VIRTIS

Instrument Description

	NAME	FUNCTION	SIGNATURE	DATE
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1. SCOPE

VIRTIS is a sophisticated imaging spectrometer that combines three unique data channels in one compact instrument. Two of the data channels are committed to spectral mapping and are housed in the Mapper (-M) optical subsystem. The third channel is devoted solely to spectroscopy and is housed in the High resolution (-H) optical subsystem.

This document describes the VIRTIS instrument in its hardware and software characteristics.
After a general overview of the whole system, section 4 includes a more detailed description of each VIRTIS module: Optical Module (OM), Proximity Electronics (PEM-M and PEM-H) and Main Electronics(ME). Specific paragraphs are devoted to the optics, to the focal planes and to the thermal design.
Section 5 is fully devoted to a software overview with a schematic description of the main functionality's for the instrument control and data handling.

2. APPLICABILITY

3. REFERENCE DOCUMENTS

RD. 1 VIRTIS ROSETTA EID-B RO-EST-RS-30015/EID B

4. ACRONYMS

A/D:	Analog to Digital
ADC:	Analog to Digital Converter
ASIC:	Application Specific Integrated Circuit
BBC:	Board and Boot Controller
CCD:	Charge Coupled Device
CCE:	Cooler Control Electronics
CDS:	Correlated Double Sampling
CLK:	CLocK
CME:	Cover Motor Electronics
CSE:	Cover Switching Electronics
CTE:	Charge Transfer Efficiency
CTIA:	Capacitive Trans-Impedence Amplifier
DAC:	Digital to Analog Converter
DHSU:	Data Handling and Support Unit
DM:	Data Memory
DN:	Digital Number
DPU:	Digital Processing Unit
DSP:	Digital Signal Processing
EEPROM:	Electrical Erasable Programmable Read Only Memory
FIFO:	First In First Out
FOV:	Field of View
FPA:	Focal Plane Assembly
FPGA:	Field Programmable Gate Array
FWHM:	Full Width Half Maximum
GA:	Galileo Avionica
HES:	Hall Effect Sensor
HK:	HouseKeeping
I/F:	InterFace
I/O:	Input Output
IFE:	InterFace Electronics
IRFPA:	InfraRed Focal Plane
ME:	Main Electronics
MOS:	Metal-Oxide Semiconductor
MPP:	Multi Pinned Phase
MTF:	Modulation Transfer Function
OM:	Optical Module
PEM-H :	Proximity Electronics Module of VIRTIS-H
PEM-M :	Proximity Electronics Module of VIRTIS-M
PM:	Program Memory
PROM:	Programmable Read Only Memory
RTOS:	Real Time Operating System
RTU:	Remote Terminal Unit
S/C:	SpaceCraft
S/N:	Signal to Noise ratio
SCA:	Sensor Chip Assembly
SEU:	Single Event Effect
SRAM:	Static Random Access Memory
SSMM:	Solid State Mass Memory
TBC:	To Be Confirmed
TC:	TeleCommand
TM:	TeleMetry
TVC:	Thermal Vacuum Chamber

UV:	UltraViolet
VIMS:	Visible Infrared Mapping Spectrometer
VIRTIS:	Visible InfraRed Thermal Imaging Spectrometer
VIS:	Visible

5. HARDWARE DESCRIPTION

5.1. GENERAL INSTRUMENT DESCRIPTION

VIRTIS is an imaging spectrometer combining three data channels in one compact instrument. Two of them are devoted to spectral mapping (Mapper optical subsystem: **-M**), while the third one is devoted to spectroscopy (High resolution optical subsystem: **-H**).

As shown in the functional block diagram of Fig. 5.2.1-1, the **-M** and **-H** optical subsystems are housed inside the Cold Box of the Optics Module. The Optics Module is externally mounted to the -X panel of the spacecraft with the **-M** and **-H** co-aligned and boresighted in the positive Z direction. Both optical systems have their slits parallel to the Y axis; the **-M** has the ability to point and scan by rotating the primary mirror around the Y axis. The Optics Module is electrically connected by the Inter-Unit Harness.to the -M and -H Proximity Electronics Modules and to the Main Electronics Module, which are internally mounted to the spacecraft on its -Y panel.

The **-M** utilizes a silicon charge coupled device (CCD) to image from 0.25 µm to 1 µm and a mercury cadmimum telluride infrared focal plane array (IRFPA) to image from 0.95 µm to 5 µm. The **-H** employes the same HgCdTe IRFPA to perform spectroscopy from 2 µm to 5 µm. The electronics to drive the CCD and the two IRFPAs are housed inside the Proximity Electronics Modules, while the remaining electronics boards are housed inside the Main Electronics Module. Both IRFPAs require active cooling to minimize the detector dark current (thermally generated Johnson noise). To minimize the thermal background radiation seen by these two IRFPAs, the Cold Box must be passively cooled to less than 130 K by radiating one of its surfaces toward cold space. While the coolers are housed inside the Optics Module Pallet, which directly interfaces with the warm spacecraft, the cold detectors and optical systems are housed in a cold structure that must be rigidly mounted to the much warmer Pallet while remaining thermally insulated from it. The VIRTIS engineering team is therefore faced with the daunting task of thermal-mechanically attaching this “Cold Box” in two counterposing ways to the Pallet: The cold fingers connecting the two active coolers inside the Pallet to their corresponding IRFPAs inside the Cold Box must maximize the thermal pathway from the coolers to the IRFPAs while remaining mechanically pliant; in contradistinction, the standoff insulators connecting the Cold Box to the baseplate of the Pallet must minimize the thermal pathway between the warm spacecraft and the cold optical subsystems while remaining mechanically rigid. In this way the structure and the delicate subsystems that it supports are not only guaranteed to survive launch vibrations, but the structure can also help in minimizing the usual thermal gradients that adversely affect the alignment of low temperature optical systems.
It is clear that the technical challenge is formidable, but it is by no means insurmountable. One approach that should ensure success is to simplify the thermal-mechanical design (ie. obviate the need for a radiator, cold finger, and cold plate) and rely on a series of backup innovative techniques to reduce temperature impacts at various levels: new MLI materials and mounting techniques, new detector technologies, clever baffling of thermal background, and proper use of optical filtering. Therefore the philosohpy of the VIRTIS team, which is to simplify the thermal-mechanical design to the greatest extent possible, can still be maintained while guaranteeing the extensive scientific return that is only possible through an instrument of this class. The team also intend to work closely with the spacecraft engineers to ensure that the interface to the spacecraft is likewise kept simple and straightforward.

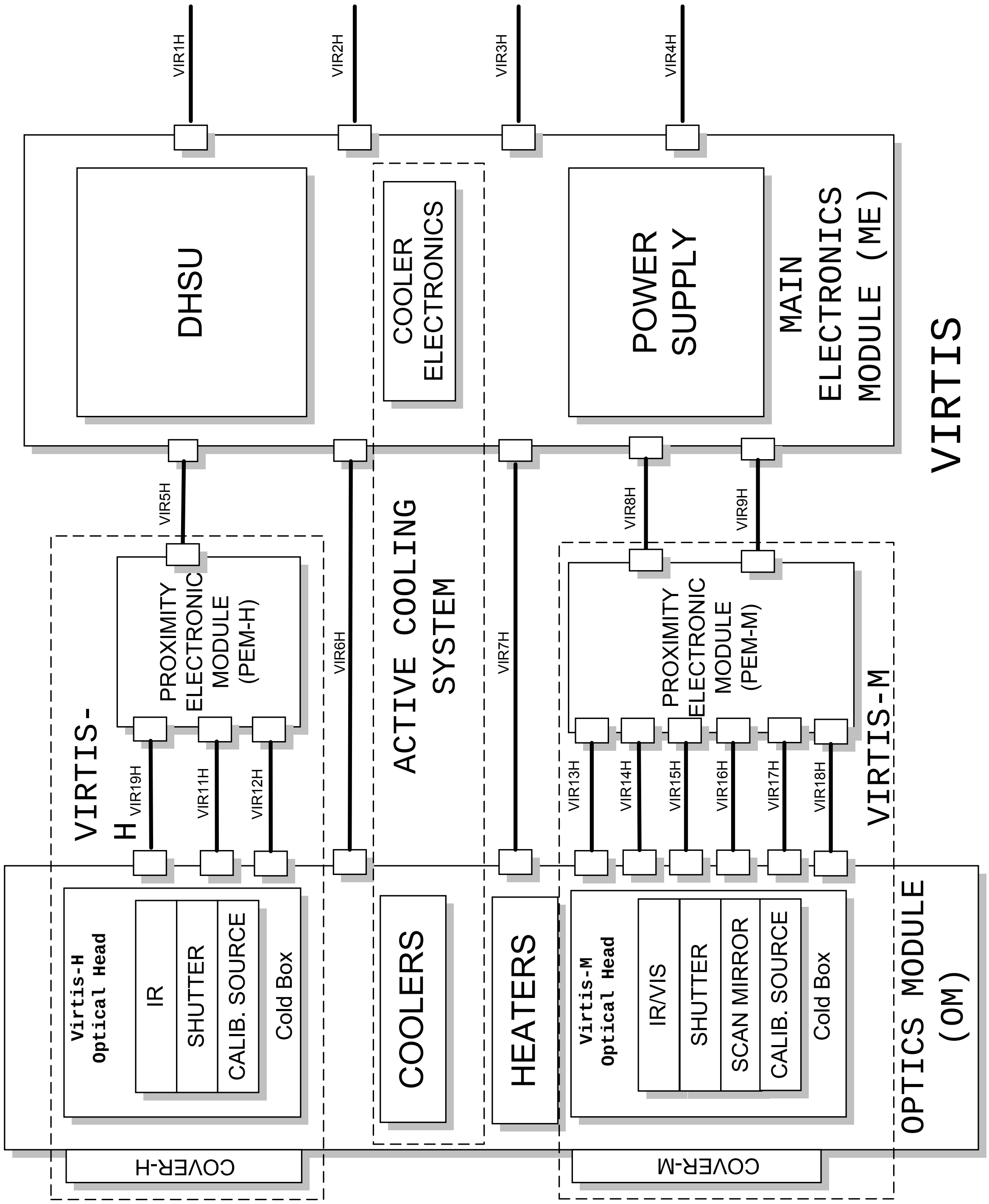


Fig. 5.2.1-1 Functional Block Diagram

5.2. OPTICS MODULE DESCRIPTION

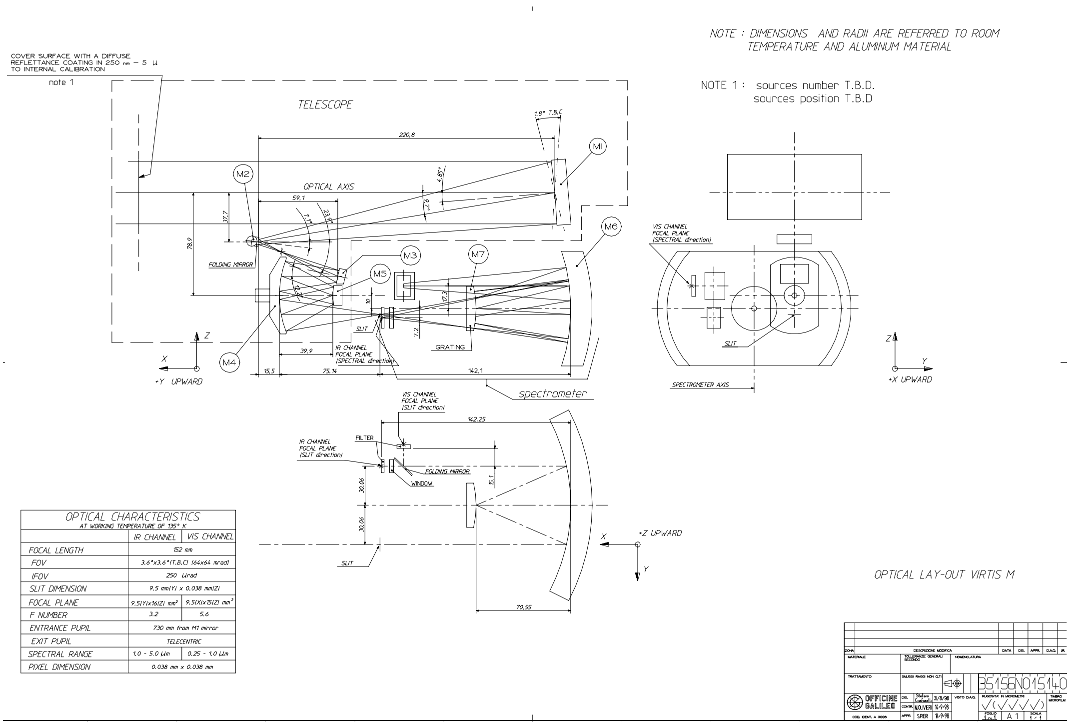
5.2.1. OPTICAL SYSTEMS

There are two unique optical systems housed in the Optics Module: the **-M** imaging spectrometer and the **-H** echelle spectrometer. The
-M optical concept is inherited from the visible channel of the Cassini Visible Infrared Mapping Spectrometer (VIMS-V) developed at Galileo Avionica and launched with Cassini S/C on October 1997. This concept matches a Shafer telescope to an Offner grating spectrometer to disperse a line image across two FPAs. The **-H**, with a quite different function, uses a cross dispersing prism and a flat diffraction grating to lay eight high resolution orders across a FPA. Fig. 5.2.1-1 and Fig. 5.2.1-2 are respectively: the **-M** optical layout and a representation of the **-H** optical system. The reference axes shown in **-M** optical layout are in agreement with the UORF

Tab. 5.2.1-1 lists the optics specifications. The two optical systems compensate for each other in the sense that while -**M** maps the target by creating moderately high resolution spectral images, **-H** performs very high resolution spectroscopy of a selected (and limited) zone of the same target. The spatial correlation between the two instrument FOV, shall be calibrated on ground and verified in flight looking simultaneously at the identical known target.

PARAMETER	VIRTIS-M	VIRTIS-H
Pupil diameter (mm)	47.5	32
Imaging F#	5.6 Vis and 3.2 IR	2.04
Etendue (m^2 sr)	$3.6 \cdot 10^{-11}$ V and $7.5 \cdot 10^{-11}$ IR	$.8 \cdot 10^{-9}$
Slit dimension	38 μm x 9.53mm	29 μm x 89μm
Spectral range (μm)	0.25÷1 (Vis) 0.95÷5 (IR)	2÷5
FOV	64mrad(slit) x 64mrad(scan)	583 μrad x 583 μrad per pixel (x3)
MTF @ (cy/1mrad)	>50%	N.A.
FWHM (LSF ⊗ slit ⊗ pix)	<60μm	<40μm
Spectral Resolution	500	1200 and 3000
In-Field straylight	<5%	<5%
Out of Field straylight	<0.1%	<0.1%
Spectrometer Magnification	1	1.27

Tab. 5.2.1-1 Optics Specifications



	IR CHANNEL	VIS CHANNEL
FOCAL LENGTH	152 mm	
FOV	3.6°x3.6°(T.B.C) (64x64 mrad)	
IFOV	250 µrad	
SLIT DIMENSION	9.5 mm(Y) x 0.038 mm(Z)	
FOCAL PLANE	9.5(Y)x16(Z) mm²	9.5(X)x15(Z) mm²
F NUMBER	3.2	5.6
ENTRANCE PUPIL	730 mm from M1 mirror	
EXIT PUPIL	TELECENTRIC	
SPECTRAL RANGE	1.0 - 5.0 µm	0.25 - 1.0 µm
PIXEL DIMENSION	0.038 mm x 0.038 mm	

Fig. 5.2.1-1 Optical Layout - M

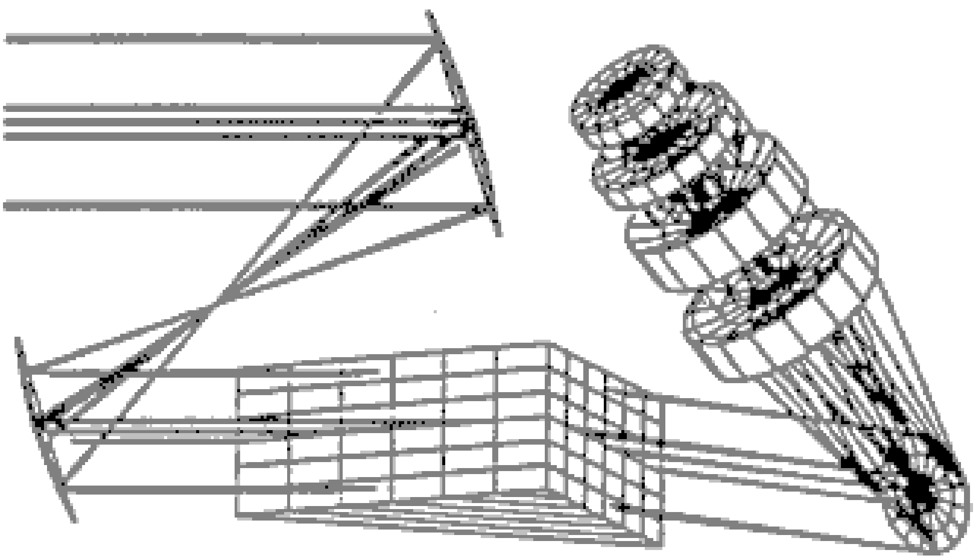


Fig. 5.2.1-2 Optical System - H

VIRTIS-M

Telescope

The Shafer telescope is the combination of an inverted Burch telescope (mirrors M1 and M3, see Fig. 5.2.1-1 Optical Layout - M) and an Offner relay (M4/6 and M5). The Offner relay takes the curved, anastigmatic virtual image of the inverted telescope and makes it flat and real without losing the anastigmatic quality. Coma optical aberration is eliminated by putting the aperture stop on M5 near the center of curvature of the primary mirror and thus making the telescope monocentric. The result is a telescope system that relies only on spherical mirrors yet remains diffraction limited over an appreciable spectrum and all vertical field (slit direction).
The horizontal field is realized rotating the mirror M1 of the Shafer telescope around an axis parallel to the Y direction (see Fig. 5.2.1-1 Optical Layout - M). The optical system is not diffraction limited on the overall field but the optical quality is sufficient.

Spectrometer

The imaging spectrometers of the Cassini (VIMS) and MARS96 (OMEGA-VNIR) missions required separately housed co-aligned instruments to cover the visible and infrared spectra. The VIRTIS-M Offner spectrometer not only does away with redundant optical systems, but also it eliminates the need for collimators, camera objectives, and beam splitters and thereby simplifies fabrication and minimizes volume and mass. However a grating spectrometer that does not rely on a collimator and camera objective require perfect matching with its collecting telescope. Not only they have matching F / #s, but the telescope must be telecentric or have its exit pupil positioned on the grating. This was one of the reasons why the compact Ritchey-Chretien telescope, with its exit pupil behind the secondary mirror, could not be used. The Shafer telescope is matched to the Offner spectrometer because both are telecentric. This means that the entrance pupil is positioned in the front focal length (FFL) of the optical system at 750 mm in front of the primary mirror (M1).
It represents the optics conjugate of the aperture stop (M5) on the object space. The aperture stop is then conjugate to the convex grating M7 and so it can be used as a cold Lyot stop.
The **-M** spectrometer grating does away with the beam splitter by realizing two different groove densities on a single substrate. Because the pupil optics conjugate is on the grating, the same spectral beam splitting is performed for each FOV angle. The grating profiles are holographically recorded into a photoresist and then etched with an ion beam. Using various masks the grating surface can be separated into different zones with different groove densities and different groove depths. The “V” regions, which make up the central 30% of the conjugate pupil area, correspond to the higher groove density needed to generate the higher spectral resolution required in the “visible” channel extending from the ultra-violet to the near infrared. The smaller pupil area allows the visible channel to operate partial coherently and achieve a smaller point spread function. It is now obvious, however, that an on-axis telescope could not be used with this grating concept because the visible portion of the conjugate grating surface would be obscured by the secondary mirror of the telescope.
The infrared channel has a pupil area equal to 70% of the total. Since the infrared channel does not require as high a resolution as the visible channel, it has been decided to accept for this channel a lower MTF caused by the visible zone’s obscuration of the infrared pupil.
In the Tab. 5.2.1-2 the diameter of diffraction spot and the diffraction MTF value at 1 cy/mrad and at the central wavelength of the visible and IR channels are listed.
In the visible channel the diffraction spot diameter is lower than the pixel size, therefore the preponderant contribute to the optical quality are the optical system aberrations. Viceversa, in the infrared channel the optical quality is affected mainly by the diffraction. Furthermore the central obscuration in the IR reduces the diffraction MTF of a further 10%.

	VISIBLE	INFRARED	
l	0.625 mm	3.0 mm	
F#	5.6	3.2	3.2

			with obscuration
f	8 mm	23 mm	
diffraction MTF (1cy/mrad)	0.976	0.928	0.844

Tab. 5.2.1-2 -M Optical Quality

A laminar grating with a rectangular groove profile is used for the visible channel's pupil zone to enable two different groove depths to alter the grating efficiency spectrum and compensate for low solar energy and low CCD quantum efficiency in the ultra-violet and near infrared regions. The resulting efficiency, improves the instrument's dynamic range by increasing the S/N at the extreme wavelengths and preventing saturation in the central wavelengths.
For the infrared zones, a blazed groove profile is used that results in a peak efficiency at 5 μm to compensate for the low signal levels expected at this wavelength.

VIRTIS-H

In the -H the light is collected by an off-axis parabola and then collimated by another off-axis parabola before entering a cross dispersing prism made of Magnesium Oxide. After exiting the prism the light is diffracted by a flat reflection grating which disperses in a direction perpendicular to the prism dispersion. The low groove density grating is the echelle element of the spectrometer and achieves very high spectra resolution by separating orders 6 through 13 across two-dimensional detector array. The spectral resolution varies in each order between 1500 and 2800.
Since the -H is not an imaging channel, it is only required to achieve good optical performance at the zero field position (boresight). This allows the telescope and collimator to operate with arbitrarily short focal lengths for a considerable reduction in volume and mass. A further reduction in volume is made by using the negative diffraction orders and allowing the objective to be folded behind the primary mirror and form a rigid triangular structure.

The focal length of the objective is set by the required IFOV and the number of pixels allowed for summing. While the telescope is F# 1.6, the objective is F# 2.04 and required 3 pixels to be summed in the spatial direction to achieve a 1mrad2 IFOV (.583 mrad x .583 mrad). The four element objective is able to achieve the three pixel spatial dimension and the single pixel spectral dimension with an ellipsoid for surface one (conic constant =.114) followed by five spherical surfaces and a window surface and a flat filter surface before the detector.

5.2.2. OPTICAL FILTERS AND BACKGROUND RADIATION

To minimise the effects of background radiation emitted in the form of photons with wavelengths longer than 4.2 μm, both IRFPAs will be protected by spectral blocking filters with cut-off wavelengths at 5.1 μm. The **-M** also requires to stop the superimposition of higher diffraction orders coming from the grating (VIS and IR channels), by inserting on the optical path, close as much as possible to the focal plane, a dedicated long pass filter for each detector. Filter transmittance characteristic will be optimised for each corresponding detector co-ordinate. To accomplish this task the IR filter shall have five different filter zones while the VIS filter shall have two zones. Each filter zone shall pass only the designed wavelength band corresponding to the spectrometer first diffraction order. In **-M** there is the additional problem of caring for the negative IR orders that fall on the CCD and the positive visible orders that fall on the IRFPA. The CdTe of the IRFPA naturally blocks the visible wavelengths shorter than .8 μm, but the CCD is sensitive to the higher orders of the IR portion of the grating. Fortunately the predicted efficiencies of the higher orders are less than 2% and will not be detectable, otherwise a long pass filter could be put on the IR pupil zone of the grating or on the conjugate zone on the mirror M5 of the telescope. Since the 4.2 μm to 5.1 μm background radiation cannot be filtered within the same spectral band in which the data are collected, the spectrometers must be cooled (to below

135K for the sake of the low signal levels on **-H** and **-M**). For -H using a two segment (1 on order 6 and 1 on order 7-13) can reduce the impact of increase in the spectrometer temperature.

5.2.3. CONTAMINATION AND STRAY LIGHT

VIRTIS deploys covers across the entrance ports to minimize contamination when scientific data is not being gathered. Some deicing/decontamination heaters will be mounted on specific points, established after a thermal analysis, of the two optical heads. They shall be driven by the S/C. Heaters will also be mounted near the FPAs for post-launch outgassing. Other than these measures, the most effective defense is to use smart optical design methods. Off-axis reimaging systems are optimum for stray light suppression because they do not have obscurations that diffract out-of-field stray light into the FOV, and the forward field stop reduce the number of optical surfaces that are illuminated by stray light. The object illuminated by straylight are those situated before the field stop (slit). In -H only the primary mirror is an illuminated optical element; in -M only the primary and M2 are illuminated. Further straylight suppression is obtained in -H by using baffles near the telescope and the detector; a good positioning of those baffles will be obtained by a sharp analysus using LightTools (stray light analysis software). On -M, straylight suppression will be obtained by putting their respective aperature stop and Lyot stop as close to the detector as possible to minimize the number of critical objects that can be seen directly by the detectors.

5.2.4. OPTICAL MOUNTING AND ALIGNMENT

The VIRTIS optical systems will be aligned first at room temperature and then checked at 130 K. An optimised iterative process will be necessary to achieve the final cold alignment; thus, minimisation of the number of adjustments on optical elements is preferential.

In the **-H** the structure and the three reflecting elements are aluminum (the grating might be either aluminium or silicon) and all other elements are glass. The grating requires an angular adjustment during alignment. To perform a good image quality, the slit is adjusted with respect to the collimator; this is perform at room temperature. Lens 3 requires a distance adjustment to perform a good focusing in the centre of the detector, while the FPA block requires an angular adjustment to perform a good focusing at the edges of the detector.

The -M is composed of two modules: Shafer telescope and Offner spectrometer which will be aligned separately and then mounted and coaligned. During the telescope alignment the aperture stop mirror, M5, must be axially adjusted and the folding mirror, M2, must have its axial and angular positions adjusted. These operations will be carried out under interferometric control at ambient temperature.
Because the grating is made of NG5 black glass to improve holographic recording, the spectrometer housing, the visible flat folding mirror in front of the CCD and the relay mirror materials, shall be selected to minimise the defocusing when the spectrometer is cooled. About the spectrometer alignment, it has been decided to avoid any adjustment movement for the two FPAs due to the complex interfaces (thermal, mechanical and electrical) of these two subassemblies. The first step of the alignement procedure shall be the mounting of the two FPAs, verifying, with passive optical system, the relative coalignment also adjusting the folding mirror in front of the CCD. After that the grating and the slit shall be rotated around the Offner axis (parallel to the X axis) until the slit, the grating grooves and both FPAs columns are aligned. These operations shall be carried out at ambient temperature testing the results with the signal collected by the -M CCD.

After having reached a good alignment at room temperature, a calibrated shim between slit and telescope/spectrometer mechanical interface shall be inserted to recover the focusing when the instrument is cooled. This phase shall require an iteration process cooling down the spectrometer module in a TVC chamber and then checking the results with the -M VIS and IR detectors switched on. Then the entire spectrometer structure shall be rotated around an axis passing through slit's center to align the detectors columns with the scan axis.
Finally, the **-H** and **-M** shall be integrated in the Optics Module and shimmed until co-boresighted to within +/- 0.25 mrad (-H is in a fixed reference).

5.2.5. FOCAL PLANE ARRAYS IR DETECTORS

The detectors used in both the high resolution spectrometer (V-H) and in the mapping spectrometer (V-M) are based on a bi-dimensional array of IR sensitive photovoltaic Mercury Cadmium Telluride.

The growth technique for the CdHgTe crystal is vital for high performance FPAs because structural defects in the material result in defective photodiodes. Therefore the preferred material growth technique for producing the best material, in terms of crystalline quality, electrical uniformity and reproducibility, is the Liquid or Molecular Epitaxy Process.

These devices have the potential to operate at a higher temperature than the more established indium antimonide (InSb) detectors due to dark current reduction by a factor of 10 or more.
Survival of temperature cycling, mechanical shock and high temperature storage are other critical aspects to be considered together with manufacturer space programs experience.

The detector is manufactured by Raytheon Infrared operations (Santa Barbara, USA) because the CTIA technology used for the ROIC has not yet been developed in Europe for a very big matrix.
CTIA (Charge Transimpedance Amplifier) technology is the best solution when external low background flux (6x107 to 2x1011 photons/cm-2 • sec.) has to be detected.

The array is formed through hybridization of cadmium mercury telluride material with dedicated silicon CMOS multiplexer.
The device is a MCT - silicon hybrid array of 270(V) x 436(H) 38µm MCT photodiodes with line and column spacing each being 38µm between diode centers, with a spectral wavelength range from 0.95 up to 5µm and an expected operating temperature of 70K.
The device has a flatpack encapsulation, adapted to take a pressure-bonded window and with an internal filter, supplied by Customers, to separate the grating's higher orders and to suppress background radiation.
In Tab. 5.2.5-1 are given the principal characteristics of the IR FPA.

The manufactured and screened devices are intended to be used for:

- operating life of 1 year in flight with 120 cycles from 200K to 65K
- flight storage life of 12 years at about 180K
- ground storage life of 3 years and flight annealing
- ground operating life of 0.5 year with 260 cycles from 310K to 65K under vacuum.

Moreover they shall be able to withstand:

- total ionization dose of 3 Krads(Si)
- latch-up free

The detector shall be packaged into a housing which will include an optical window and will provide suitable mechanical, thermal and electrical interfaces for its integration on both VIRTIS-H and VIRTIS-M Focal Plane Assemblies.
The encapsulation design shall be constituted of a flat pack (ventilated with air filter) with one side exiting I/O electrical pins. The encapsulation shall be sealed with a coated window.

The -H filtering window is used to eliminate/reduce the background thermal radiation due to the higher temperature of the instrument housing.

technology:	MCT, LPE , PV
multiplexer type:	CMOS
sensitive area format:	270(V) x 436(H)
pixel pitch	38 µm
operating temperature	65K to 90K
spectral range:	from 0.95 up to 5 µm

saturation charge capacity	≥ 2 x 10^6 el.
power dissipation	≤ 60 mW
global quantum efficiency with photon flux from 6x10^7 to 2x10^{11} photons cm^{-2} sec^{-1}	≥ 50 % x T_{IF} (1) (2)
cross talk	≤ 3 % (2)
mean dark current @ 70K	≤ 10 x 10^{-15} A
mean dark current @ 90K	≤ 100 x 10^{-15} A (3)
max. dark current @ 70K	≤ 20 x 10^{-15} A
1/f noise coefficient	≤ 4 x 10^{-34} A^2 (2)
dark current relative change per temperature relative change (ΔI/I divided by ΔT/T)	≤ 20
readout noise (rms) for exposure time up to 30 sec	≤ 0.2 x sqrt[satur. charge] el.
non-linearity wrt time from 10% to 90% of full well capacity without calibration	≤ ± 2 %
number of defective pixel	≤ 4 %
weight	≤ 50 grms
settling time @ 0.01%	≤ 5 µsec
output impedance	≤ 500 Ohms
outputs	1
readout mode	snapshot
surface flatness (pic - valley)	≤ 20 µm

(1) T_{IF} is the internal filter optical transmission
(2) this requirement will be not tested, but guaranteed by analysis
(3) goal

Tab. 5.2.5-1 IRFPA Specifications

Its transmittance characteristics are optimized for each corresponding detector position so that for each filter zone shall pass only the designed wavelength range.
The -H filtering window, to be included inside the detector package, will be supplied by O. de Paris to the Manufacturer.
The filtering window is covered with Anti-Reflection coating optimized in the 2 to 5 µm region. Two segment filters are coated in the window with the following passbands:

- 1st region: 2.0 to 4.34 µm (TBC)
- 2rd region: 4.0 to 5.0 µm (TBC)

Opaque metal mask deposited on the filter's top surface defines the filter aperture. This mask covers also the junctions (dead zone) between adjacent filter segments with a separation of 60 µm (TBC).

The -M filtering window is used to stop the superimposition of higher diffraction orders coming from the grating and also to eliminate/reduce the background thermal radiation due to the higher temperature of the instrument housing.
Its transmittance characteristics are optimized for each corresponding detector position so that for each filter zone shall pass only the designed wavelength range corresponding to the spectrometer first diffraction order.
The -M filtering window, to be included inside the detector package, will be supplied by Galileo Avionica to the Manufacturer.
The filtering window is covered with Anti-Reflection coating optimized in the 1 to 5.1 µm region. Five segment filters are coated in the window with the following passbands:

- 1st region: 0.9 to 1.6 µm
- 2nd region: 1.2 to 2.5 µm
- 3rd region: 2.4 to 3.75 µm
- 4th region: 3.6 to 4.4 µm

- 5th region: 4.3 to 5.0 μm

Opaque metal mask deposited on the filter's top surface defines the filter aperture. This mask covers also the junctions (dead zone) between adjacent filter segments with a separation of 300 μm (TBC).

Each device shall be delivered with an attached ribbon cable.

The overall detector organization is shown in Fig. 5.2.5-1.
The detector includes the following main functions:

- an array of at least 270 lines of 436 photosensitive pixels
- two column and 270 rows of insensitive pixels

one output stage for charge conversion to deliver an electrical output signal.

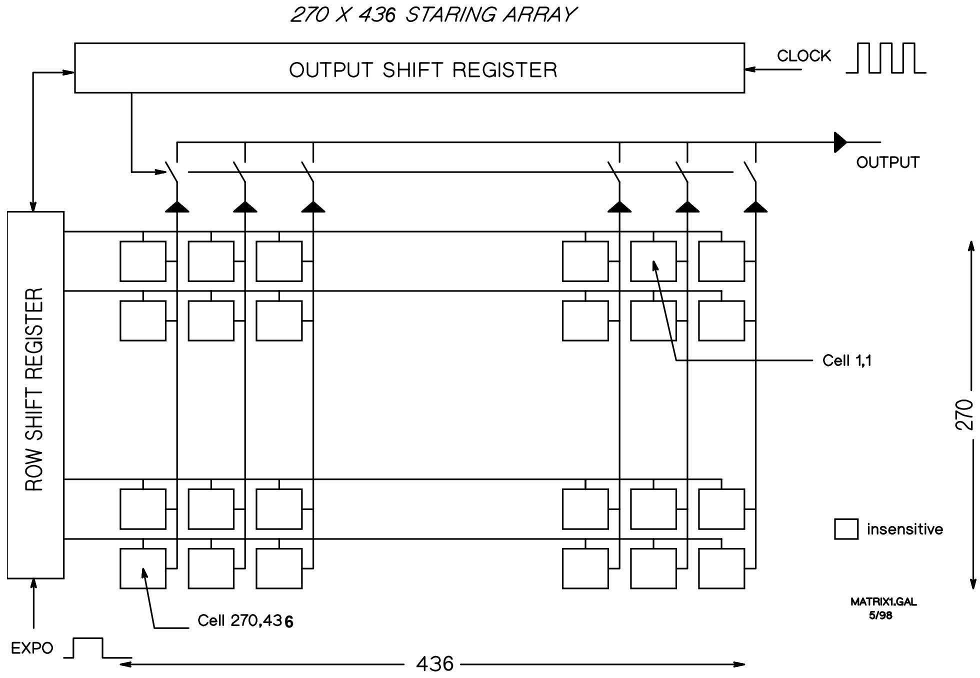


Fig. 5.2.5-1 IRFPA detector organization

The input cell, used to convert the photo-generated current into an output voltage, is based on the Capacitive Trans-Impedance Amplifier (CTIA), or reset Miller integrator. The signal from the CTIA goes to the Correlated Double Sampling (CDS) circuit, whose function is to provide rejection of 1/f type low frequency noise. The CDS capacitor samples the signal at the start and again at the end of the integration, providing a difference signal that subtracts out any slowly varying noise.
Then the signal is sampled by a dedicated capacitor that provides storage of the photo-generated signal so that the previous scene can be output while the current scene is being integrated, in snapshot mode. The column buffer provides isolation of the sample and hold circuitry from the output bus, and it is composed of a linear, stable, differential input, output buffer amplifier.
The output buffer provides isolation of the bus from the output load as well as the necessary drive capability to slew fast enough the required cable load, and it is composed of a differential input, linear, stable and output differential buffer amplifier.

Surface mounting capacitors shall be mounted in the Sensor Chip Assembly (SCA) on the power supply lines for bypass filtering and noise suppression.
One temperature transducer based on silicon temperature sensing diode shall be located in the SCA.

5.2.6. FOCAL PLANE ARRAYS: VISIBLE DETECTOR

The visible FPA is based on the Thomson-CSF type TH7896 CCD detector. It uses a buried channel design and two poly-silicon N-MOS technology to achieve good electro-optical performance. Moreover it includes a Multi Pinned Phase (MPP) boron implant to operate fully inverted and substantially to decrease the surface dark current, residual images after strong exposure and other effects due to ionising radiation.
The TH7896M is a full frame image sensor with 1024x1024 sensitive elements, two registers and four outputs, but it will be used as a frame transfer device shielding half sensitive area that will work as memory section. Only one horizontal register and one output will be used.

The specifications of the visible FPA are reported in the following table:

M - VISFPA	
technology	4 phases, buried channel, MPP front-side illuminated
architecture	frame transfer
useful sensitive area format:	508(V) x 1024(H)
pixel pitch	19 µm
operating temperature	150K to 190K
spectral range:	from 250 up to 1050 nm
vertical saturation charge capacity	$\geq 0.4 \times 10^6$ el.
horizontal saturation charge capacity	$\geq 0.8 \times 10^6$ el.
conversion ratio	from 1 to 1.5 µV/el.
2 x 2 summing full well output swing	≥ 1.6 V
power dissipation [with a load resistor ≥2KΩ]	≤ 100 mW
residual image after strong exposure	no by design
global charge transfer efficiency	≥ 97 %
fill factor	≥ 90 %
mean dark signal rate DSR per pixel	≤ 1 el. s^{-1}
responsivity @ 700 nm	≥ 2.7 V μJ^{-1} cm^{-2}
photo response non-uniformity (pk-pk) excluding defective pixels (PRNU)	≤ ± 6%
readout noise (rms)	≤ 15 el.
non-linearity wrt time from 5 to 400 mV of output voltage swing without calibration	≤ ± 2 %
non-linearity wrt time from 0.4 to 1.6 Volts of output voltage swing without calibration	≤ ± 4 %
number of defective pixel with DSR > 1 el./sec per pixel and/or PRNU < -6 %	≤ 3 %
weight	≤ 15 grms
settling time @ 0.01%	≤ 300 nsec
output impedance	≤ 1500 Ohms
outputs	1
surface flatness (pic - valley)	≤ 20 µm

Tab. 5.2.6-1 VIS FPA Specifications

To obtain a sensitivity till 250nm the device is coated with UV-coating on columns 1 through 300 (± 25 columns). The UV coating emits light at approximately 540 to 580 nm when excited with light of wavelengths shorter than 450 nm and it is transparent in the visible and near IR, not significantly influencing quantum efficiency performance in this portion of the spectrum.

In order to generate the scientific correct information (to meet the IFOV = 250urad requirement and to have the same pixel size in the IR and visible detectors), a 2x2 binning is implemented at detector level.
This approach permits to achieve the required pixel size with a less expensive solution (38μm pixel size is feasible but with custom based design).

Effects on charge transfer efficiency (CTE) due to radiation induced dark current spikes and residual bulk image are minimised when operating at very low temperatures. Proton interactions with the silicon lattice produce deep-level traps that begin to freeze-out at a temperature of 200 K and become inactive at 160 K. In fact once filled with electrons these traps remain filled due to the long emission time constant involved. The challenge is then to keep the CCD temperature as close as possible to the cold box (135 K) but preventing degradation of the charge transfer efficiency due to buried channel freeze-out and bulk traps characteristics. Dedicated tests will be executed to determine the operative temperature, clock overlaps, clock rate, charge pocket size and silicon quality to fulfil vertical and horizontal CTE requirement.

An agreement on the CCD procurement contract has been reached and test and delivery dates are in accordance with the VIRTIS project schedule:

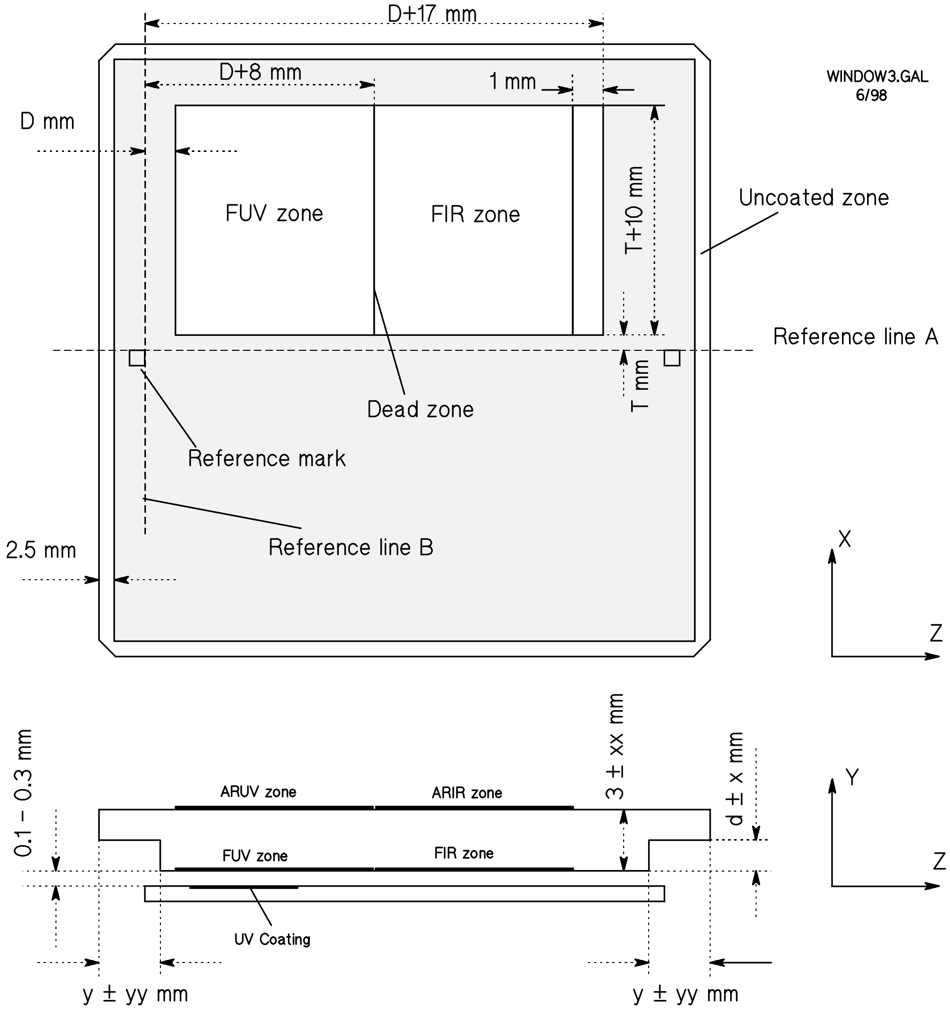


Fig. 5.2.6-1 CCD front side view

5.2.7. CALIBRATION SHUTTERS

Since the CCD is a frame transfer device, and the IRFPAs are direct injection devices, exposure times can be controlled electronically. However, measurement of the detector dark current plus background radiation requires calibration shutters to be placed at the entrance light limiting slit of each spectrometer (telescope background contribution is negligible because of its low temperature and the narrow width of the slit). Ideally the shutter would be cooled to a temperature lower than the spectrometer temperature to eliminate the thermal contribution of the blade. However, this would increase the thermal load on the active coolers so the shutters will be at the same temperature as the optical system (fortunately this is 30 K lower than the expected cold comet temperature). To minimize the shutters' background contribution, the blade will be on the telescope side of the spectrometer entrance slit to minimize the viewing area of blade. The baseline shutter is the one being used on the descent imager-spectral radiometer on the Titan Huygens probe. The shaft is mounted on TiC coated ball bearings, which are considered critical items, but no failures have been reported during the DISR enviromental and life test.

5.2.8. THERMOMECHANICAL ARCHITECTURE

The following figure is a representation of the VIRTIS Optics Module.

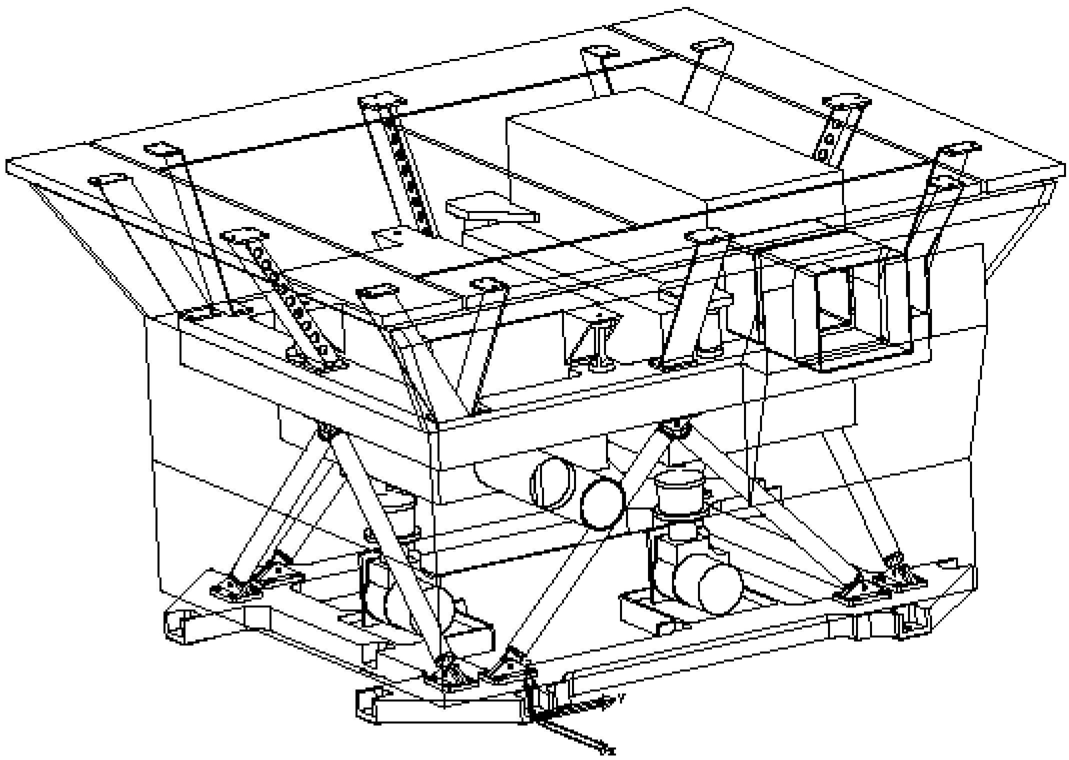


Fig. 5.2.8-1 VIRTIS Optics Module

The OM main functions are to provide a mechanical support for the -M and -H optical subsystems, while maintaining them at an operative temperature of 130 K, and the two IR focal planes at a temperature of 70 K. For these purposes, the OM is divided in two principal functional parts: a warm enclosure and a cold enclosure

(in the following simply named as cold box).
The warm enclosure includes the OM baseplate, the Inter-Unit Harness brackets, the Active Cooling Subsystem (a pair of cryocoolers, one for -M and one for -H) and the structural truss which thermally insulates the upper cold box from the baseplate.
The cold box includes the two optical subsystems -M and -H, mounted on a cold ledge which supports also the covers mechanisms, the two baffles and the Passive Cooling hardware.
The -M and -H are coaligned and boresighted to the positive +Xv direction of the Optics Module.
The mechanical interface with the S/C is the OM baseplate via eight mounting feet plus four screws to increase the thermal dissipation from the two cryocoolers to the S/C. The eight mounting feet are positioned on the baseplate external perimeter (two per side), while the other four additional fixations are positioned inside the baseplate perimeter, close to the cryocoolers. In this way, most of the power generated on the baseplate is conductively dissipated to the S/C.
The cryocoolers cold-tips are conductively connected to the -M and -H IR detectors by means of flexible thermal straps.
The Passive Cooling, necessary to keep the -H and -M temperature at 130 K, consists of a primary radiator, conductively connected to the ledge, and two secondary radiators, one for -M and one for -H.
The three radiators are placed on the OM +Z face, looking at the cold space; their overall envelope is 590x650 mm2.
The primary radiator purpose is to refrigerate the ledge to a temperature slightly higher than the instruments temperature, by dissipating the heat coming from the truss and from part of the internal cabling.
The secondary radiators are each mounted directly on top of the -M and -H instruments.
The cold box and the warm enclosure are externally covered with MLI. An MLI blanket is used also to separate, from radiative point of view, the cold box from the warm enclosure.
The low conductive heat load between cold and warm enclosures is achieved by mounting the cold box on eight Titanium hollow struts, whose number and attachment positions are selected to avoid distortion upon cooling from room temperature. All of the struts will be blanketed with MLI, to reduce the thermal load and avoid differential heating of the cold ledge.
The two optical benches -M and -H are each attached to the cold ledge by means of three points mounts. The heat flow through the cold box is small enough that the optical subsystems -M and -H are mounted inside an essentially isothermal cavity. To help maintain this isothermal cavity, the covers and actuators for the entrance ports of -M and -H are placed inside the cold box, between the optical subsystems and the external MLI blanket.

5.2.9. FOCAL PLANE COOLING

To reduce the dark current, the two IRFPAs M and H, shall be cooled to 70K. Preliminary system analisys rejected passive cooling due to the very large radiator area required (more than 1m2) and for the risk of contamination during the comet mapping phase. So, a solution with an active cooling system, consisting in a pair of Stirling cryocoolers (one for each IRFPAs), has been preferred. Each cryocooler is driven by dedicated electronics, powered by the spacecraft main power bus.

The cryocoolers are mounted on the VIRTIS baseplate by means of brackets, which provide a good conductive link, and they are thermally shielded by an MLI cover. Moreover, the cooler compressor is directly thermally connected to the baseplate by thermal straps.
The coolers cold tips are linked to the IRFPAs by high conductance thermal straps.
The cryocooler electronic drivers are placed into the Main Electronics.
They can drive the cryocoolers compressors in two different ways:

- closed loop, with a temperature feedback from sensors placed on the cryocoolers cold end
- open loop, driving the cryocooler with predefined values of speed (rpm), as a backup solution or to get specific cooling performance.

The main performance required to the Active Cooling Subsystem are:

- cooling power (max): 160mW (-H); 220mW (-M) at 65K (cooler cold tip)
- temperature stability: 1,5 K in a period of 1 minute

- operating temperature: -20°C - +50°C
- non operating temperature: -30°C - +60°C
- operating life: 2000 hours
- electrical power (steady state): 22W (both cryos working)
- electrical power (cooldown): 27W (both cryos working)
- For what concern VIRTIS-M, the task of maintaining the IR detector at 70K, with the spectrometer and telescope at 130K, is even more difficult due to the very short separation from the VIS detector, which must be kept at 155K. With only a few millimeters separation and 85 degrees thermal difference between the two active areas (VIS and IR), a special design will be needed for the FPA's structures.
- Each of the two FPA's has to guarantee a very good thermal insulation, together with the required stiffness and dimensional stability.
- The present design architecture adopted for the FPA's is described in sect. 2.2.1.1. of the VIRTIS-Rosetta EID-B.

5.3. MAIN ELECTRONICS DESCRIPTION

The Main Electronics (ME) which is housed in the ME box will be physically separated from the Optics Module (OM) and the Proximity Electronic Modules (PEM's).

The Main Electronics (shown in Fig. 5.2.9-1) consists of two DPUs, including the S/C interface electronics and the related power supply units, the power supply for VIRTIS-M/H, the VIRTIS-M/H interface electronics (M/H-IFE) including the respective Cooler Controller Electronics (CCE) and Cover and cooler Switching Electronics (CSE) and the M/H reference clock generator (MCLK/RCLK).

The DPUs, S/C interfaces, VIRTIS-M/H interfaces are also called DHSU (Data Handling and Support Unit).

Because of the central control and support function of the ME/DHSU in the VIRTIS instrument a very high reliability is required for the operation of the DPU and the power supply unit. Therefore, there are a cold redundant DPU including the respective redundant power supply unit and redundant common clock generators. Each power supply unit supplies the representative DPU.

To power the VIRTIS-M/H sub-systems one power supply unit is implemented which is not redundant due to the logical redundancy of the two channels VIRTIS-M and -H.

If the main DPU or main power supply unit (main channel) fails the redundant channel (red. DPU and power supply unit) can be switched on by the S/C redundant power interface.

The cross-strapping between the two VIRTIS-M and -H sub-systems and the main or redundant channel (power supply and DPU) is implemented in the ME M-IFE H-IFE. An additional cross strapping is implemented to provide the +28V input power for the VIRTIS-M/H power converter.

The VIRTIS-M/H interface electronics (M/H-IFE) are supplied by the main or redundant DPU power. The resulting power is distributed by respective switches in order to turn-on or -off the VIRTIS-M/H IFE separately.

The VIRTIS sub-systems (VIRTIS-M, -H, coolers and covers) are switched on/off by means of TCs and controlled by the DHSU. Only the VIRTIS-M/H decontamination heaters are switched directly by additional S/C power lines.
For controlling the two coolers (located inside the OM) two electrically independent CCE's are located in the ME box which can be switched on or off by the respective +28V (Cover and Cooler Switching Electronics CSE) and controlled by the DPU via the
M/H-IFE.

The DHSU provides the platform for the data processing/handling and the instrument control functions, which are performed by software. The main tasks of the DHSU are:

- Acquisition, pre-processing, compression and formatting of the science and calibration data of VIRTIS-M and -H sub-system
- Control and power switching of VIRTIS-M, -H (including the electromechanical devices, the scan mirror for -M and shutters), the coolers and covers
- Health check of the instrument and providing the operational status of VIRTIS to the S/C
- Execution of up- and down link activities to and from VIRTIS
- Interpretation, execution and acknowledgement of telecommands
- Management and synchronization of activities between VIRTIS and the S/C

The data processing and the data handling activities by the DHSU will be performed on-line. The data will be processed and transferred to the spacecraft in real time. The Solid State Mass Memory (SSMM) of the S/C will be used to store or buffer a large data volume. All data processing activities including the data compression will be performed by software.

The DHSU communicates to the VIRTIS-M, VIRTIS-H and S/C via serial interfaces and a ME common bus, which is separated from the local bus of the DPU.

Each DPU has a high speed data interface to the SSMM, a low speed data interface (TM I/F) and low speed command interface (TC I/F) to the RTU.

All interfaces are handled by interrupt, in order to decouple the asynchronous processes between the DPU and the interfaces and to put the DPU in a power down mode while no operation.

The data processing and handling activities are sub-slice-oriented (sub-slice: e.g. 64 pixel x 144 or 64 x 72 spectrels). The sixteen-bit organized data from VIRTIS-M and -H are transferred via serial interfaces, FIFO buffer and common bus into the local data memory of the DHSU. This data acquisition process is performed in the background, while the processor completes the processing of data from previous exposures. The DPU performs the data processing, including data compression and TM packing. The steps and the kind of data processing and instrument control are defined by special operation modes selected by telecommands.

After processing and compression, the scientific and HK data are formatted and transferred to the FIFO buffer of the S/C data interface. The interface hardware controls the transfer of the serial blocked data to the S/C (SSMM or RTU).

The DHSU also controls and monitors the status of the different subsystems, including the DHSU itself. The operational HK are periodically acquired and transferred via S/C Slow Speed telemetry interface.

Based on the data handling requirements, a low power and radiation hardened Digital Signal Processor (DSP, TCS 21020) is used for the DPU with a computing power of about 20 MIPS.

In general all I/O-Ports, the program and data memory as well as the registers are mapped into memory address space (Memory bank select PMSx and DMSx) of the DSP. The controlling of the instrument will be performed by writes and reads of the respective registers or memory areas. All memory areas are defined in the software architecture file as separate segments.

The DPU memory is divided into three sections, the program code memory, the program data memory and the image data memory. The program memory consists of the PROMs, EEPROMs and the SRAMs. The program code for execution of the Safe Mode is stored in the radiation hardened PROM and will be downloaded by primary boot after power-on to the fast and low power program SRAM, radiation hardened too.

The EEPROM stores the main part of the application S/W and parameters. The EEPROM content as well as the PM RAM content can be up-loaded by TC and down-loaded by sending of TM-packets. The validity of the EEPROM content is verifiable by checksum which will be read before secondary boot. The checksum together with other status data are stored three times in physical independent configuration areas of the EEPROM.

An image data memory will be used to store the raw science data and the intermediate products.

The architecture of the DPU will have a watch-dog to detect program lock-ups and endless loops.

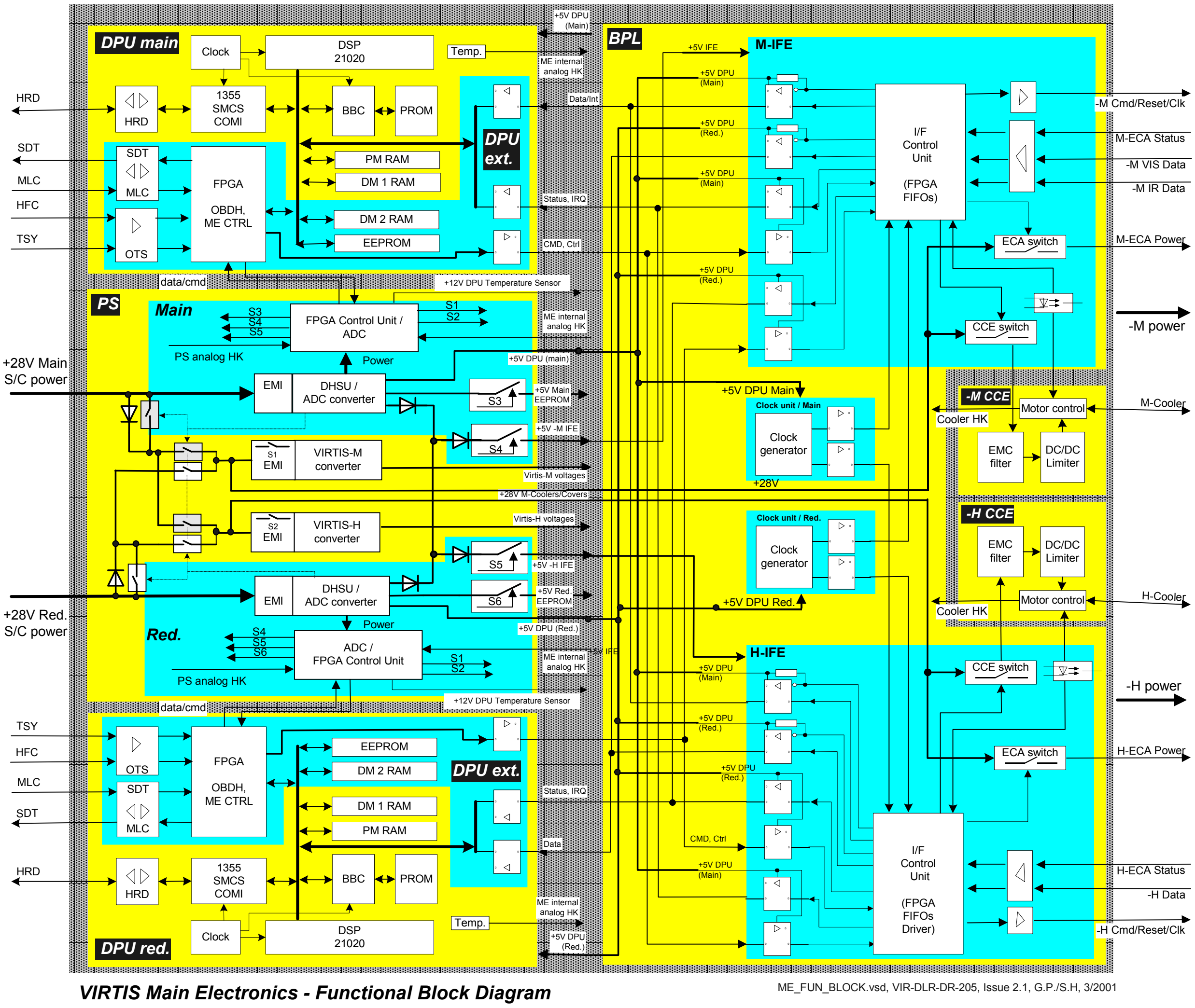


Fig. 5.2.9-1 Main Electronics functional block diagram

5.4. PROXIMITY ELECTRONICS MODULE: PEM-M

The PEM-M, housed into the S/C, contains all the electronics needed to interface the Main Electronics, to drive the FPAs, the scan mirror and the cover mechanism and to perform the acquisition and conversion of the science and housekeeping data.
The electronics package is constituted by a mother board and four daughter boards (eurocard format) of which two are committed to the visible channel, one to the IR channel and one to the scan and cover control units.

The following figure shows the PEM-M block diagram together with the Optical Head:

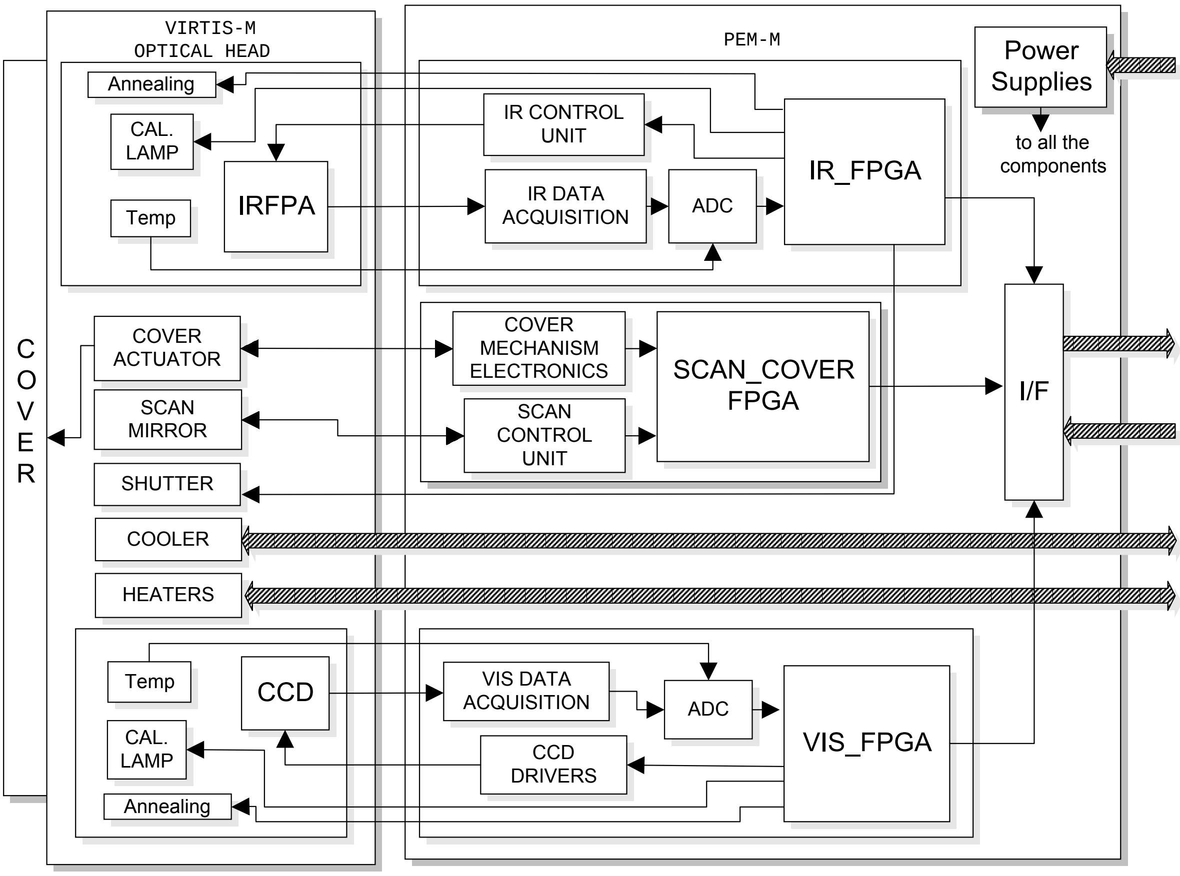


Fig. 5.2.9-1 Virtis-M Block Diagram

The interface circuits with the Main Electronics are located on the mother board and are implemented with monodirectional balanced interfaces.

The visible channel is constituted by four main blocks:

- the data acquisition
- the analog to digital converter
- the CCD bias and drivers
- the FPGA

The data acquisition block is based on a low noise amplifier chain containing a Correlated Doubling Sample circuit to eliminate every uncertainty caused by the reset noise.
The ADC (SEI 7805ALPRP) ensures a 16 bit resolution with a 10us conversion time.

The CCD phase drivers translate the patterns generated by a dedicated ASIC to MOS levels in order to drive corretly the large capacitive loads of the CCD rows and columns with low power consumption.
The main function of the FPGA (ACTEL RT14100) is to initialize the timing generator ASIC, to perform the ME command interpreter, the data transmission, the calibration source and annealing heaters control.

From a functionally point of view the IR channel is very similar to the visible one. Actually the IRFPA control unit and aquisition chain are simpler and therefore all the electronics is placed in one board. Moreover the IR FPGA (ACTEL RT14100) is also dedicated to control the shutter mechanism.

The acquisition, conversion and transmission of the VIRTIS-M housekeeping data (temperature, voltage and current measuraments) is divided between the visible and IR channel.

The scan unit board performs accurate positioning of the primary mirror at the commanded angle. The scanning movement is done step by step. Each step moves a new portion of the field of view of the interferometer slit.
The control is accomplished using a two phases DC brushless motor to provide the necessary torque: the current flowing in the stator windings produces a torque at the permanent magnet rotor.
The position transducer is an inductosyn allowing 10 arcseconds of accuracy: it is essentially a variable-coupling transformer the magnitude of which varies according to the position of the rotating element.
The Control Logic interface is based on an FPGA (ACTEL RT14100) receiving scan unit commands via sincronous serial link and calculating the position error.

This FPGA contains also the cover mechanism control logic. The cover is actuated by a stepper motor. The end positions (open and closed) are computed step by step starting from a mechanical reference (end-stop). In addition, two Hall Efect Sensors (HES) are used to monitor the position reached by the cover after opening or closing command. The Cover Mechanism Electronics includes two drivers for the windings of the stepper motor and the front end for the two HESs. Two different supply lines permit to close or open the cover, then power-off the motor and continue to monitor the cover position by the HES outputs.

5.5. PROXIMITY ELECTRONICS MODULE: PEM-H

The VIRTIS-H PEM is constituted of the following functions (cf. Fig. 5.2.9-1, HPE_BLK8.VSD):

- The Video Amplification & Filtering amplifies and filtrates the video signal and sends it to the A/D Conversion.
- The Analog Housekeeping Handling processes the Analog Housekeeping (HK)housekeeping signals (temperatures, voltages and currents), multiplexes and sends them to the A/D Conversion.
- The A/D Conversion multiplexes the analog signals (Video & HK) and converts them into 16 bits serial data.
- The PEM Controller (FPGA) handles the DHSU commands, the PEM and detector control signals, the PEM and detector clocks, the I/Os, etc. It is implemented in a FPGA. It comprises the following subfunctions:
- The Command Interpreter translates the DHSU commands into PEM commands for all the other functions.
- The PEM Parameters Memory stores the current PEM configuration parameters. Some of these (command bits) are sent directly to the other functions by the PEM Parameters Memory.
- The Detector & ADC Controller generates the detector clocks and synchronizes accordingly the detector acquisitions by the ADC. The acquisitions are controlled by the Pixel Map.
- The Output Data Formatting handles the Science and analog HK Data (generated by the ADC) and the digital HK data (assigned values and status), formats them and generates the Data Blocks.
- The Detector Biases includes four detector bias sources controlled by 4 DACs.
- The Pixel Map contains the image of the detector pixels and is used to control the pixels acquisition (only the illuminated pixels are converted). It is written into by the Command Interpreter, controls the Detector & ADC Controller and can be read by the Output Data Formatting.

- The Calibration Lamps Controller powers the 3 calibration lamps by means of 3 programmable current sources (3 DAC channels).
- The Shutter Controller controls the shutter closing by means of a programmable current source (1 DAC channel), allowing to set the closing angle.
- The Cover Controller (CME) controls the cover device and handles the cover status data. This is an additional function developed by G.A. is very simple since it requires only one transistor and a few passive components.
- The DHSU Interface handles the commands and data exchanges with the DHSU: unidirectional control signals and serial synchronous data (RS422), PEM synchronization clock at 8 MHz and Reset control signal.

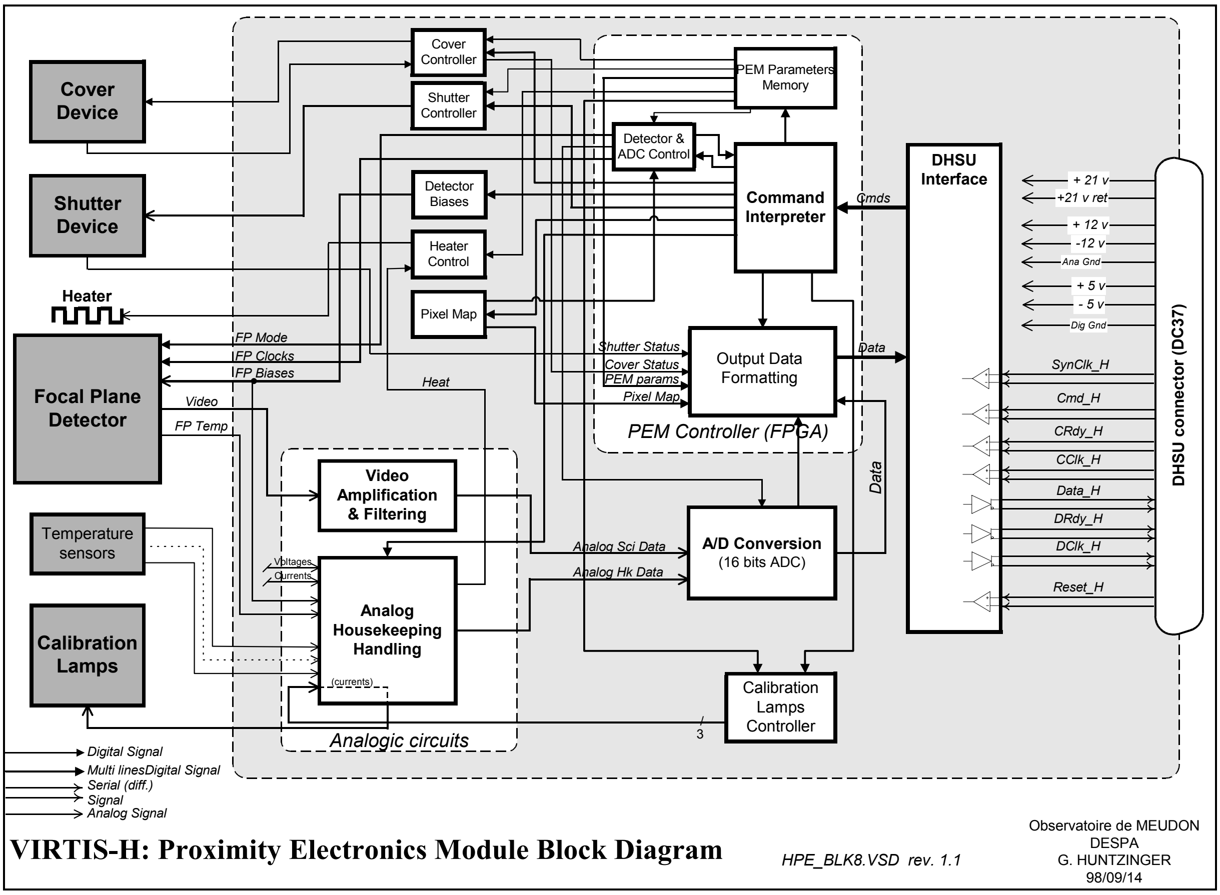


Fig. 5.2.9-1 PEM-H Block Diagram

6. SOFTWARE DESCRIPTION

6.1. PROXIMITY ELECTRONIC SOFTWARE

The electronics needed to drive the detectors and digitize the data are on the two proximity electronics modules housed inside the S/C.

Both -H and -M electronics are designed around FPGA based sequences.
The operational modes setup and in general the control of the acquisition will be driven by the DHSU on-board software. Therefore no software is needed inside the PEMs.

6.2. DHSU SOFTWARE DESCRIPTION

6.2.1. SOFTWARE FUNCTION

The main purposes of the VIRTIS software are the control of the VIRTIS instrument, specifically of the two VIRTIS sub-systems (VIRTIS-H and VIRTIS-M) and the handling of the scientific data. The software system manages the Mapping spectrometer sub-system including the visible and infrared detector units and in-flight calibration devices (VIRTIS-M), the spectral high resolution spectrometer sub-system (VIRTIS-H) including the infrared detector unit, the active cooling sub-system (-M and -H COOLERs) and -M and -H COVERS. In addition, some ME internals (e.g. non volatile memory) or external test facilities are managed.
The main **software tasks** are:

- Receipt, decode and process TC packets from the spacecraft,
- Execution of telecommand and telemetry Packet Services,
- Low power command and management of the VIRTIS sub-systems (Proximity Electronics Modules, Covers, Coolers) according to the received telecommands,
- According to the commanded mode, perform pixel summing, composition, decomposition and data compression of Science Data coming from the 3 data channels,
- Packing of Science data and sending of Science telemetry packets via the High Speed Link,
- Collection housekeeping data to prepare and send housekeeping telemetry packets,
- Performing in-flight software maintenance (memory up- and down-load) and health check activities.
- Providing of system status information for verification purposes

6.2.1.1. INSTRUMENT CONTROL

The software has to manage a lot of instrument modes. If a severe system or a sub-system malfunction is detected, VIRTIS goes in the **Safe mode** where all sub-systems are switched off and a reduced set of functions (e.g. memory up- and download) can be initiated by telecommand.
In order to reduce the produced scientific data volume, different specific VIRTIS-M and -H ***Science modes*** are implemented. These are characterised by varying the spectral and/or spatial resolution and by selecting specific spectral ranges, which are achieved by e.g. pixel summing and slice summing. In addition, a composition of science data to slices (spatial line with spectral resolution), a decomposition to sub-slices and a lossless or a lossy data compression lead to data reductions by a factor 2 ... 12. All options together allow a higher reduction of the data volume. Several internal operational sequences have to be managed on -M and -H sub-system level for e.g. on-board calibration purposes.
A summary of the main **instrument control functions** are the following:

- Verification and consistency check of telecommands
- Managing the start-up procedure after power-on

- Initiating and overall control of the instrument modes
- Health checking, diagnostics and event handling including watch-dog control
- Management/storage/maintenance of system parameter configuration and system status
- Initialising of sub-system (e.g. parameter, pixel map upload)
- Control of Visible and IR detector units, calibration sources, shutters, annealing heaters
- Movement and status control of covers by controlling the stepper motors and Emergency cover actuators
- Commanding and mode control of active cooling sub-systems
- Request, acquisition and verification of science data and housekeeping
- Calculation and management of pixel map for -H selective pixel read-out
- Performing and managing of operation sequences
- Management of power and telemetry resource

6.2.1.2. DATE HANDLING

On-board data compression for VIRTIS is important for maximizing the science return of VIRTIS. Both reversible and lossy compression algorithms are implemented. The reversible algorithm is derived from that developed for the OMEGA and VIMS imaging spectrometers. It takes advantage of spatial / spectral correlations for pre-processing, then a Rice coding is applied on the residuals. It will mainly be used for validation purposes early in the mission and it provides typical compression ratios of 2 to 3 depending on the entropy content of the data.
The lossy algorithm is based on wavelet transforms. There is a specific compression mode for coma observations by VIRTIS-H, which implements very long observation times (up to 1 hour). In this case, a one dimension wavelet transform is applied, followed by coefficients entropy coding. This provides a minimum compression ratio of 4 within the acceptable distortion limits.
The nominal compression strategy is based on wavelet transforms of spectral / spatial rectangles of data, which are obtained either directly from the VIRTIS-M detectors or by accumulating time series of VIRTIS-H spectra. These rectangles are divided in sub-units of typically 64 pixels x 144 spectrals, hence 4 steps of transform in each direction. Each sub-unit provides a self-consistent telemetry stream, so that an SEU can only result in the loss of a small fraction of the data. The result of the transform is coded using a version of the Said-Perlman tree coding algorithm which has been optimized for speed on a TSC21020E. The processing power obtained with the breadboard is 500 k data per second, which is adequate for VIRTIS. With this algorithm, the compression ratio can easily be modified as a TC parameter. Tests on AVIRIS, ISM and VIMS data show that compression ratios of 8 to 12 provide distortion levels of less than 2 DN.

6.2.2. SOFTWARE DESIGN

6.2.2.1. GENERAL

From the design point of view, the software is divided in two parts, the PROM software and the EEPROM software. The PROM software (also called Primary Boot software) is active after VIRTIS ME power-on. The EEPROM software (also called Secondary Boot software) is started by the user after a special TC, given in Safe mode (i.e. VTC_Enter_Idle_Mode).

The PROM software is hard coded in the Main Electronics/DPU and the EEPROM software is stored in EEPROM and is changeable by memory upload (memory management service).
The PROM software is written in Assembler, has a size of about 5000 48bit instructions and consists of about 50 modules.

After Primary Boot the PROM software runs always in Program Memory (PM) for safety reasons. Primary Boot is performed by the DPU Board and Boot Controller (BBC) after +28V power-on. The PM has a very good Single Event Upset (SEU) performance (almost SEU free) while the Data Memory (DM) is SEU sensitive. Therewith a safe behaviour of all PROM software functions can be assumed.

The EEPROM software is stored in EEPROM as PM and DM segments with segment checksum for verification during upload and start (i.e. Secondary Boot from EEPROM in RAM). It runs in PM and DM RAM.

The EEPROM software is mainly written in C with low level functions in Assembler for speed and code optimization. The Real Time Operating System (RTOS) VIRTUOSO is used and about 60 (EQM status) processes can be active simultaneously.

The size of FM code will be about 100K Instructions (100kx48bit) including code and parameter, the EEPROM can store 170K Instructions as maximum and up to 8 different executables.

PROM software (primary boot) function

The PROM software provides low level functionality and is the 'BIOS' of VIRTIS with the following functions:
- Initialization of the ME DPU and ME Power Supply (PS) after power-on
- Power-up and reset management, timer synchronization
- Entering the Safe mode (default for VIRTIS operation) or Development mode (only for EEPROM S/W development purposes)
- Collection and providing VIRTIS Default HK
- Low level TC verification, acceptance and execution
- TM packing, buffering and transfer to S/C
- ME DPU Memory Management
- Health check and error/event handling
- Test display control

Note: In Safe mode (or with PROM software) it is never possible for the user to have access to the –M and –H sub-system, to transfer science data or the initialize the high speed IEEE1355 interface. These functions are only possible by secondary boot software.

EEPROM software (secondary boot) function

The EEPROM software provides partially the same functionality (e.g. TC/TM interface handling) as the PROM software and additionally all VIRTIS-M and -H control functions. These are:
- Initialization of the ME M- and/or H-Interface Electronics as well as the –M and –H sub-system after power-on
- Low level and high level TC verification, acceptance and execution
- TM packing, buffering and transfer to S/C
- Timer re-synchronization
- Collection and providing of VIRTIS Default, General and PEM science HK
- Interfacing the M-PEM and H-PEM
- Control and monitoring of control and science sequences
- Entering the ME IDLE mode, instrument control modes and Science modes
- Science data acquisition, TM packing and transfer to the S/C via 1355 HS link
- Science data processing and compression (not in this EQM software version)
- Health check and error/event handling
- Test display control (only for on-ground verification)

6.2.2.2. SAFETY

The software for Safe Mode is stored in the radiation-hard PROM and executed after primary boot by the BBC hardware only in the PM RAM which is radiation-hard too and has a low SEU sensitivity.

The PROM software contains all functionality for the safe operation of the instrument, especially for:

- Execution of a small TC list (timer synchronisation, memory up- and download, failure override and "Enter IDLE" TC)
- Health check including acquisition of a small list of timer triggered HK and TM packet transmission
- Performing of the secondary boot either from EEPROM or from S/C to RAM
- Starting of the ME IDLE mode

Before executing of the secondary boot from EEPROM a check of EEPROM content will be performed by using of the stored checksums.

Severe errors detected by the instrument control software leads to entering of the Safe Mode.

Error/event handling can be avoided by a special "failure override" TC

6.2.2.3. RELIABILITY

There is a watch-dog implemented for detecting of lock-ups and endless loops which can be caused by i.e. an Single Event Upset (SEU).

The program code and parameter of the EEPROM are stored with checksum in order to verify the content before using.

The software for the Safe Mode which contains up- and download functionality is stored in the radiation-hard PROM and is always executed in the radiation-hard PM RAM.

In case of detection of severe failures VIRTIS enters into the Safe Mode. It provides the possibility for verification of the program code or parameter by downloading or a correction by uploading.

The commercial Real Time Operating System VIRTUOSO will be used as VIRTIS software core. VIRTUOSO is optimized in terms of memory space usage and provides a wide set of well tested functionality's for task organization and real-time aspects of the VIRTIS software system.

6.2.2.4. MAINTAINABILITY

The VIRTIS software (code + parameter) is organized in segments.

The segments or patches can be uploaded by transferring of TC packets and will be permanently stored in the EEPROM or directly written into the RAM (if the EEPROM fails).

An EEPROM error will be detected by using of the stored checksum.

6.2.2.5. VERIFIABILITY

The whole EEPROM content can be checked for validity of the content by the checksum stored for each EEPROM segment.
The PROM software provides periodically Default HK TM packets which contains the operational status of VIRTIS, e.g. the current active instrument mode.

6.2.2.6. TESTABILITY

During the secondary boot process the detection of a test configuration of the instrument leads to the Development Mode for on-ground verification (usable only by the software developers).

The Development Mode allows PC host communication including the performing of VIRTUOSO test capabilities (e.g. task level debugging) and sending of the software status via a separate test interface.

6.2.2.7. POWER-ON PROCEDURE

The following procedure will be executed after VIRTIS power-on.

- Hardware Primary boot by DPU Board and Boot Controller (BBC) i.e. copy of PROM content to the Program Memory (PM) RAM on a predefined address.
- Start PROM software in PM by BBC
- Performing the self test, especially these DPU parts which are necessary for executing the Safe mode.
- Synchronizing the ME internal SCET timer by a "Time Update" TC
- Entering the Safe mode (or Development mode, foreseen only for software development purposes on-ground initiated by special test connector configuration)
- Default HK TM are transferred periodically to the S/C by SDT
- The secondary boot from EEPROM is activated by sending of a respective TC. Otherwise VIRTIS remains in the Safe Mode !!
- While secondary boot the EEPROM content is copied into the RAM, program code is started and leads to entering of the ME IDLE mode. A science mode can be enterred only from IDLE Mode by the "Enable Science" TC
- If an severe error is detected the software goes back to the Safe Mode.

7. OPERATIONAL MODES

7.1.1. OPERATIVE MODE DEFINITION

VIRTIS distinct modes are defined where at least one of the following applies:

- Different resource usage (e.g. power, data rate, SSMM demand);
- Specific requirements put on the S/C (e.g. pointing);
- Different operative phase for the instrument.

The H/K TMs provide a specific parameter "VIRTIS Mode Id" that unambiguously identifies the instrument mode of operation. This parameter is contained in the "default" H/K report with the following format:

ME Operative Mode				V-H Operative Mode						V-M Operative Mode					
b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	b_{11}	b_{12}	b_{13}	b_{14}	b_{15}

1 ME_Off 2 ME_Safe 3 ME_Development 4 ME_Idle 5 ME_Science 6 ME_Test	1 H_Off 2 H_Cool_Down 3 H_Idle 4 H_Annealing 5 H_PEM_On 6 H_Test 7 H_Calibration 8 H_Nominal_Simulation 9 H_Science_Maximum_Data_Rate 10 H_Science_Nominal_Data_Rate 11 H_Science_Minimum_Data_Rate 12 DELETED 13 H_Science_Backup 14 H_User_Defined 15 DELETED 16 DELETED 17 DELETED 18 H_Spectral_Calibration_Simulation 19: H_Degraded (**) 63 H_ME_Test (*)	1 M_Off 2 M_Cool_Down 3 M_Idle 4 M_Annealing 5 M_PEM_On 6 M_Test 7 M_Calibration 8 M_Science_High_Spectral_1 9 M_Science_High_Spectral_2 10 M_Science_High_Spectral_3 11 M_Science_High_Spatial_1 12 M_Science_High_Spatial_2 13 M_Science_High_Spatial_3 14 M_Science_Nominal_1 15 M_Science_Nominal_2 16 M_Science_Nominal_3 17 M_Science_Nominal_Compressed 18 M_Science_Reduced_Slit 19 M_User_Defined 20: M_Degraded (**) 63 M_ME_Test (*)

(*) H_ME_Test and M_ME_Test, which physically correspond to have PEM off but IFE on, is used in Test modes.
(**) H_Degraded and M_Degraded are used when HS link is not available and therefore science data are sent on RTU Link

Tab. 7.1.1-1 VIRTIS Mode Id

A VIRTIS Mode is a unique combination of these 3 fields. Not all combinations are valid. Valid combinations are in according to the following constraints:

- If V-X mode is Cool_Down, V-Y mode can only be Off or Cool_Down;
- If V-X mode is Annealing, V-Y mode can only be Off;
- If V-X mode is Idle, V-Y mode can only be Off or Idle;
- If V-X mode is Test, V-Y mode can only be Test as well. (Test mode is used to command the PEMs bypassing the standard ME processing; commands to both PEMs are accepted without causing mode transitions: the only consistent way to do that is to consider both PEMs in Test mode);
- If V-X mode is User_Defined, V-Y mode can only be User_Defined as well. (User_Defined is a non nominal Science mode entered if the Enter_Science request is received when one or both PEMs has an operative parameter set that is not in line with any Science mode);
- If V-X mode is BIT, V-Y mode can only be Off;
- If V-X mode is Calibration, V-Y mode can only be Off or Idle or PEM_On or Calibration;
- If V-X mode is one of Science modes, V-Y mode can only be Off or Idle or one of the Science modes;
- If ME mode is Off, Safe, Development or Test, then both PEMs are Off.

Additional information about VIRTIS operative modes are described in sect 2.8 of the VIRTIS Rosetta EID-B, in the VIRTIS OBDH SW ICD (VIR-GAL-IC-0048) or in the SW User Manual.