Mars Surveyor 2001 Project

Functional Requirements for the THEMIS - Orbiter

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Functional Requirements Document

Thermal Emission Imaging System (THEMIS)

Mars Surveyor Program

2001 Orbiter Mission

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1.0 SCOPE

This document establishes the functional and performance requirements for the Thermal Emission Imaging System (THEMIS) aboard the Mars Surveyor Project 2001 (MSP'01) Orbiter. The THEMIS instrument will be used to provide thermal infrared and visible images of the surface of Mars throughout the science phase of the MSP'01 mission.

Note: The information included in this section is for information only. The THEMIS Functional, Performance and Interface Requirements are defined in sections 3.0, 4.0 and 5.0, respectively.

1.1 Scientific Objectives

To contribute to the success of the scientific objectives of the MSP'01 mission, the THEMIS shall:

- Determine the mineralogy and petrology of localized deposits associated with hydrothermal or sub-aqueous environments, and to identify sample return sites likely to represent these environments
- Provide a direct link to the global hyper-spectral mineral mapping from the MGS TES by utilizing the same infrared spectral region at high (100 m) spatial resolution
- Study small-scale geologic processes and landing site characteristics using morphologic (20 m spatial resolution) and thermo-physical properties
- Search for pre-dawn thermal anomalies associated with active sub-surface hydrothermal systems

1.2 THEMIS Baseline Design

The THEMIS will determine surface mineralogy and thermo-physical properties using multi-spectral thermal-infrared images in (9) spectral bands from 6.3 to 15.5 µm. The entire planet will be mapped at 100 m spatial resolution within the available data volume by using a multi-spectral imaging approach. The THEMIS will also measure 20 m spatial resolution surface morphology using multi-spectral visible imaging in (5) spectral bands from 425 to 950 nm. Over 15,000 panchromatic (3,000 5-color), 20 x 20 km images will be acquired for morphology studies and landing site selection. The combined infrared/visible imager is a spacecraft body-mounted push-broom, multi-spectral sensor with co-aligned infrared and visible fields of view (FOV). The THEMIS instrument shall be comprised of two sensor assemblies, the Infrared Subsystem (IRS) and the Visible Imaging Subsystem (VIS), each using their own dedicated electronic subsystem and sharing common optical and mechanical subsystems.

The THEMIS IRS and VIS will each use their own independent focal planes, read-out, data processing, data interface, and power supply electronics. The IRS electronics will provide digital data collection and processing as well as the instrument control and data interface to the spacecraft of the infrared data stream. Both the IRS and VIS will utilize commercial off-the-shelf electronics with only minor modifications (primarily to packaging) to accommodate space environmental requirements.

1.2.1 Infrared Subsystem (IRS)

The IRS design will include the Infrared Imaging Subsystem (IRIS) and IRS Electronics as shown in Figure 1 of section 3.0.

The IRIS will include the Infrared Detective Assembly (IRDA), which is comprised of the infrared focal plane, thermal electric cooler, and spectral stripe filters, and the IR Camera Electronics. The IRDA will include an un-cooled micro-bolometer detector array for the infrared focal plane. The micro-bolometer array will contain 320 pixels cross-track by 240 pixels along-track, with a 50 µm pitch. The array's temperature will be controlled by the small IRDA thermal electric (TE) cooler which stabilizes the detector temperature to nominally ±0.002 K. Spectral discrimination in the infrared will be achieved with the IRDA spectral filters which are mounted directly over the focal plane. The IRDA will use (9) 1 µm wide narrowband stripe filters in the 6.3 to 15.5 µm range. Each stripe filter will cover the entire cross-track width of the array and 48 pixels (32 pixels clear aperture) in the along-track direction for the shortest wavelength filter and 24 pixels (16 pixels clear aperture) in the along-track direction for the remaining spectral filters. The array will be clocked out at effective frequency of 30 Hz. In order to increase the SNR, 16 consecutive frames will be co-added using time-delay integration. The resulting ground spatial resolution will be 100 m for each of the spectral bands. The IR Camera Electronics will provide ultra-stable, low-noise clock and bias signals to the focal plane, control of the TE cooler, and perform the initial analog and digital processing of the data stream.

The IRS Electronics will include the command and control, timing and sequencing, shutter control, post-processing, spacecraft interface, and power conditioning electronics. The command and control electronics will process the commands from the spacecraft that control the operation of the IRIS and IRS Electronics. The timing and sequencing electronics will generate the control timing clocks for the operation of the IRIS with the IRS Electronics. The shutter control electronics will control the operation of the IRS shutter assembly. The post-processing electronics will supply final processing of the IRIS data, including the (16:1) TDI processing, and lossless (~2:1) data compression using a Rice data compression algorithm. The spacecraft interface electronics will provide the final data formatting and data interface to the spacecraft. The power conditioning electronics will use DC to DC converters to perform the necessary power conditioning for the IRIS and IRS Electronics. The power conditioning electronics will use off-the-shelf converters and discrete input filtering components to assure electromagnetic compatibility with the rest of the spacecraft.

The THEMIS sequencing software running on the spacecraft processor will perform the sequencing of the IRS image acquisition including band selection and image length. The THEMIS data processing software running on the spacecraft processor will perform final CCSDS data stream packetization of the IRS data.

1.2.2 Visible Imaging Subsystem (VIS)

The VIS design will include the VIS sensor and VIS electronics as shown Figure 2 of section 3.0.

The VIS sensor design will use a 1024 x 1024 - 2.6 x 6.2 µm pixel (1018 x 1008 photoactive), 9 µm pitch CCD for the visible focal plane. Spectral discrimination in the visible will be achieved by mounting five filters directly to the detector. The five 50 nm wide narrowband stripe filters are distributed over the 425 to 950 nm range. Each stripe filter will cover the entire cross-track width of the array and ~200 pixels in the along-track direction. Band selection will be accomplished by selectively reading out only part of the resulting frame for transmission to the spacecraft computer. The entire detector array will be read out every 1.3 seconds which will provide a ground spatial resolution of 20 m.

The VIS readout electronics will generate the clocks, biases, CCD sampling clock, and A/D conversion clock signals. These electronics will also perform DC offset correction, amplification and the A/D conversion. The VIS digital electronics will perform correlated double sampling subtraction, lossless (2:1) data compression using a first-difference Huffman data compression algorithm, initial data formatting, and storage of the visible data stream into internal memory until the spacecraft is ready to receive the data. The VIS spacecraft interface electronics will provide the data interface to the spacecraft and the command interface from the spacecraft to the VIS. The power conditioning electronics will use DC to DC converters to perform the necessary power conditioning for the VIS electronics. The power conditioning electronics will use off-the-shelf converters and discrete input filtering components to assure electromagnetic compatibility with the rest of the spacecraft.

The THEMIS sequencing software running on the spacecraft processor will perform the sequencing of the VIS image acquisition including band selection and image length. The THEMIS data processing software running on the spacecraft processor will perform final data stream compression and CCSDS packetization of the VIS data stream.

1.2.3 Optical Subsystem

The THEMIS will use a fast, wide FOV reflective telescope in order to accommodate the infrared and visible bands performance with a single telescope. The 80 mrad x 60 mrad FOV will be achieved with an all-reflective, (3) mirror f/1.7 anastigmatic telescope with an effective aperture of 12 cm and an effective focal length of 20 cm. The design will incorporate baffling to minimize stray and scattered light. The visible signal will be re-directed to the visible focal plane using a dichroic beamsplitter. The thermal infrared signal will be passed through this beamsplitter on its way to the infrared focal plane. The system will be optimized to match the high signal performance required for the IRS and the high spatial resolution required for the VIS. The 50 µm pitch of the IR focal plane array will map to a ground sample distance (GSD) of 100 m. The system will produce a Noise Equivalent Delta Emissivity (NE ε) of ~0.025 in the infrared. Similarly, the 9 µm pitch of the visible array will map to a GSD of 20 m with an MTF of approximately 0.2 at Nyquist. A full-field shutter will provide DC restore capability of the IRS, and will also be used to protect the detectors from unintentional direct illumination from the Sun when the instrument is not in use.

1.2.4 Mechanical Subsystem

The THEMIS main frame will provide the mounting structure for the IRS, VIS, and optical subsystems, the mounting interface to the spacecraft and thermal blankets, and the thermal control surface. The instrument size and mass will fit within the spacecraft allocations. The focal plane assemblies will be mounted in the main frame using brackets that provide for the necessary degrees of freedom for alignment to the telescope. The calibration shutter flag will have a known temperature for calibration purposes. Aluminum covers will be installed over the IRS electronics' circuit cards to provide EMI, RFI, and radiation shielding as required. All of these circuit cards will employ laminated printed wiring. The VIS electronics' circuit cards will be enclosed and shielded in the integrated VIS aluminum housing.

There will be no reliance on the spacecraft for thermal control of THEMIS. The thermal control plan will include the use of multi-layer insulation blankets, and appropriate thermal control surfaces to provide a stable thermal environment throughout the various mission phases. The THEMIS will also incorporate replacement heaters for both the IRS and VIS to be used when either subsystem is powered off.

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2.0 APPLICABLE DOCUMENTS

The following documents are guidelines for the preparation of the THEMIS Functional Requirements Document (FRD). The initial release of the applicable documents are listed below. Since the versions of these documents may change during the project, the contract between ASU and SBRS shall determine which version shall be used to define the requirements. In the event of a conflict between the contents of this document and the documents referenced herein, the requirements will be based on the following order of precedence:

1) THEMIS Statement of Work (ASU)
2) MSP'01 Orbiter, Interface Control Document for the THEMIS (LMA)
3) THEMIS Functional Requirements Document (ASU)
4) MSP'01 Orbiter, Environmental Requirements Specification (LMA)
5) MSP'01 Orbiter, EMC Control Plan (LMA)
6) MSP'01, Announcement of Opportunity, Proposal Information Package (JPL)

2.1 Arizona State University Documents (ASU)

THEMIS Proposal	Mars Surveyor Program, '01 Orbiter Science Instrument Proposal, Thermal Emission Imaging System, THEMIS, Volume I: Investigation and Technical Plan, August 1997.
VIS Proposal	Visible Imaging Subsystem (VIS) for the Mars Surveyor '01 Thermal Emission Imaging Spectrometer (THEMIS), A Proposal to Arizona State University, Volume 1: Investigation and Technical Plan, Malin Space Science Systems, August 1997.
THEMIS SOW	Thermal Emission Imaging System (THEMIS), Statement of Work for Instrument Design, Fabrication, Alignment, Test, and Delivery, SBRS #Y1617.
VIS SOW	Visible Imaging Subsystem (VIS), Statement of Work, MSSS #**TBD**

2.2 Lockheed Martin Astronautics Documents (LMA)

MSP01-97-0008	Mars Surveyor Program 2001, Interface Control Document for the Thermal Emission Imaging System (THEMIS).
MSP01-98-0029	Mars Surveyor Program 2001, Environmental Requirements Document.
MSP01-97-0007	Mars Surveyor Program 2001, Electromagnetic Compatibility Control Plan.

2.3 Mars Surveyor Project 2001 Documents (JPL)

AO-97-OSS-04	Mars Surveyor Program, Announcement of Opportunity, 2001 Orbiter Mission, Proposal Information Package, Final, 30 June 1997.

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3.0 FUNCTIONAL REQUIREMENTS

The THEMIS shall provide the following functionality:
(Overview - for information only)

1) A focal plane that is capable of collecting high quality thermal infrared images of the Martian surface from the mapping orbit.
2) Spectral filters that will allow the infrared images to be collected in multiple narrowband wavelengths in the infrared to allow discrimination of geologic features on the Martian surface.
3) A focal plane that is capable of collecting high quality visible images of the Martian surface from the mapping orbit.
4) Spectral filters that will allow the visible images to be collected in multiple narrowband wavelengths in the visible to allow multi-spectral analysis of features on the Martian surface.
5) Image forming optics that are capable of collecting high resolution and high quality infrared and visible images of the Martian surface from the nominal mapping orbit.
6) A mechanical structure that can support and protect the instrument and its subsystems over the thermal, vibration and radiation environments that will be encountered during the mission. Also, a mechanical design that fits within the mass, volume and thermal constraints of the spacecraft.
7) Electronics that are capable of controlling the collection of the images by the focal planes, conversion of the analog signals from the focal planes into digital signals that can be transmitted to the spacecraft processor, accept commands from the spacecraft processor, transmit instrument telemetry to the spacecraft processor, and generate the necessary regulated power signals from the unregulated spacecraft power. An electrical design that fits within the power, data volume, and electrical interface constraints of the spacecraft.
8) Software and/or firmware that is capable of controlling the sequencing for the collection of the images by the focal planes, post-processing of the image data, data compression and formatting, and that can be interpreted and sequenced by the spacecraft processor.
9) Software that will run on the spacecraft's processor to control the instrument image acquisition and perform any additional data post-processing.

The THEMIS instrument shall be comprised of two sensor assemblies, the Infrared Subsystem (IRS) and the Visible Imaging Subsystem (VIS), each using their own dedicated electronic subsystem and sharing common optical and mechanical subsystems.

The THEMIS instrument shall be designed to include the following functionality while satisfying the performance requirements listed in section 4.0 and the interface requirements listed in section 5.0:

3.1 Infrared Subsystem (IRS) Functionality

The THEMIS Infrared Subsystem (IRS) shall collect high quality multi-spectral thermal infrared images of the Martian surface from the mapping orbit and transfer the processed digital data to the spacecraft PACI interface.

The IRS design shall include the Infrared Imaging Subsystem (IRIS) and IRS Electronics as shown in Figure 1.

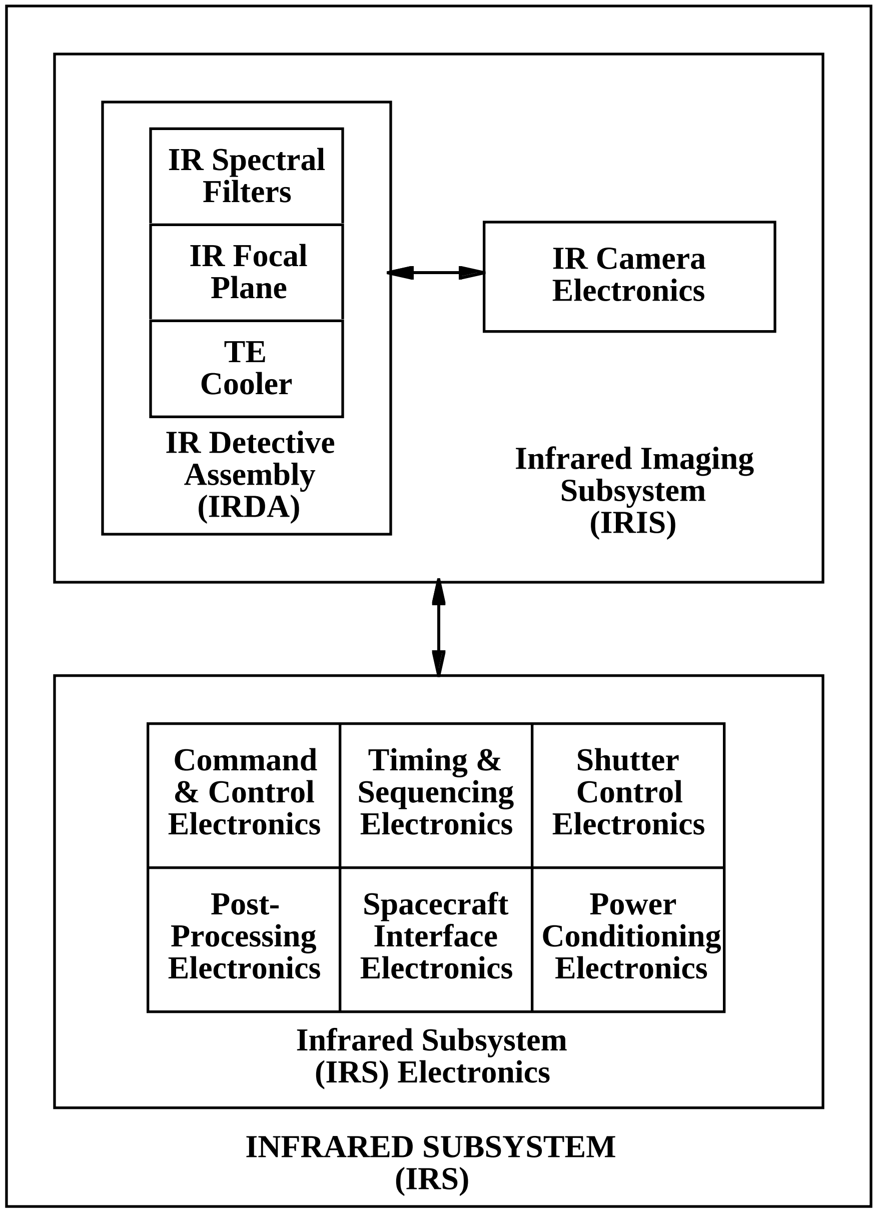

Figure 1: IRS Functional Block Diagram

3.1.1 Infrared Imaging Subsystem (IRIS)

The IRIS shall include the Infrared Detective Assembly (IRDA) and the IR Camera Electronics.

3.1.1.1 Infrared Detective Assembly (IRDA)

The Infrared Detective Assembly (IRDA) shall include the infrared focal plane, thermal electric cooler, and spectral stripe filters.

3.1.1.1.1 IRDA Infrared Focal Plane

The IRDA infrared focal plane shall use a 240 x 320 un-cooled silicon micro-bolometer detector array to measure the thermal infrared energy and generate the high spatial resolution images.

3.1.1.1.2 IRDA Thermal Electric (TE) Cooler

The IRDA thermal electric (TE) cooler shall be designed to stabilize the detector temperature so that the functional requirements of Section 3 and the performance requirements of Section 4 are achieved.

3.1.1.1.3 IRDA Spectral Stripe Filters

The IRDA shall have (9) nominally 1 µm wide narrowband stripe filters in the 6.3 to 15.5 µm range mounted directly over the IR focal plane. Each filter shall be placed so that it covers the entire cross-track width of the array. The band 1 filter (see Table 1) shall cover 48 pixels (32 pixels clear aperture) in the along-track direction and the remaining filters shall cover 24 pixels (16 pixels clear aperture) in the along-track direction to allow multi-spectral discrimination in the thermal infrared.

3.1.1.2 IR Camera Electronics

The IR Camera Electronics shall provide ultra-stable, low-noise clock and bias signals to the focal plane, control the thermal electric cooler, perform 8-bit analog offset correction, analog to 12-bit digital conversion, 8-bit encoded data conversion, and digital gain and offset corrections to the output signal during image acquisition. These electronics shall also provide the capability of selecting various gain and offset parameters that will be used during image acquisition.

3.1.2 IRS Electronics

The IRS Electronics shall include the command and control, timing and sequencing, shutter control, post-processing, spacecraft interface, and power conditioning electronics.

3.1.2.1 Command and Control Electronics

The command and control electronics shall process the parameter loads and commands from the spacecraft interface electronics that control the operation of the IRIS and IRS electronics.

3.1.2.2 Timing and Sequencing Electronics

The timing and sequencing electronics shall provide the timing waveforms and control signals necessary to operate and synchronize the IRIS and the command and control, shutter control, post-processing, spacecraft interface, and power conditioning electronics during IRS operation.

3.1.2.3 Shutter Control Electronics

The shutter control electronics shall control the full-field shutter mechanism that shall provide a uniform calibration target during IRIS focal plane offset corrections. The shutter control electronics shall provide redundant circuitry to control the shutter in the event of failure of the primary control circuitry. The "home" position for the shutter mechanism shall be in the "open" position whenever power is first applied to the IRS electronics.

The shutter control electronics shall also control the shutter to protect the focal planes from illumination from the Sun while the THEMIS is not collecting images or is powered off. This protection shall be enabled by commanding the shutter to the "closed" position prior to power off.

3.1.2.4 Post-Processing Electronics

The post-processing electronics shall perform spectral band selection, removal of unusable rows in the focal plane, image length control, removal of pre- and post-image data, (16:1) TDI processing, and lossless (~2:1) data compression on-chip using a Rice data compression algorithm prior to data formatting. The post-processing electronics shall provide the necessary compression telemetry to allow decompression of the IRS data on the ground. The data compression circuitry shall allow the Rice compression to be enabled or disabled by IRS commands.

The post-processing electronics shall monitor all IRS data acquisition modes and settings, as well as housekeeping measurements of internal temperatures and voltages. A sufficient number of temperature sensors shall be provided to monitor the temperature of key elements of the optical, mechanical, and electrical subsystems. The post-processing electronics shall also provide the necessary image sync telemetry (i.e. compression parameters, image id, start of frame, start of row, start of band, etc.) to allow identification and reconstruction of the IRS images on the ground.

These compression, imaging parameters, health and welfare, and image sync telemetry shall be formatted and merged into telemetry header words in the IRS data stream following the data compression. These telemetry shall be used to support the reconstruction, interpretation, and analysis of the infrared images as well as to monitor the health of the IRS and THEMIS instrument.

3.1.2.5 Spacecraft Interface Electronics

The spacecraft interface electronics shall use the 4-wire differential pair PACI electrical interface that is described in the THEMIS Interface Control Document referenced in Section 2.2.

The spacecraft interface electronics shall provide the RS-422 command interface from the spacecraft PACI card to the IRS command and control electronics.

The spacecraft interface electronics shall provide the formatting, serializing and buffering of the IRS data stream. The spacecraft interface electronics shall provide the RS-422 data interface to allow the transfer of these data from the IRS data buffer to the spacecraft PACI card. The spacecraft interface electronics shall also provide a "data valid" discrete digital control line to the spacecraft CPU that will signal when the IRS data buffer is ready to transfer 4096 data words to the PACI electronics. The IRS downlink software running on the spacecraft's CPU shall poll this line every 100 msec to determine when the data shall be transferred to the spacecraft PACI card. The spacecraft interface electronics shall provide a sufficient FIFO memory data buffer to accommodate any interrupts in the data transfer to the spacecraft PACI card during an IRS image acquisition.

3.1.2.6 Power Conditioning Electronics

The power conditioning electronics shall use DC to DC converters to provide the necessary power conditioning to the spacecraft's unregulated power for the IRIS and IRS electronics. The power conditioning electronics shall use off-the-shelf converters and discrete input filtering components to assure electromagnetic compatibility with the rest of the spacecraft.

The power conditioning electronics shall accommodate a "power reset" discrete digital control line from the spacecraft CPU that will allow the IRS sequencing software running on the spacecraft CPU to reset the IRS power converters.

The power conditioning electronics shall provide latch-up protection circuitry that will allow autonomous power resets when latch-ups occur in the IRS or IRIS electronics. The latch-up protection circuitry shall allow the protection to be enabled or disabled and to be set to high or low sensitivity by IRS commands.

3.1.3 IRS Firmware and Software

The combination of firmware and software shall allow the IRS to collect high resolution and high quality infrared images of the Martian surface from the mapping orbit.

3.1.3.1 IRS Control Firmware and Sequencing Software

The collection of the IRS images shall be controlled by both IRS software running on the spacecraft's CPU and by IRS firmware running in the IRS electronics. The acquisition of the infrared images shall be controlled by the imaging commands sequenced to the IRS by the IRS sequencing software running on the spacecraft's CPU. These commands shall include the imaging parameters and timing for each of the imaging opportunities. The IRS electronics firmware shall use these commands to configure the IRS to collect the desired images.

3.1.3.1.1 Sequencing Software

The IRS sequencing software running on the spacecraft's CPU shall receive IRS "non-interactive payload commands" (NIPC's) from the THEMIS team on a regular basis. These NIPC's shall contain all the information necessary to collect IRS images, in an autonomous mode, for extended periods of time. The NIPC's shall detail the order and absolute timing of the images to be acquired using individual IRS imaging commands. Each imaging command in the NIPC shall include the absolute start time and associated parameters for each image. The start time for each image acquisition shall be specified by the spacecraft clock (SCLK) time included in each imaging command. This absolute clock shall be used in conjunction with the predicted spacecraft geometry and ephemeris files to plan targeting of specific locations on the Martian surface. The IRS sequencing software shall use this start time to sequence the parameter loads, pre-image calibration command (including shutter control commands), and start data acquisition command for each image.

The IRS and IRIS parameter loads and commands for each image shall be transmitted to the IRS through the RS-422 command interface between the spacecraft PACI card and the IRS spacecraft interface electronics.

3.1.3.1.2 Parameter Loads

The IRS sequencing software running on the spacecraft's CPU shall control the transfer of parameter loads to the IRS. The parameter loads shall configure the IRIS electronics' control parameters and the IRS imaging parameters for each image. These loads shall occur prior to image acquisitions in order to set the IRIS and imaging parameters prior to data collection. The loaded parameters shall remain in effect until either the IRIS and IRS power is cycled or another parameter load is issued.

The IRIS parameter loads shall include the VNSTRIP voltage, FPA on-chip configuration, integration start time, integration end time, post-ADC global gain select, and post-ADC global offset select. These parameters shall allow the IRIS read-out and data processing to be adjusted on orbit to optimize the performance of the IRS.

The IRS imaging parameter loads shall include image length, spectral band selection, data compression (on/off), latch-up protection (on/off), and latch-up protection sensitivity (high/low). The image length parameter (# of pre-TDI frames) shall specify the duration of the image acquisition. The spectral band selection parameter shall specify the bands (any combination) to be acquired during the image acquisition. The compression and latch-up protection parameters shall allow these functions to be enabled or disabled as required.

The IRS sequencing software shall control the sequencing of the IRS and IRIS parameter loads to ensure the correct timing of events during each image acquisition.

The IRIS and imaging parameter loads shall be transmitted to the IRS through the RS-422 command interface between the spacecraft PACI card and the IRS spacecraft interface electronics.

3.1.3.1.3 IRS & IRIS Commands

The IRS sequencing software running on the spacecraft's CPU shall control the transfer of IRS and IRIS commands to the IRS. The IRS commands shall execute when issued to the IRS and shall control the IRS imaging data acquisitions and shutter control. The IRIS commands shall execute when issued to the IRS and shall control the operation of the IRIS.

The IRS commands shall include the start data acquisition, the shutter "open" (primary and redundant), and the shutter "closed" (primary and redundant) commands. The start data acquisition command shall initiate the data acquisition and shall pass an 8-bit image identification number to the IRS to be included in the data stream telemetry. This ID number shall be incremented on subsequent image acquisitions to allow image identification during ground processing. The shutter "open" and shutter "closed" commands shall control the position of the shutter mechanism. The shutter shall be commanded "open" during image acquisitions and commanded "closed" during offset corrections. The shutter shall also be commanded "closed" when the IRS is not collecting images or is powered off to protect the IRS and VIS focal planes from illumination from the Sun.

The IRIS commands shall include the perform calibration, the store IRIS configuration parameters, and the IRIS logic reset commands. The perform calibration command shall initiate the IRIS's focal plane's per pixel offset correction routines. The store configuration parameters command shall take the latest parameters loaded into IRIS RAM and store them into IRIS EEPROM. The IRIS reset commands shall allow the IRIS logic to be reset when it enters into an anomalous state.

The IRS sequencing software shall control the sequencing of the shutter "closed", perform calibration, shutter "open", and start data acquisition commands to ensure the correct timing of events during each image acquisition.

The IRS and IRIS commands shall be transmitted to the IRS through the RS-422 command interface between the spacecraft PACI card and the IRS spacecraft interface electronics.

3.1.3.1.4 Command Integrity

Uploaded IRS NIPC's shall be protected with checksums and validated by the spacecraft CPU before any commands are issued to the IRS. If an error is encountered the command shall be discarded.

3.1.3.1.5 Command Receipt

Spacecraft command verification shall be generated for each IRS NIPC sent to the spacecraft and shall be available to ground operations to verify successful receipt of IRS commands. When commands are discarded or lost during transmission, command verification shall indicate the error.

3.1.3.1.6 Command Execution

All valid commands shall be decoded and sequenced to the IRS by the IRS sequencing software running on the spacecraft CPU. The IRS NIPC commands shall be sequenced using the absolute SCLK timing defined in each imaging command. The IRS sequencing software shall transmit commands to the IRS using the RS-422 command interface between the spacecraft PACI card and the IRS spacecraft interface electronics.

3.1.3.2 <u>IRS Downlink Firmware and Software</u>

During IRS image acquisition, the IRS electronics' firmware shall perform data post-processing including unused data reduction, time-delayed integration, Rice compression, and data formatting and serialization. Following these tasks the IRS downlink software running on the spacecraft's CPU shall control the transfer of the IRS data stream in near-realtime to the spacecraft's PACI card DRAM and then to the spacecraft's CPU DRAM. This software shall use the IRS "data valid" discrete line to synchronize the transfer of data from the IRS data buffer to the PACI card. Once the data is available in CPU DRAM, the IRS downlink software shall perform the final data stream formatting, spacecraft time tagging, and CCSDS data packetization. The spacecraft shall then transfer the IRS packets to the mass memory card where they will be stored until the next available DSN downlink pass occurs.

3.1.3.2.1 Data Processing

The IRS post-processing electronics shall use field-programmable gate arrays (FPGA) to perform the post-processing of the IRS data stream. This processing shall include spectral band selection, removal of unusable rows in the focal plane, removal of pre- and post-image data, and (16:1) TDI processing. The parameters for these tasks will be burned into EEPROM and can be adjusted during integration and test by re-burning the EEPROM but cannot be changed in flight.

3.1.3.2.2 Data Compression

The IRS post-processing electronics shall use an Rice compressor integrated circuit to perform the lossless (~2:1) data compression of the IRS data stream. There shall be no software required to perform this task. However, the FPGA firmware shall generate the necessary compression telemetry to allow uncompression of the IRS data on the ground.

3.1.3.2.3 Data Formatting

The IRS post-processing electronics shall use FPGA's to perform the formatting of the IRS data stream. There shall be no software required to perform this task. The FPGA firmware shall format and merge the compression, imaging parameters, health and welfare, and image sync telemetry into telemetry header words in the IRS data stream following the data compression.

3.1.3.2.4 Data Transfer

The IRS spacecraft interface electronics shall use FPGA firmware to perform the formatting, serializing and buffering of the IRS data stream. There shall be no software required to perform this task. During each IRS image acquisition, the IRS downlink software running on the spacecraft's CPU shall control the transfer of the IRS data stream in near-realtime through the RS-422 data interface to the spacecraft's PACI card and then to the spacecraft's CPU DRAM. This software shall use the IRS "data valid" discrete line to synchronize the transfer of data from the IRS data buffer to the PACI card. The IRS spacecraft interface electronics will use this line to signal when the IRS data buffer is ready to transfer 4096 data words to the PACI electronics. The IRS data transfer software shall poll this line every 100 msec to determine when the data shall be transferred to the spacecraft PACI card. The IRS to PACI to CPU DRAM interface(s) shall support an effective 1 Mbits/sec throughput for the duration of each image acquisition.

3.1.3.2.5 Data Packetization

When IRS data is placed in CPU DRAM, the IRS downlink software shall call spacecraft software routines to perform the final data stream formatting, spacecraft SCLK time tagging, and CCSDS data packetization. The IRS data packetization shall be synchronized with the image acquisition so that only valid image data is packetized and transferred to mass memory.

3.1.3.2.6 Data Storage

When IRS data packetization is complete, the IRS downlink software shall call spacecraft software routines to control the transfer of the these packets from CPU DRAM to the mass memory card. The spacecraft software shall control the downlink of these data packets based on DSN coverage. The CPU DRAM to mass memory card interface shall support an effective 1 Mbits/sec throughput for the duration of each image acquisition.

3.1.3.3 <u>Power On Reset (POR)</u>

After a power on reset, the IRS and IRIS shall power up, set-up its default parameters, and wait until a parameter load or imaging command is received from the spacecraft. The IRS shall not transfer data to the PACI card until the spacecraft requests the data.

After a spacecraft power on reset, the IRS sequencing and downlink software shall be reloaded from EEPROM to DRAM and then standby until an IRS NIPC is received.

3.1.3.4 <u>Reprogramming</u>

The IRS electronics shall be controlled by firmware which is burned into FPGA's and cannot be changed in flight.

The IRS sequencing and downlink software that runs on the spacecraft's CPU shall be burned into spacecraft EEPROM and can be changed in flight. Modifications to this software can be transmitted to the spacecraft to replace the existing EEPROM code if necessary. This software will be transferred to spacecraft DRAM after spacecraft initialization and will run out of DRAM during IRS operation.

3.1.3.5 Fault Tolerance

The high energy radiation environment at Mars will cause single event upsets (SEU's) that can affect the contents of memory, registers, and peripherals. Software, firmware, and hardware techniques shall be used to minimize the effects of SEU's. These techniques shall ensure that after an SEU, the IRS will resume normal operation with a minimum of data loss. In the event of hardware latch-up, the IRS power may need to be cycled to reset the latch-up protection.

3.2 Visible Imaging Subsystem (VIS) Functionality

The THEMIS Visible Imaging Subsystem (VIS) shall collect high quality multi-spectral visible images of the Martian surface from the mapping orbit and transfer the processed digital data to the spacecraft processor.

The VIS design shall include the VIS sensor and VIS electronics as shown in Figure 2.

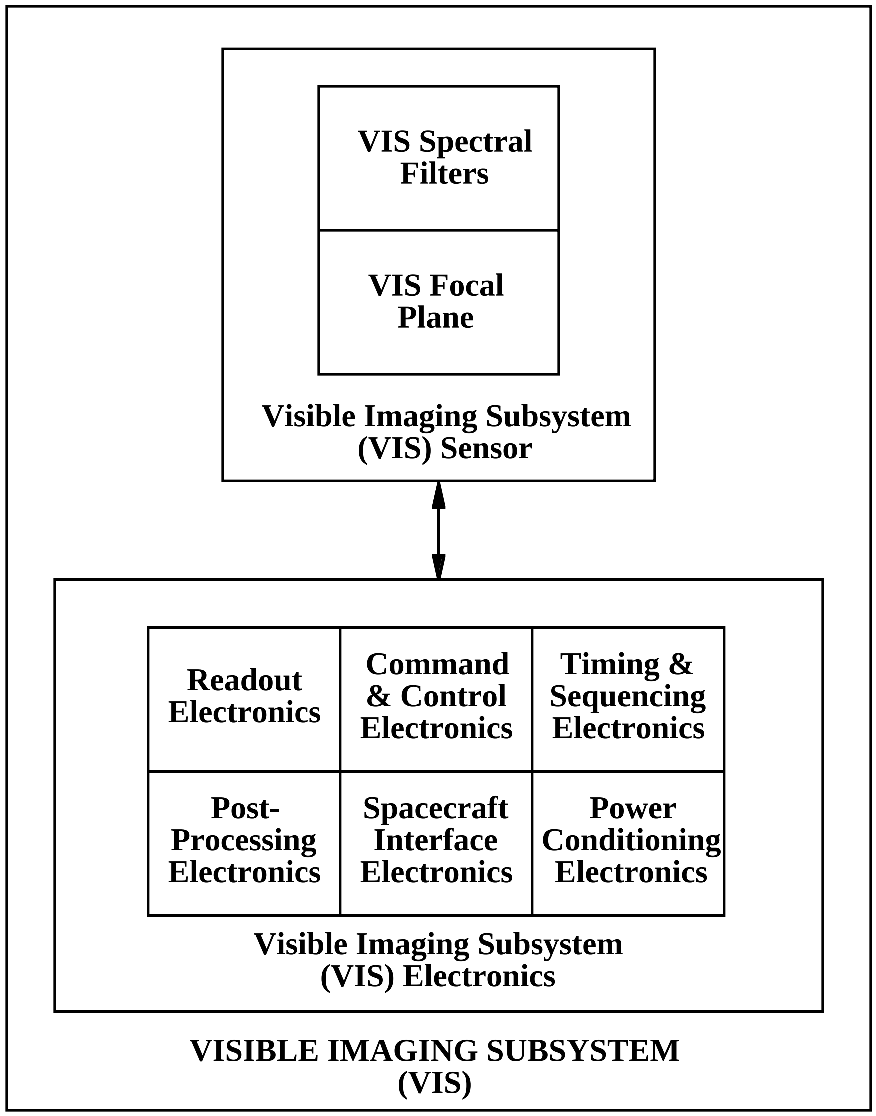

Figure 2: VIS Functional Block Diagram

3.2.1 VIS Sensor

The VIS sensor shall include the VIS focal plane and VIS spectral filters.

3.2.1.1 <u>VIS Focal Plane</u>

The VIS focal plane shall use a minimum of a 1000 x 1000 CCD detector array to measure the visible energy and generate the high spatial resolution images. The VIS focal plane shall incorporate a spacecraft readable temperature sensor.

3.2.1.2 <u>VIS Spectral Filters</u>

The VIS sensor shall have (5) 50 nm wide narrowband stripe filters in the 425 to 950 nm range mounted directly on the VIS CCD focal plane. Each filter shall be placed so that it covers the entire cross-track width of the array. The filters shall cover ~200 pixels (**TBD** pixels clear aperture) in the along-track direction to allow multi-spectral discrimination in the visible spectral range.

3.2.2 VIS Electronics

The VIS electronics shall include electronics that are capable of collecting high resolution and high quality visible images of the Martian surface from the mapping orbit and transferring these data to the spacecraft processor for storage and downlink.

3.2.2.1 <u>Readout Electronics</u>

The readout electronics shall provide the clock, bias, and sampling signals required to readout the CCD using the input logic level clock signals from the digital electronics.

3.2.2.2 <u>Digital Electronics</u>

The digital electronics shall include the command and control, timing and sequencing, post-processing, and spacecraft interface electronics.

3.2.2.2.1 Command and Control Electronics

The command and control electronics shall process commands from the spacecraft interface electronics that control the operation of the VIS. These electronics shall process image acquisition commands from the spacecraft CPU.

3.2.2.2.2 Timing and Sequencing Electronics

The timing and sequencing electronics shall provide the timing waveforms and control signals necessary to synchronize the readout, digital, and power conditioning electronics while the VIS is powered on. These electronics shall provide the logic level clock signals to the readout electronics in order to acquire and readout the color band data from the focal plane.

3.2.2.2.3 Post-Processing Electronics

The post-processing electronics shall perform the analog to 12-bit digital conversion of the video and reset levels and the correlated double sampling subtraction for each pixel. They shall also perform pixel summing as commanded and 12 to 8-bit encoded data conversion prior to storage of the image data in the VIS data buffer.

The post-processing electronics shall also monitor all visible sensor data acquisition modes and settings. These measurements shall be formatted and merged into the VIS data stream prior to data storage. These telemetry shall be used to support the interpretation and analysis of the visible images as well as to monitor the health of the VIS. A spacecraft readable temperature sensor shall also be provided to monitor the temperature of the electrical subsystem.

3.2.2.2.4 Spacecraft Interface Electronics

The spacecraft interface electronics shall use the 4-wire differential pair PACI electrical interface that is described in the THEMIS Interface Control Document referenced in Section 2.2.

The spacecraft interface electronics shall provide the RS-422 command interface from the spacecraft PACI card to the VIS electronics.

The spacecraft interface electronics shall provide the formatting, serializing and storage of the VIS data stream into internal memory. The spacecraft interface electronics shall provide the RS-422 data interface to allow the transfer of these data from the VIS data buffer to the spacecraft PACI card when the spacecraft is ready to receive the data. The spacecraft interface electronics shall provide a minimum 4 megabyte SRAM data buffer memory to accommodate the simultaneous collection of 20 x 20 km VIS images in all (5) bands.

3.2.2.3 Power Conditioning Electronics

The power conditioning electronics shall use a DC to DC converter to provide the necessary power conditioning to the spacecraft's unregulated power for the VIS. The power conditioning electronics shall use an off-the-shelf converter and discrete input filtering components to assure electromagnetic compatibility with the rest of the spacecraft.

The power conditioning electronics shall accommodate a discrete digital control line from the spacecraft CPU that is controlled by the VIS sequencing software running on the spacecraft CPU. Power to the VIS shall be controlled by a VIS internal switch that is commanded by the discrete digital control line.

3.2.3 VIS Software

The VIS spacecraft software shall allow the VIS to collect high resolution and high quality visible images of the Martian surface from the mapping orbit.

3.2.3.1 VIS Control and Sequencing Software

The collection of the VIS images shall be controlled by both VIS software running in the VIS digital electronics' DSP and by VIS sequencing software running on the spacecraft's CPU. The acquisition of the visible images shall be controlled by the imaging commands sequenced to the VIS by the VIS sequencing software running on the spacecraft's CPU. These commands shall include the imaging parameters and timing for each of the imaging opportunities. The VIS DSP shall use these commands to configure the VIS to collect the desired images.

3.2.3.1.1 VIS DSP Software

At VIS power up, the VIS DSP software shall be loaded from the spacecraft CPU. This software shall control all aspects of the image acquisitions. The VIS DSP software shall generate the timing signals necessary to perform the data read out from the CCD, analog to 12-bit digital conversion, correlated double sampling, 12 to 8-bit encoded data conversion, pixel summing as commanded, storage of the data in the VIS data buffer, and transfer of the data to the spacecraft.

3.2.3.1.2 VIS Sequencing Software

The VIS sequencing software running on the spacecraft's CPU shall receive VIS imaging "non-interactive payload commands" (NIPC's) from the THEMIS team on a regular basis. These NIPC's shall contain all the information necessary to collect VIS images, in an autonomous mode, for extended periods of time. The NIPC's shall detail the order and absolute timing of the images to be acquired using individual VIS imaging commands. Each imaging command in the NIPC shall include the absolute start time and associated parameters for each image. The start time for each image acquisition shall be specified by the spacecraft clock (SCLK) time included in each imaging command. This absolute clock shall be used in conjunction with the predicted spacecraft geometry and ephemeris files to plan targeting of specific locations on the Martian surface. The VIS sequencing software shall use this start time to sequence the setting of parameters and the start of data acquisition for each image.

3.2.3.1.3 VIS Commands

The VIS sequencing software running on the spacecraft's CPU shall control the transfer of commands to the VIS. The VIS commands shall configure the VIS imaging parameters prior to image acquisition. The loaded parameters shall remain in effect until either the VIS power is cycled or another parameter load is commanded.

For a given image acquisition, the following parameters shall be commandable: starting time of acquisition, integration time, width of image, pixel sampling (summing), color band selection, internal data storage vs. direct to spacecraft CPU, and compression algorithm selection.

The VIS commands shall be transmitted to the VIS through the RS-422 command interface between the spacecraft PACI card and the VIS spacecraft interface electronics.

3.2.3.1.4 Command Integrity

Uploaded VIS NIPC's shall be protected with checksums and validated by the spacecraft CPU before any commands are issued to the VIS. If an error is encountered the command shall be discarded.

3.2.3.1.5 Command Receipt

Spacecraft command verification shall be generated for each VIS NIPC sent to the spacecraft and shall be available to ground operations to verify successful receipt of VIS commands. When commands are discarded or lost during transmission, command verification shall indicate the error.

3.2.3.1.6 Command Execution

All valid commands shall be decoded and sequenced to the VIS by the VIS sequencing software running on the spacecraft CPU. The VIS NIPC commands shall be sequenced using the absolute SCLK timing defined in each imaging command. The VIS sequencing software shall transmit commands to the VIS using the RS-422 command interface between the spacecraft PACI card and the VIS spacecraft interface electronics.

3.2.3.2 <u>VIS Data Processing Software</u>

Following the completion of a VIS image acquisition, the VIS data processing software running on the spacecraft's CPU shall control the transfer of the VIS data from the VIS internal data buffer to the spacecraft's PACI card and then to the spacecraft's CPU DRAM.

The VIS to PACI to CPU DRAM interface(s) shall support an effective 1 Mbits/sec throughput.

Once the data is available in CPU DRAM, the VIS data processing software shall perform the data compression using the commanded compression algorithm, final data stream formatting, and spacecraft time tagging. When VIS data formatting is complete, the VIS data processing software shall call spacecraft software routines to perform the CCSDS data packetization and the transfer of the VIS data packets to the mass memory card where they will be stored until the next available DSN downlink pass occurs. The CPU DRAM to mass memory interface shall support an effective 1 Mbit/sec throughput.

3.2.3.3 Power On Reset (POR)

After a power on reset, the VIS DSP software shall be loaded from the spacecraft. The VIS shall not transfer data to the PACI card until the spacecraft requests the data.

After a spacecraft power on reset, the VIS sequencing and downlink software shall be reloaded from EEPROM to DRAM. The VIS software shall operate in a non-data collection mode until a VIS NIPC is received.

3.2.3.4 Reprogramming

The VIS software shall be burned into spacecraft EEPROM and can be changed in flight. Modifications to this software can be transmitted to the spacecraft to replace the existing EEPROM code if necessary. This software will be transferred to spacecraft DRAM after spacecraft initialization and will run out of DRAM during VIS operation.

3.2.3.5 Fault Tolerance

The high energy radiation environment at Mars will cause single event upsets (SEU's) that can affect the contents of memory, registers, and peripherals. Software, firmware, and hardware techniques shall be used to minimize the effects of SEU's. These techniques shall ensure that after an SEU, the VIS will resume normal operation with a minimum of data loss. In the event of hardware latch-up, the VIS power may need to be cycled to reset the latch-up protection.

3.3 Optical Subsystem

The THEMIS optical subsystem shall include image forming optics that are capable of collecting high resolution and high quality infrared and visible images of the Martian surface from the mapping orbit.

3.3.1 Telescope

The THEMIS telescope shall be of sufficient aperture size and quality to achieve the desired performance and resolution requirements.

3.3.2 Beamsplitter

The THEMIS beamsplitter shall be capable of splitting the infrared and visible optical energy collected by the telescope to the infrared and visible focal planes, respectively.

3.4 Mechanical Subsystem

The THEMIS mechanical subsystem shall include the structure to support, house, and protect the infrared sensor, visible sensor, and optical subsystems.

3.4.1 Mainframe

The THEMIS main frame shall provide the mounting structure for the infrared sensor, visible sensor, and optical subsystems, the mounting interface to the spacecraft and thermal blankets, and the thermal control surface.

3.4.2 Electronic Housings and Circuit Cards

The IRS electronics' circuit cards shall be enclosed in aluminum housings to provide EMI, RFI, and radiation shielding as required. The VIS electronics' circuit cards shall be enclosed and shielded in the integrated VIS aluminum housing.

3.4.3 Shutter Assembly

The THEMIS shutter assembly shall provide a full-field shutter mechanism that shall provide a uniform calibration target during IRIS focal plane offset corrections. The THEMIS shutter assembly shall have a known temperature for calibration purposes. The "home" position for the shutter mechanism shall be in the "open" position whenever power is first applied to the IRS electronics.

The shutter shall also provide protection to the focal planes from illumination from the Sun while the THEMIS is not collecting images or is powered off. This protection shall be enabled by commanding the shutter to the "closed" position prior to power off.

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4.0 PERFORMANCE REQUIREMENTS

The THEMIS shall be capable of providing the performance characteristics described in the following sections.

4.1 IRS Performance

The IRS shall be capable of providing the following performance characteristics in the infrared spectral range.

4.1.1 In-band Spectral Response

The IRS shall be capable of collecting infrared images in (9) thermal infrared bands. The spectral characteristics of each band pass filter are listed in Table 1. The band 9 bandwidth is defined at the full-width at half-maximum points (FWHM).

Band Pass Filter #	Minimum Wavelength (μm)	Minimum Wavelength Tolerance (μm)	Maximum Wavelength (μm)	Maximum Wavelength Tolerance (μm)
1	6.3	± 0.10	7.3	± 0.07
2	7.3	± 0.07	8.3	± 0.10
3	8.1	± 0.10	9.1	± 0.10
4	8.9	± 0.10	9.9	± 0.10
5	9.7	± 0.10	10.7	± 0.11
6	10.5	± 0.11	11.5	± 0.12
7	11.3	± 0.12	12.3	± 0.15
8	12.1	± 0.15	13.0	+ 0.10/-0.20
9	Center Wavelength 14.99	Center Tolerance ± 0.10	Bandwidth 0.70	Bandwidth Tolerance ± 0.10

Table 1: IRS Band Pass Filter Specifications

4.1.2 Out-of-band Spectral Response

For each spectral band, the IRS response to wavelengths outside the band (out-of-band) shall be less than 1% of the response to wavelengths inside the band (in-band). Out-of-band radiation is defined as the radiation from 1.8 to 50 microns that is outside 1.5 times the full-width at half-maximum (FWHM) wavelengths for the band. In-band radiation is defined as the radiation that is within 1.5 times the FWHM wavelengths for the band. The spectral distribution of the source radiation is defined by a 245 K blackbody combined with a 5900 K greybody with an emissivity of 1 x 10^{-5}.

4.1.3 Spectral Sensitivity

The IRS spectral sensitivity shall be such that for a 245 K blackbody thermal radiance from the surface of Mars (ε = 1), the NE ε's in Table 2 shall be achieved.

Band	NE ε	SNR
1	0.030	33.3
2	0.030	33.3
3	0.015	66.7
4	0.015	66.7
5	0.015	66.7
6	0.015	66.7
7	0.015	66.7
8	0.015	66.7
9	0.015	66.7

Table 2: IRS Spectral Sensitivity

4.1.4 Instantaneous Field of View (IFOV)

The IRS instantaneous field of view shall be 227 ± 10 µrad in the cross-track direction and 123 ± 10 µrad in the along-track direction.

4.1.5 Ground Sampling Distance (GSD)

The IRS ground sampling distance shall be 100 ± 10 m at a spacecraft altitude of 400 km.

4.1.6 Field of View (FOV)

The IRS shall have 320 pixels in the cross-track direction in order to collect acceptable images and 240 pixels in the along-track direction to allow for 9 spectral bands with (16:1) TDI. The resulting IRS field of view shall be 80 ± 5 mrad (4.58°) in the cross-track direction and 60 ± 5 mrad (3.44°) in the along-track direction.

4.1.7 Total Encircled Energy

With the IRS IFOV normalized total encircled energy shall be as shown in Table 3.

Sensing Area (µrad square)	Minimum Normalized Response
250	0.85
750	0.95
1250	0.99

Table 3: IRS Total Encircled Energy

4.1.8 Modulation Transfer Function (MTF)

The IRS system modulation transfer function shall be at least 0.2 at the Nyquist frequency for all field angles.

4.1.9 Dynamic Range

The IRS dynamic range shall be adjustable in order to achieve a response that is digitized to 8-bits, full scale when viewing a 310 K blackbody spectral distribution integrated from 1.8 to 18 µm.

4.1.10 Linearity

The IRS linearity shall be known within 5% of the full scale signal in all bands.

4.1.11 Transient Response

The IRS transient response shall settle to within 85% of its final value when the output changes over the full dynamic range within (1) frame.

4.2 VIS Performance

The VIS shall be capable of providing the following performance characteristics in the visible spectral range.

4.2.1 In-band Spectral Response

The VIS shall be capable of collecting visible images in (5) visible bands. The spectral characteristics of each band pass filter are listed in Table 4. The bandwidth is defined as the full-width at half-maximum points (FWHM).

Band Pass Filter #	Center Wavelength (nm)	Center Wavelength Tolerance (nm)	Bandwidth (nm)	Bandwidth Tolerance (nm)
1	425	± 10	50	± 5
2	550	± 10	50	± 5
3	650	± 10	50	± 5
4	750	± 10	50	± 5
5	950	± 10	50	± 5

Table 4: VIS Band Pass Filter Specifications

4.2.2 Out-of-band Spectral Response

For each spectral band, the VIS response to wavelengths outside the band (out-of-band) shall be less than 5% of the response to wavelengths inside the band (in-band). Out-of-band radiation is defined as the radiation from 0.3 to 1.1 microns that is outside 1.5 times the full-width at half-maximum (FWHM) wavelengths for the band. In-band radiation is defined as the radiation that is within 1.5 times the FWHM wavelengths for the band. The source radiation is defined by a fixed intensity, uniformly distributed target of know radiance and spectral distribution over 0.3 to 1.1 microns.

4.2.3 Spectral Sensitivity

The VIS spectral sensitivity shall be measured at the system level. As a goal, the VIS spectral sensitivity shall be such that for a low albedo (0.1), solar incidence angle of 75°, aphelion illumination conditions, flat surface at a 5 PM orbit, and the optical throughputs listed below, the following SNR's shall be achieved at full spatial resolution.

Band	Center Wavelength (nm)	Telescope Throughput	Beamsplitter Throughput	SNR
1	425	0.89	0.80	15
2	550	0.92	0.80	40
3	650	0.89	0.80	25
4	750	0.80	0.80	10
5	950	0.75	0.80	1

Table 5: VIS Spectral Sensitivity

4.2.4 Instantaneous Field of View (IFOV)

The VIS instantaneous field of view shall be 13 ± 1.3 µrad in the cross-track direction and 31 ± 3 µrad in the along-track direction.

4.2.5 Ground Sampling Distance (GSD)

The VIS ground sampling distance shall be 18 ± 2 m at a spacecraft altitude of 400 km.

4.2.6 Field of View (FOV)

The VIS shall have at least 1000 pixels in the cross-track direction in order to collect acceptable images and at least 1000 pixels in the along-track direction to allow for 5 spectral bands with ~200 pixels per filter. The resulting VIS field of view shall be at least 80 mrad (4.58°) in the cross-track direction and at least 60 mrad (3.44°) in the along-track direction.

4.2.7 Total Encircled Energy

With the VIS IFOV normalized total encircled energy shall be as shown in Table 6.

Sensing Area (µrad square)	Minimum Normalized Response
45	0.85
135	0.95
225	0.99

Table 6: VIS Total Encircled Energy

4.2.8 Modulation Transfer Function (MTF)

The VIS system modulation transfer function shall be at least 0.1 at the Nyquist frequency for all field angles.

4.2.9 Dynamic Range

The VIS dynamic range shall be measured at the system level. The VIS dynamic range shall be adjustable in order to achieve a response that is digitized to 8-bits, full scale when viewing a target with an albedo of 1.0.

4.2.10 Linearity

The VIS linearity shall be measured at the system level. The VIS linearity shall be determined to within 5% of the full scale signal in all bands.

4.3 IRS and VIS Sensor Co-Registration

The IRS and VIS shall be co-aligned so that their optical axes are within ± 1 mrad to allow co-registration of the infrared and visible images.

4.4 Pointing and Alignment

The pointing accuracy of the IRS and VIS shall be within ± 5 mrad of the alignment cube to allow for targeting.

The pointing knowledge of the IRS and VIS shall be within ± 1 mrad of the alignment cube to allow for image reconstruction.

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5.0 PHYSICAL CHARACTERISTICS & INTERFACE DEFINITION

The THEMIS shall be capable of providing the physical characteristics and interface definition described in the following sections.

5.1 Mechanical Interfaces

All spacecraft mechanical interfaces shall be defined in the MSP'01 THEMIS ICD.

5.1.1 Mass

The THEMIS mass shall be defined in the MSP'01 THEMIS ICD.

5.1.2 Volume

The THEMIS volume shall be defined in the MSP'01 THEMIS ICD.

5.1.3 Mounting

The THEMIS mounting shall be defined in the MSP'01 THEMIS ICD.

5.1.4 Clear Field of View

The THEMIS clear field of view shall be defined in the MSP'01 THEMIS ICD.

5.2 Electrical Interfaces

All spacecraft electrical interfaces shall be defined in the MSP'01 THEMIS ICD.

5.2.1 Power

The THEMIS power and typical power profile shall be defined in the MSP'01 THEMIS ICD.

5.2.2 Electrical Inputs

The THEMIS electrical inputs shall be defined in the MSP'01 THEMIS ICD.

5.2.3 Electrical Outputs

The THEMIS electrical outputs shall be defined in the MSP'01 THEMIS ICD.

5.3 Quality and Workmanship

The THEMIS shall be constructed to quality requirements that are consistent with the MSP'01 program requirements.

5.3.1 Quality Assurance

The THEMIS shall follow quality assurance policies that are consistent with the MSP'01 project policy.

5.3.2 Reliability

The THEMIS shall use parts that are consistent with the MSP'01 project policy.

5.3.3 Lifetime

The THEMIS shall be designed to operate within specifications for a **minimum** of (12) months powered on during integration and test prior to launch, (9) months powered off in cruise, (7) months powered on during the THEMIS mapping phase #1, (13) months powered off during the GRS mapping phase, and (7) months powered on during the THEMIS mapping phase #2.

5.4 Environmental Conditions

The THEMIS shall be designed and constructed to operate within specification while subjected to the environments that will be experienced during the duration of the mission. These environments shall be defined by the MSP'01 Environmental Requirements Document (LMA Document #MSP01-98-0029) and the Electromagnetic Compatibility Control Plan (LMA Document #MSP01-97-0007).

5.4.1 Pressure

The THEMIS shall be designed and constructed to operate within specification while subjected to the pressure environment as described in the MSP'01 Environmental Requirements Document.

5.4.2 Thermal

The THEMIS shall be designed and constructed to operate within specification while subjected to the thermal environment as described in the MSP'01 Environmental Requirements Document.

5.4.3 Radiation

The THEMIS shall be designed and constructed to operate within specification while subjected to the radiation environment as described in the MSP'01 Environmental Requirements Document.

5.4.3.1 Total Ionizing Dose

The THEMIS shall be designed and constructed to operate within specification while subjected to the total ionizing dose environment as described in the MSP'01 Environmental Requirements Document.

5.4.3.2 Heavy Ion Flux

The THEMIS shall be designed and constructed to operate within specification while subjected to the heavy ion flux environment as described in the MSP'01 Environmental Requirements Document.

5.4.4 Humidity

The THEMIS shall be designed and constructed to operate within specification while subjected to the humidity environment as described in the MSP'01 Environmental Requirements Document.

5.4.5 Atomic Oxygen

The THEMIS shall be designed and constructed to operate within specification while subjected to the atomic oxygen environment as described in the MSP'01 Environmental Requirements Document.

5.4.6 Vibration

The THEMIS shall be designed and constructed to operate within specification while subjected to the vibration environment as described in the MSP'01 Environmental Requirements Document.

5.4.7 Acoustics

The THEMIS shall be designed and constructed to operate within specification while subjected to the acoustic environment as described in the MSP'01 Environmental Requirements Document.

5.4.8 Pyrotechnic Shock

The THEMIS shall be designed and constructed to operate within specification while subjected to the pyrotechnic shock environment as described in the MSP'01 Environmental Requirements Document.

5.4.9 Structural Loads

The THEMIS shall be designed and constructed to operate within specification while subjected to the structural load environment as described in the MSP'01 Environmental Requirements Document.

5.4.10 Electromagnetic Interference / Compatibility (EMI / EMC)

The THEMIS shall be designed and constructed to operate within specification while subjected to the electromagnetic interference / compatibility environment as described in the MSP'01 Electromagnetic Compatibility Control Plan.

5.5 Electrostatic Discharge (ESD)

The THEMIS shall be designed and constructed to operate within specification while subjected to the electrostatic discharge environment as described in the MSP'01 Electromagnetic Compatibility Control Plan.

5.6 Packaging

The THEMIS shall be bagged, back-filled with gaseous nitrogen, and placed in a specially designed shipping container for storage and transport in uncontrolled environments.

5.7 Handling Fixture

The THEMIS shall be mounted within a handling fixture whenever practical during temporary storage, facility transport, and during installation on the spacecraft science deck.

5.8 Identification and Marking

The THEMIS identification and marking shall conform to standard practices.

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6.0 VERIFICATION OF REQUIREMENTS

The THEMIS functional and performance requirements shall be verified prior to shipment. ASU, SBRS and MSSS are responsible for the compliance testing as specified below.

6.1 Verification of Functional Requirements

The functional requirements of section 3.0 shall be verified for the IRS and VIS in the following sections.

6.1.1 Verification of IRS Functional Requirements

The functional requirements of section 3.1 shall be verified by the following conformance verification table:

Section	Function	Req./Goal	Method	Performed
3.1	IRS Functionality	N/A-Info	N/A-Info	N/A-Info
3.1.1	IRIS	N/A-Info	N/A-Info	N/A-Info
3.1.1.1	IRDA	N/A-Info	N/A-Info	N/A-Info
3.1.1.1.1	IRDA IR Focal Plane	Requirement	D	SBRC
3.1.1.1.2	IRDA TE Cooler	Requirement	D	SBRC
3.1.1.1.3	IRDA Spectral Stripe Filters	Requirement	D	SBRC
3.1.1.2	IR Camera Electronics	Requirement	D	SBRC
3.1.2	IRS Electronics	N/A-Info	N/A-Info	N/A-Info
3.1.2.1	Command & Control Electronics	Requirement	D	SBRS
3.1.2.2	Timing & Sequencing Electronics	Requirement	D	SBRS
3.1.2.3	Shutter Control Electronics	Requirement	D	SBRS
3.1.2.4	Post-Processing Electronics	Requirement	D	SBRS
3.1.2.5	Spacecraft Interface Electronics	Requirement	D	SBRS
3.1.2.6	Power Conditioning Electronics	Requirement	D	SBRS
3.1.3	IRS Firmware & Software	N/A-Info	N/A-Info	N/A-Info
3.1.3.1	IRS Control Firmware & Seq. Software	N/A-Info	N/A-Info	N/A-Info
3.1.3.1.1	Sequencing Software	Requirement	D	ASU
3.1.3.1.2	Parameter Loads	Requirement	D	SBRS/ASU
3.1.3.1.3	IRS & IRIS Commands	Requirement	D	SBRS/ASU
3.1.3.1.4	Command Integrity	Requirement	D	ASU
3.1.3.1.5	Command Receipt	Requirement	D	ASU
3.1.3.1.6	Command Execution	Requirement	D	SBRS/ASU
3.1.3.2	IRS Downlink Firmware & Software	N/A-Info	N/A-Info	N/A-Info
3.1.3.2.1	Data Processing	Requirement	D	SBRS
3.1.3.2.2	Data Compression	Requirement	D	SBRS
3.1.3.2.3	Data Formatting	Requirement	D	SBRS
3.1.3.2.4	Data Transfer	Requirement	D	SBRS/ASU
3.1.3.2.5	Data Packetization	Requirement	D	ASU
3.1.3.2.6	Data Storage	Requirement	D	ASU
3.1.3.3	Power On Reset	Requirement	D	SBRS/ASU
3.1.3.4	Reprogramming	Requirement	D	ASU
3.1.3.5	Fault Tolerance	Requirement	D	SBRS/ASU

Table 7: IRS Functionality Requirements Compliance Matrix

Compliance Methods: Test (T), Test at lower level (TLL), Inspection (I), Analysis (A), Design (D)

6.1.2 Verification of VIS Functional Requirements

The functional requirements of section 3.2 shall be verified by the following conformance verification table:

Section	Function	Req./Goal	Method	Performed
3.2	VIS Functionality	N/A-Info	N/A-Info	N/A-Info
3.2.1	VIS Sensor	N/A-Info	N/A-Info	N/A-Info
3.2.1.1	VIS Focal Plane	Requirement	D	MSSS
3.2.1.2	VIS Spectral Filters	Requirement	D	MSSS
3.2.2	VIS Electronics	N/A-Info	N/A-Info	N/A-Info
3.2.2.1	Readout Electronics	Requirement	D	MSSS
3.2.2.2	Digital Electronics	Requirement	D	MSSS
3.2.2.2.1	Command & Control Electronics	Requirement	D	MSSS
3.2.2.2.2	Timing & Sequencing Electronics	Requirement	D	MSSS
3.2.2.2.3	Post-Processing Electronics	Requirement	D	MSSS
3.2.2.2.4	Spacecraft Interface Electronics	Requirement	D	MSSS
3.2.2.3	Power Conditioning Electronics	Requirement	D	MSSS
3.2.3	VIS Software	N/A-Info	N/A-Info	N/A-Info
3.2.3.1	VIS Control & Seq. Software	N/A-Info	N/A-Info	N/A-Info
3.2.3.1.1	VIS DSP Software	Requirement	D	MSSS
3.2.3.1.2	VIS Sequencing Software	Requirement	D	MSSS
3.2.3.1.3	VIS Commands	Requirement	D	MSSS/ASU
3.2.3.1.4	Command Integrity	Requirement	D	ASU
3.2.3.1.5	Command Receipt	Requirement	D	ASU
3.2.3.1.6	Command Execution	Requirement	D	MSSS/ASU
3.2.3.2	VIS Data Processing Software	N/A-Info	D	MSSS
3.2.3.3	Power On Reset	Requirement	D	MSSS
3.2.3.4	Reprogramming	Requirement	D	MSSS
3.2.3.5	Fault Tolerance	Requirement	D	MSSS

Table 8: VIS Functionality Requirements Compliance Matrix

<u>Compliance Methods</u>: Test (T), Test at lower level (TLL), Inspection (I), Analysis (A), Design (D)

6.1.3 Verification of Optical and Mechanical Functional Requirements

The functional requirements of section 3.3 and 3.4 shall be verified by the following conformance verification table:

Section	Function	Req./Goal	Method	Performed
3.3	Optical Subsystem	N/A-Info	N/A-Info	N/A-Info
3.3.1	Telescope	Requirement	D	SBRS
3.3.2	Beamsplitter	Requirement	D	SBRS
3.4	Mechanical Subsystem	N/A-Info	N/A-Info	N/A-Info
3.4.1	Mainframe	Requirement	D	SBRS
3.4.2	Electronic Housings & Circuit Cards	Requirement	D	SBRS
3.4.3	Shutter Assembly	Requirement	D	SBRS

Table 9: Opto/Mech Functionality Requirements Compliance Matrix

Compliance Methods: Test (T), Test at lower level (TLL), Inspection (I), Analysis (A), Design (D)

6.2 Verification of Performance Requirements

The performance requirements of section 4.0 shall be verified by the following conformance verification table:

Section	Parameter	Req./Goal	Method	Performed
4.1	IRS Performance	N/A-Info	N/A-Info	N/A-Info
4.1.1	In-Band Spectral Response	Requirement	T	SBRS
4.1.2	Out-of-Band Response	Requirement	A, TLL	SBRS
4.1.3	Spectral Sensitivity	Requirement	T	SBRS
4.1.4	IFOV	Requirement	T	SBRS
4.1.5	GSD	Requirement	T	SBRS
4.1.6	FOV	Requirement	T	SBRS
4.1.7	Total Encircled Energy	Requirement	T	SBRS
4.1.8	MTF	Requirement	T	SBRS
4.1.9	Dynamic Range	Requirement	T	SBRS
4.1.10	Linearity	Goal	T	SBRS
4.1.11	Transient Response	Goal	T	SBRS
4.2	VIS Performance	N/A-Info	N/A-Info	N/A-Info
4.2.1	In-Band Spectral Response	Requirement	TLL	MSSS
4.2.2	Out-of-Band Response	Requirement	A, TLL	MSSS
4.2.3	Spectral Sensitivity	Requirement	T	SBRS
4.2.4	IFOV	Requirement	T	SBRS
4.2.5	GSD	Requirement	T	SBRS
4.2.6	FOV	Requirement	T	SBRS
4.2.7	Total Encircled Energy	Requirement	T	SBRS
4.2.8	MTF	Requirement	T	SBRS
4.2.9	Dynamic Range	Requirement	TLL, T	MSSS/SBRS
4.2.10	Linearity	Goal	TLL	MSSS
4.3	Visible/IR Co-registration	Requirement	T	SBRS
4.4	Pointing and Alignment	Requirement	T	SBRS

Table 10: Performance Requirements Compliance Matrix

Compliance Methods: Test (T), Test at lower level (TLL), Inspection (I), Analysis (A), Design (D)

6.3 Verification of Physical Characteristic Requirements

The physical characteristic requirements of section 5.0 shall be verified by the following conformance verification table:

Section	Characteristic	Req./Goal	Method	Performed
5.1	Mechanical Interfaces	Requirement	N/A-Info	N/A-Info
5.1.1	Mass	Requirement	T	SBRS
5.1.2	Volume	Requirement	T	SBRS
5.1.3	Mounting	Requirement	T	SBRS
5.1.4	Clear Field of View	Requirement	D	SBRS
5.2	Electrical Interfaces	N/A-Info	N/A-Info	N/A-Info
5.2.1	Power	Requirement	T	SBRS
5.2.2	Electrical Inputs	Requirement	I	SBRS
5.2.3	Electrical Outputs	Requirement	I	SBRS
5.3	Quality and Workmanship	N/A-Info	N/A-Info	N/A-Info
5.3.1	Quality Assurance	Requirement	I	SBRS
5.3.2	Reliability	Requirement	D, A	SBRS
5.3.3	Lifetime	Requirement	D, A	SBRS
5.4	Environmental Conditions	N/A-Info	N/A-Info	N/A-Info
5.4.1	Pressure	Requirement	D	SBRS
5.4.2	Thermal	Requirement	T	SBRS
5.4.3	Radiation	Requirement	A, TLL	SBRS
5.4.3.1	Total Ionizing Dose	Requirement	A, TLL	SBRS
5.4.3.2	Heavy Ion Flux	Requirement	A	SBRS
5.4.4	Humidity	Requirement	A	SBRS
5.4.5	Atomic Oxygen	Requirement	A,	SBRS
5.4.6	Vibration	Requirement	T	SBRS
5.4.7	Acoustics	Requirement	A	SBRS
5.4.8	Pyrotechnic Shock	Requirement	A	SBRS
5.4.9	Structural Loads	Requirement	A	SBRS
5.4.10	EMI/EMC	Requirement	T	SBRS
5.5	ESD	Requirement	I	SBRS
5.6	Packaging	Requirement	I	SBRS
5.7	Handling Fixture	Requirement	I	SBRS
5.8	Identification and Marking	Requirement	I	SBRS

Table 11: Physical Characteristic Requirements Compliance Matrix

<u>Compliance Methods</u>: Test (T), Test at lower level (TLL), Inspection (I), Analysis (A), Design (D)

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7.0 SAFETY CONSIDERATIONS

The following safety precautions shall be taken into consideration during the fabrication, integration, and testing of the THEMIS instrument.

7.1 Personnel Safety

There are no special safety precautions that are required to assure operator safety during the operation of the THEMIS.

7.2 Instrument Safety

The THEMIS instrument safety precautions shall be defined in the MSP'01 THEMIS ICD.