system shortly after reboot, runs the dark/calibration/starfield sequences once each hour, and runs either the idle mode or datataking mode sequences each minute.

In the current datataking configuration, ‘xi’ is programmed to take one image each at the 557.7 nm and 630.0 nm wavelengths, and to save these images in two different quadrants of summation memory. The exposure configuration is such that each image is a summation of 16 frames, each with a 100 ms exposure time. The dark frame and calibration frame sequences are the same. The starfield sequence takes two single-shot images with the 737.0 nm filter, of 12 seconds exposure time each. In the idle mode sequence, ‘xi’ simply collects the current camera and computer system status information.

At the end of each command sequence, the ‘xi’ program sends a trigger signal to the data message preparation program, ‘msgprep.’

In the present configuration, the ‘xi’ command sequence takes about 12 clock seconds to complete, but consumes only about 3 seconds of CPU time.

‘msgprep’

The ‘msgprep’ program prepares one data message for each camera image quadrant prepared. A trigger signal and control block are passed to the program from ‘xi.’ The control block describes which of the four camera image quadrants has been exposed. Thus, ‘msgprep’ can prepare messages from up to four images, taken at any wavelength, and stored in up to four image quadrants in the summation memory.

The image data in each summation memory quadrant consists of 256×256, 16-bit pixel values. This amounts to 131,072 bytes of image data, in addition to the 120 bytes of the image header. ‘msgprep’ reduces the volume of data to be transmitted in two ways. First, the 256×256 image array is subsampled by using only the central circular area of radius 99 pixels. This circular cropping is centered on the measured optical axis of the imager. Programmatically, this cropping is accomplished with an ancillary file, which is loaded into memory once after system boot. This file contains an array of some 30,896 elements, which contain the addresses of the pixels of each quadrant which are ‘inside’ the circular cropped zone. The array is ordered to produce the fastest ‘lookup’ method. The 99 pixel radius of the cropped zone corresponds to a zenith angle of 74°.

Secondly, ‘msgprep’ compresses the original 16-bit data into 8-bit pixels. The method uses a combination of linear and logarithmic compression. This compression is done through a lookup method, to reduce the runtime of the code.

Employing these techniques, the ‘msgprep’ program produces from one to four data messages. A header is prepended to the image data, and each message buffer is marked with a flag to indicate it is ready for data transmission. In the present configuration, ‘msgprep’ produces two messages of 31016 bytes. ‘msgprep’ includes a block sequence number in each data message prepared. The sequence number is only incremented when a new data message has been prepared.

In idle mode, ‘msgprep’ creates a short message containing only the status header.

‘wdt’

This is the watchdog timer program. It receives a trigger signal from the ‘master’ program, and simply reads a memory location which is mapped to a register on the SVM interface board. The watchdog timer board is strapped to force a reboot if this register has not been read within 7 minutes. The CPU time consumed is negligible.

‘serout’

This is the data transmission program. Passed a trigger signal by the ‘master’ program, and control information from the ‘msgprep’ signal, ‘serout’ transmits all prepared data messages out the RS-232 serial port connected to the satcom multiplexer.

In the present configuration, ‘serout’ sends two 31,016-byte messages each minute, when not in idle mode. Normally, if the output signalling rate is 19,200 bits per seconds, this process should take 34 seconds. Internal to the process, about 3.5 seconds of CPU time are consumed servicing the serial port interrupts. An additional 0.5 seconds of CPU time are consumed prior to start of transmission.

This process has been observed to take this amount of time under normal circumstances, but when the ‘missing minutes’ phenomenon was upon us, the data sending could take more than 73 seconds, which as explained below, would tend to cause the whole process to skip a minute.

‘timelord’

This program has the function of making sure the system clock is accurately synchronized to the GPS clock. It periodically reads the GPS timecode string from the serial port connected to the timecode distribution box, and if the system time has drifted by more than ±1 second, it sets the system clock.

Additionally, if, during bootup, the GPS clock is unreadable or the lock quality indicator becomes worse than the ±500 ms threshold, it will set a system flag which will cause the ‘master’ program to reboot the system, effectively keeping ASI ‘off the air.’ If, during normal operations, the GPS clock becomes unreadable, or the lock quality poor, the program will cause the ‘master’ program to reboot if the condition has not improved after some 10 minutes.

This program behavior is an historical artifact from the days when ASI shared the satcom link in real time with other instruments, and was required not to transmit if unsure of the time. Under the present situation, the program is still useful in that it prevents the generation of image data with faulty header times.

3.2.2 Process Control

The process control is effected through the use of interprocess control signals (semaphores), and with information contained in control blocks, held in shared memory. The control mechanism can be described for each program:

'master': neither knows nor cares whether things have been completed. Simply sends a 'start' signal to the various programs, as depicted above in the description of the cycle table. 'master' is aware of the current second of the cycle, the current minute of the cycle, and time of day when the daily reboot takes place [Note: daily reboots are no longer performed]. It passes control information to 'xi' which determines what command sequence to run.

'xi': triggered at second 02, executes whatever command sequence is in its control block. It marks a flag for each new quadrant of image data exposed. In datataking mode, finishes at second 12, when it directly triggers 'msgprep.'

'msgprep': Triggered by 'xi,' checks two things: has the previous minute's data finished being sent?, and has new data been exposed by 'xi'? In the event of a negative in either case, 'msgprep' sets a system debugging flag, and goes dormant again. In the normal case, it prepares data messages and marks a flag for each message prepared. It normally finishes at second 24.

'serout': Started at second 59, checks if there is any new data to transmit. If there isn't, it sets a system debugging flag, and goes dormant again. Otherwise, it takes a private copy of the prepared data, and marks the buffers free. It then passes the data 8 kB at a time to the serial I/O device driver. The actual data transmission happens entirely in the interrupt service routine. When the data transmission is actually completed, it marks a flag for 'msgprep,' and goes dormant again.

Using the above scheme, the system will either complete a normal cycles' worth of processing, or will skip a cycle. For periods in the past, the 'serout' program at times took up to 73 seconds to complete; from second 59 when it was triggered, until second 12 of the next minute, when 'msgprep' would look to see if the previous minute's data has been sent. Note that all such 'missing minute' related problems have since been solved.

4 ASI Operational Modes

4.1 Automatic Modes

The ASI has a single automatic mode wherein it operates the camera system and sends data to the satcom link. Within this automatic mode, ASI has a number of submodes:

1. Idle mode : gather information about the state of the camera and the computer system, and send as a single idle mode data message. This includes the same information which forms the headers of the normal datataking messages.
2. 'Normal' datataking mode. ASI exposes two images and sends two data messages to the satcom link. The headers of each image include status information about the camera system, as well as summary condition flags about the Venix file system. Within 'normal' mode, are four submodes:
    (a) 'Normal' mode: ASI exposes two images, at 557.7 nm and 630.0 nm, and sends two data messages in a repeating 60-second cycle. The images are a sum of 16 frames, each exposed for 100 ms.
    (b) 'Dark Frame' mode: ASI exposes two images with the shutter closed, and sends two data messages. Exposure is the same as 'normal' mode.
    (c) 'Calibration' mode: ASI exposes two images with the shutter closed and the internal calibration source on. ASI sends two data messages. Exposure is the same as 'normal' mode.
    (d) 'Starfield' mode: ASI exposes two images with the 737.0 nm filter, each being a single exposure of 12 seconds. ASI sends two data messages.

4.2 Manual Modes

Through the use of the local console terminal, or by means of the telephone modem, ASI may be operated manually in an interactive session of the camera control program. There are two levels of control: 'campaign' use (misnomer), and 'full control.' A campaign user has been created which allows this user to access a variant of the camera control program. This program allows a limited set of actions on the camera system, implementing essentially a 'read-only' interface to the camera. In this way, a user can log on to the Gillam system and interrogate certain aspects of camera system status, without perturbing either normal automatic mode or another interactive user. In this sense, the term 'campaign' is a misnomer, since the ASI cannot really be operated from this user level.

The other user level has not been implemented for 'public' access. This level of use allows full control over the camera system, and camera data can be written to either disk or 9-track tape. This is the mode University of Calgary personnel use to perform calibrations, etc. It is not possible, for obvious reasons, to operate the ASI via manual mode while ASI is running in automatic mode. It is the responsibility of the user to shut off the automatic mode and start it up again when finished. While these tasks are very simple, at the present time they are not permitted by other than the root user.

Whenever a remote user is logged in to the ASI system, this is reflected in a change in the system mode flag.

5 Some problems and deficiencies

Difficulties with ASI stem mainly from two sources: reliability and obsolescence. Some specific areas of concern are detailed below.

5.1 Camera Head

Filter Wheel

The filter wheel has failed a number of times since installation. It has several modes of failure, but the most common is shearing of the Geneva drive wheel cam pin. Other failures, in rough order of frequency/severity are: failure of the positioning system, loosening of the filterwheel-to- driveshaft bolts, anodizing finish appearing on filters, filter cracking shearing of motor shaft.

Most of these problems have been solved, but we have no way of guaranteeing operation. Our procedure thus far has been to disassemble, clean, inspect, replace worn parts, reassemble, and bench-test the filterwheel unit. All the key parts: the Geneva mechanism, the drive pin, and the motor are all still available [NOTE: This statement last verified in 1995].

Thermoelectric cooler (TECA)

The TECA unit failed many times in the early days. This was eventually traced down to a faulty design of its controller circuitry. Since this repair, neither the TECA unit in use, nor the spare have shown any problems. With several operating seasons behind us, we can venture to say that the reliability has improved. However, the unit contains two fans, which should probably be replaced at regular intervals.

Weather Shroud

The weather shroud manages to keep out the rain, ice, and snow. It requires annual refurbishment, usually replacement of the soft rubber gaskets which form the seals.

Detector Module

The detector module is not gastight. We had problems in the early years with moisture finding its way into the module, and then forming ice or water on the CCD chip cooler. In one case, this resulted in having to replace the cooler unit.

In the original build we were unable to obtain gastight connectors due to high costs and large minimum purchase volumes. We have done a good job of sealing the unit, but it is not gastight. The unit is thoroughly purged before reinstallation, and a bag of silica desiccant is installed in the detector during refurbishment. This seems to have worked in keeping the moisture out, but a better solution would be to make the module gastight.

The detector module is not mechanically indexed to the optics module. The detector module is held to the optics module with a clamping ring. The attachment procedure involves locating the detector module under the optics module, and partially tightening the clamp ring. Then, using realtime video as feedback, the module is maneuvered into proper position. We seem to be getting about ±1.5 pixels and ±1/2 column in repeatability, but things would be much easier if the modules were indexed.

We believe the modules could be indexed fairly easily. We have used a method before which employs a triad of carefully machined holes and locator pins. The resulting endplay is less than 0.001 inches, which would result in an azimuthal error of about ±0.015 degrees in azimuth, and about ±0.5 pixels in translational error.

Spectral Calibration Source

Although not directly related to reliability, the ASI's present calibration source does not include the interference filters between the source and detector. In the past, a feasibility study has been done which studied how an external spectral calibration source might be implemented, and a basic design was produced. Inclusion of such a source would give us a way of continually monitoring the wavelength stability of the interference filters.

MCU and ANB circuit cards

These cards are no longer in manufacture. The MCU card uses some parts which are no longer available. We have one spare for each. Note that the ANB spare card is defective and cannot be repaired.

Alignment

The problems related to alignment are discussed in an email to D. Ewchuk, of April, 1995. The text is included here:

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1. The uncertainties in azimuth and tilt angle were provided in our alignment
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report presented to you last year. It is unlikely we can do much better than this.

2. We routinely use a two-axis spirit level to adjust the tilt of the ASI when we install it in the field. This is to say that we use the spirit levels to adjust the tilt with the leveling rods, until the tilt is at or below the indication limits of the spirit levels. As such, we do not actually measure the tilt, just estimate that it is less than some limit.

   Actually measuring the tilt, and worse, the azimuth of the tilt, would be very difficult, and may be problematic for a number of reasons:

   > The platform on which the ASI rests deforms significantly when someone is standing on it, say, to read the spirit level.
   >
   > The platform probably takes some time to recover from all the marching around that goes on during a dismount or mount operation.
   >
   > Given the instability of the terrain up there, we don’t know how long a careful alignment would last.
   >
   > The reference plate we use for the leveling adjustment cannot be accessed without removing the ASI dome, which disturbs the instrument.
   >
   > Internally, the ASI is not constructed in such a way as to guarantee consistency of alignment of the CCD detector to the optical system beyond some practical limit. The alignment is only as good as the machining tolerances and free-play in the CCD mounting allow. Actually measuring these tolerances would be a daunting task.

3. With respect to realignment in the fall. When we dismount ASI, it’s baseplate (azimuthal swivel) comes with it. We have no very accurate way of remounting the ASI into the same alignment it had at the time of dismounting. We have always aligned it azimuthally after remounting and leveling, using it’s azimuthal swivel, and using the same external geographic reference point. What we are proposing to do in the summer program is to attach an alignment cube or telescope to the upper plate of the optics module, and determine in the laboratory the alignment of that cube to the internal CCD.

   We already know, however, that this alignment will not survive the reshipment to Gillam intact. We will therefore make some effort to determine the tolerances, but only insofar as finding the limits of misalignment. The alignment telescope will allow us to "survey in" the ASI azimuth, using a sextant and theodolite to create a fiducial reference some distance from the ASI.

   We are concerned that you are attempting to determine (and use) the ASI alignment data (especially tilt) to a precision which is beyond repeatability, given the realities discussed above.

```
To answer your questions:

a. All we could do is obtain a calibrated clinometer and reduce the tilt to
   some small value, and measure the residual tilt of the upper plate of
   the optics module. Doing this without disturbing the instrument is
   impossible. It may be the case that we can borrow a clinometer, in
   which case there would be no additional cost in making this measurement.
   We will investigate whether this is possible, and will let you know.

b. You have not specified what you mean by "desired alignment data". The
   precision of such a specification will sharply drive the cost, and may
   well be beyond our ability to measure or repeat. We propose proceeding
   as we plan for the summer work and the reinstallation next fall. We will
   be able to align ASI azimuthally to within (about) +/- 0.1 degrees of
   geographic north, and reduce the tilt to less than 0.5 degrees. Perhaps
   we can reduce the tilt to 0.1 degrees, but no promises. Measuring the
   azimuth of the tilt is probably impossible.

c. With the exception of a precision clinometer, we have all the necessary
   equipment to perform the work.
```

5.2 Indoor System

Summation Memory

Two of the three circuit boards and one of the two power supplies in this unit have failed over the years. We have managed to repair/replace all defective components. We have a complete unit as a spare. The unit is no longer in manufacture. The unit uses some parts which are proprietary (FPLAs,EPROMs), and it is not known is if their contents are still available. Some other parts (memory chips, drivers) are no longer in manufacture.

System Computer

The system computer is a fairly high-performance, low-cost IBM PC/486 clone. A standard AT-type architecture and an ample supply of commercial spare parts ensures easy future repair and/or upgradability. The current performance is more than adequate for the task at hand.

Operating System

The operating system, Linux, is developed and improved on an on-going basis by volunteers world-wide. This Unix implementation and its C compiler is still considered ideally suitable for the task at hand, including any required future software development.

DAT Tape Drive

The tape drive now installed at Gillam is functioning well. Drives like these need their tape heads cleaned after every 30 or so hours of read/write operation.

Console Monitor

The user terminal has failed several times. Replacement ASCII terminals are becoming hard to find, and are expensive ($\sim$CAD 1,000). The terminal is not required for normal automatic mode.

Data Transmission

Currently, the ASI is tasked to provide only two cropped images of the sky per minute. ASI is able to deliver this volume of data 100% of the time.

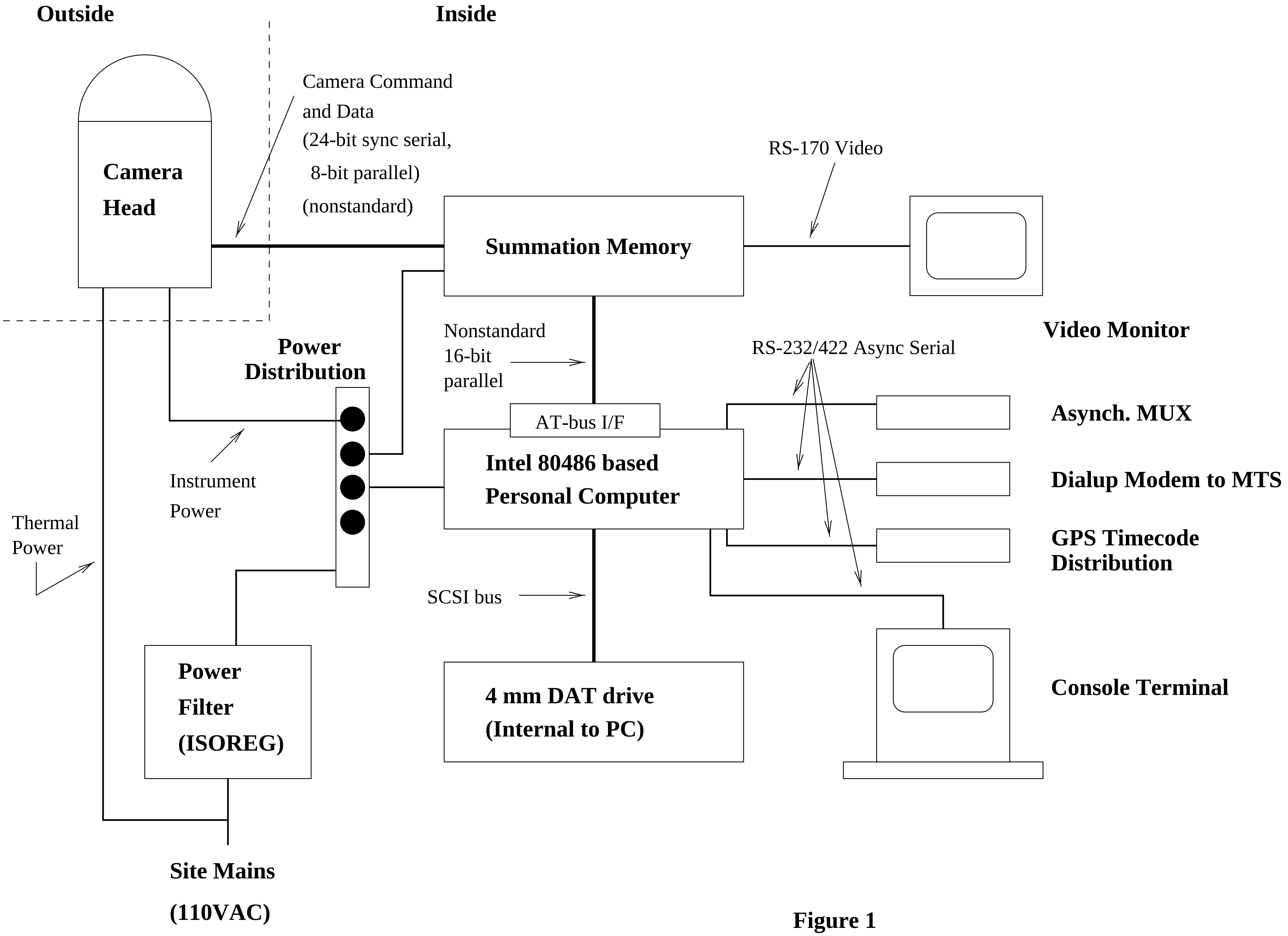


Figure 1

CANOPUS ASI System Configuration

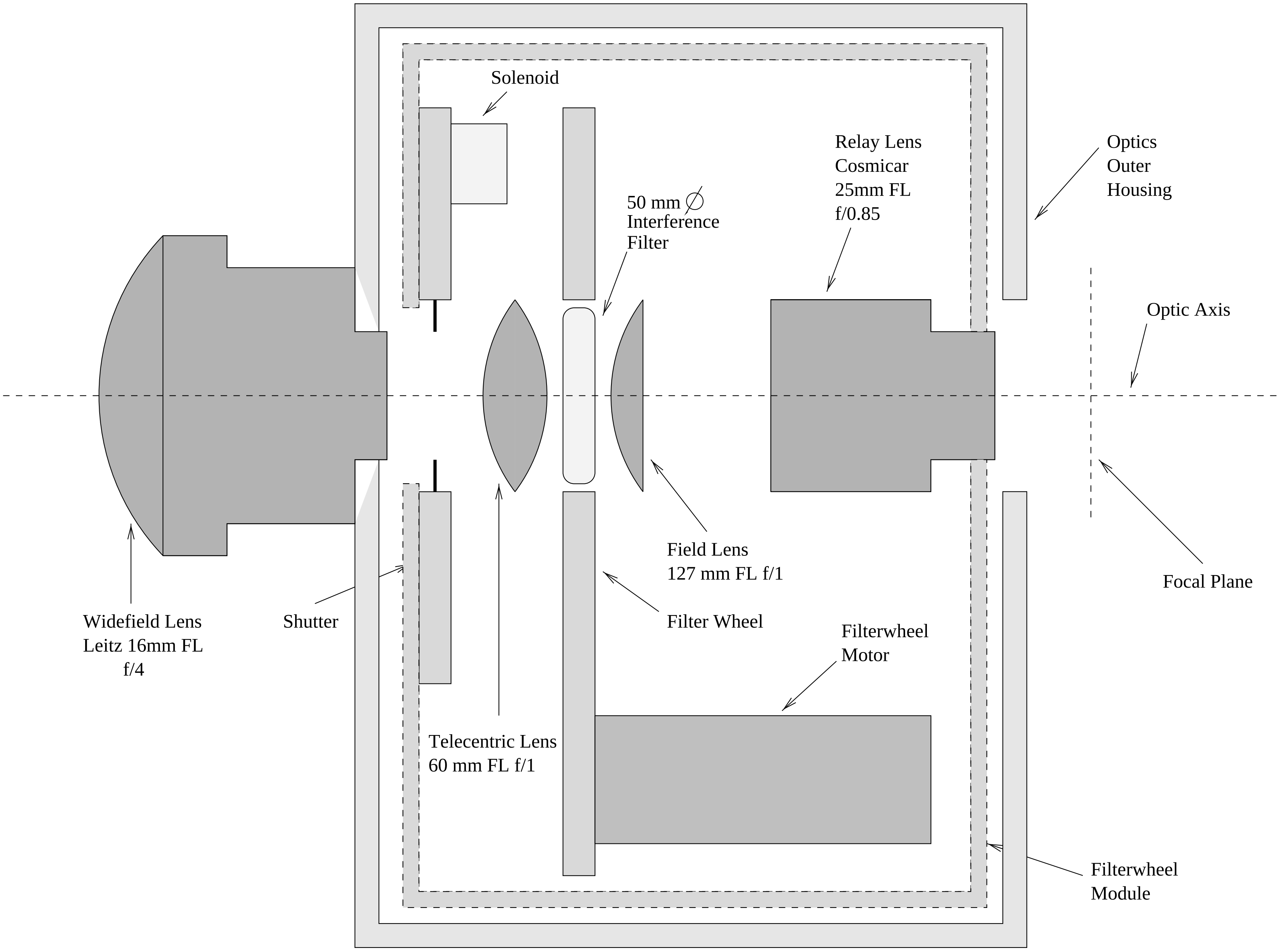
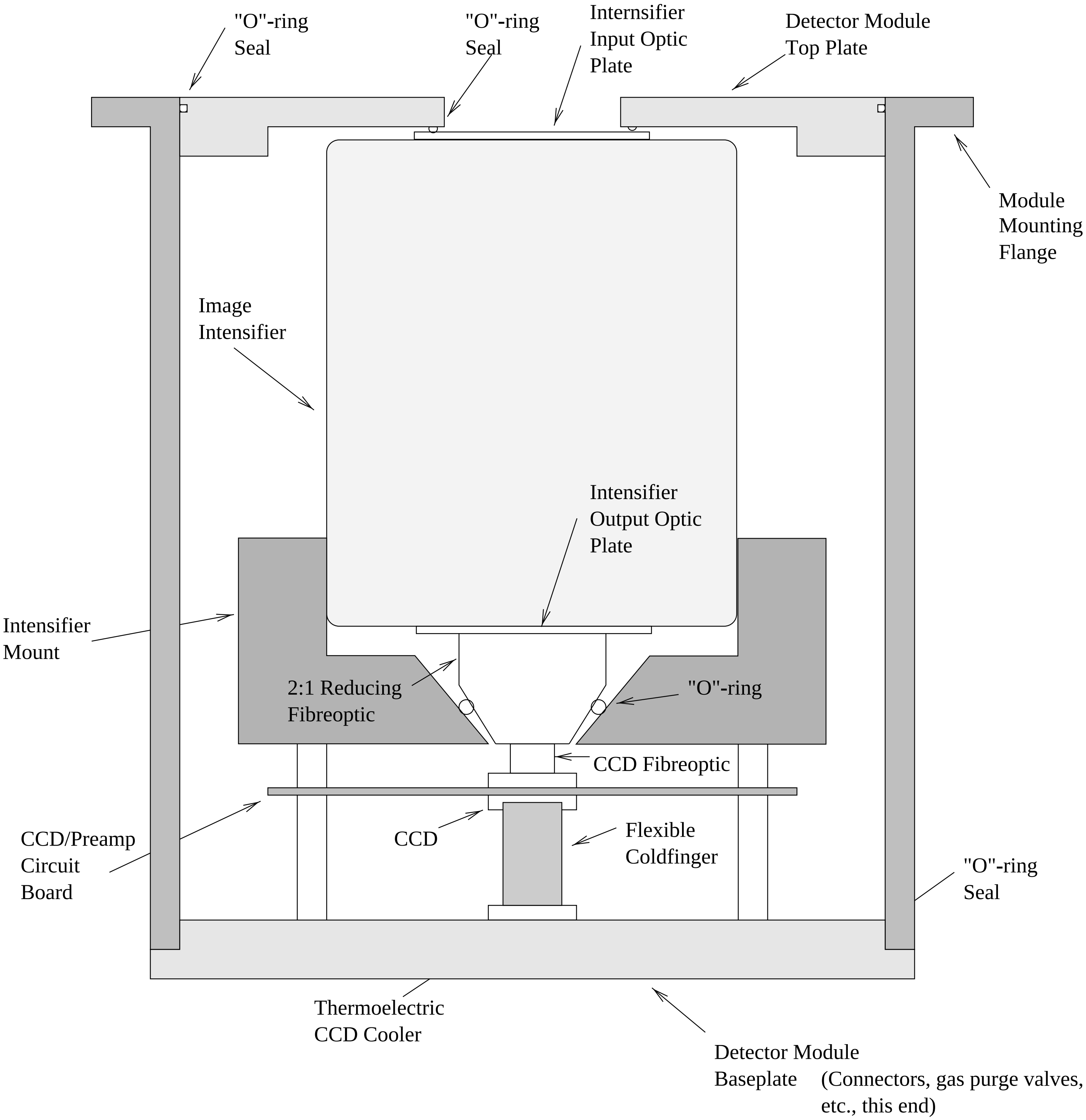


Figure 2 CANOPUS ASI - Optical System Schematic

Figure 3 CANOPUS Allsky Imager Detector Module Schematic



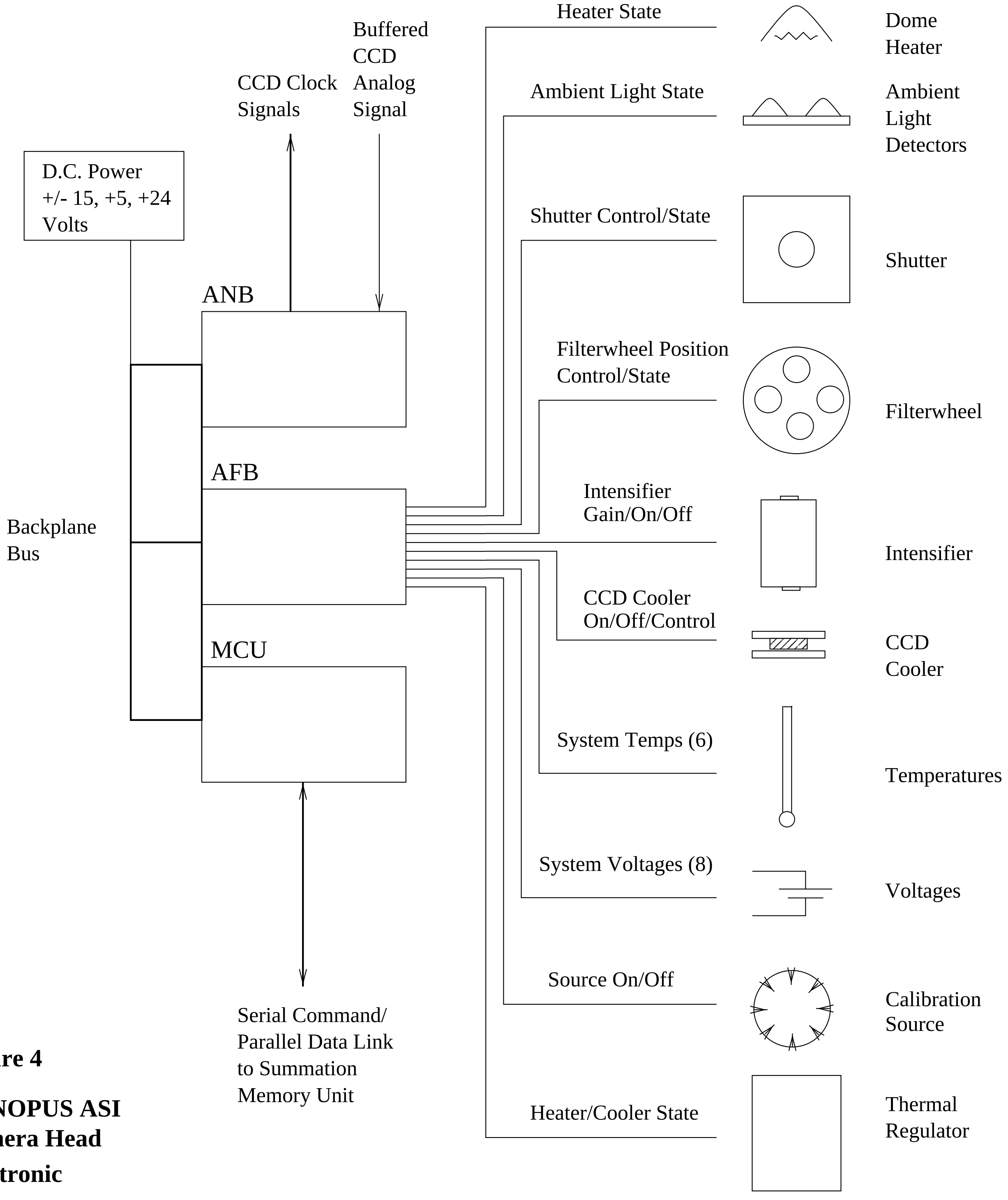


Figure 4

CANOPUS ASI Camera Head Electronic Configuration

Figure 5 CANOPUS ASI Software Organisation