MRO HIGH RESOLUTION IMAGING SCIENCE EXPERIMENT (HIRISE): INSTRUMENT DEVELOPMENT.

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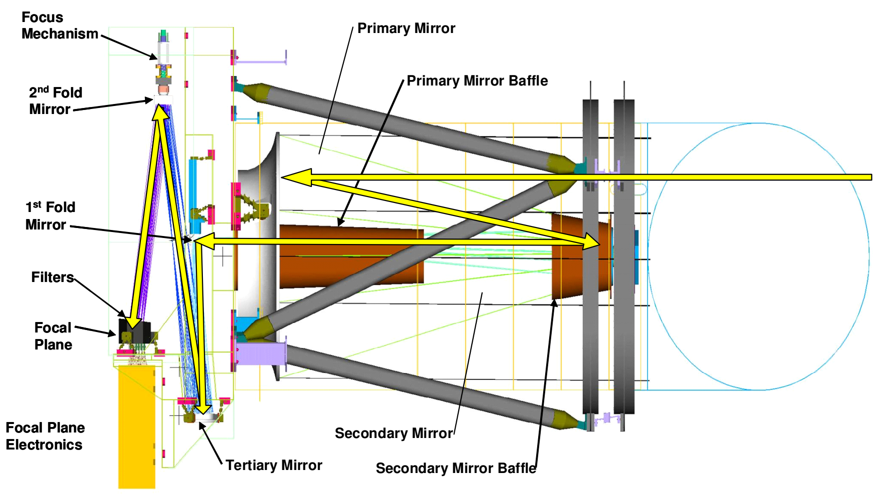

Figure 1 Camera optical path optimized for low mass

HiRISE Science Instrument

The primary functional requirement of the HiRISE imager, figure 1 is to allow identification of both predicted and unknown features on the surface of Mars to a much finer resolution and contrast than previously possible [1], [2]. This results in a camera with a very wide swath width, 6km at 300km altitude, and a high signal to noise ratio, >100:1. Generation of terrain maps, 30 cm vertical resolution, from stereo images requires very accurate geometric calibration. The project limitations of mass, cost and schedule make the development challenging. In addition, the spacecraft stability [4] must not be a major limitation to image quality. The nominal orbit for the science phase of the mission is a 3pm orbit of 255 by 320 km with periapsis locked to the south pole. The track velocity is approximately 3,400 m/s.

HiRISE Design Features

The HiRISE instrument performance goals are listed in Table 1. The design features a 50 cm aperture and a detector with 128 lines of Time Delay and Integration (TDI) to create very high (100:1) signal noise ratio images.

Parameter		Performance	Comments
Ground Sample Distance (GSD)		30 cm/pixel	From 300 km altitude
Telescope Aperture		0.5 m, f/24	For resolution and SNR
Spectral range		400 to 600 nm 550 to 850 nm 800 to 1000 nm	Blue-Green (BG) Red Near infra-red (NIR)
SNR	Blue-Green	Typically 100:1	Achieved with TDI, backside thinned CCDs, and 50 cm aperture
	Red	Typically 200:1	
	NIR	Typically 100:1	
Swath Width	Red	> 6 km	From 300 km altitude
	Blue-Green & NIR	> 1.2 km	From 300 km altitude
Swath length		> 2× swath width	Along track
Data Precision		14 bit A/D	12 to 13 bit usable
Data Compression		Real-time 14 to 8 bit	Look-up table
		Up to 16 × 16 binning	Increases areal coverage
		Lossless compression at SSR	~ 2:1
Data storage		28 Gbits	All channels
Number of pixels across swath		20,264 Red 4,048 Green and NIR	From swath width and pixel scale
TDI line time		≥76 µsec	To match ground track speed
CCD read noise		< 50 electrons rms at 22°C	Achieve SNR at low signal levels
FOV		1.14° × 0.18°	
IFOV		1 × 1 µrad	Detector angular subtense
Relative Radiometry		< 1 % pixel to pixel	Absolute 20%

Table 1. HiRISE Requirements and Performance Characteristics

The imager design is an all-reflective three mirror astigmatic telescope with light-weighted Zerodur optics and a graphite-composite structure. The Cassegrain objective with relay optic and two fold mirrors is optimized for diffraction-limited performance over the long, narrow field-of-view (FOV) required for "push-broom" scanning and imaging. Filters in front of the detectors provide images in the three wavelength bands: red (or panchromatic), blue-green (BG), and near infrared (NIR).

The detector-chip-assemblies (DCA) housing the charge coupled devices (CCDs) are staggered to provide full swath coverage without gaps. Both the BG and NIR bands have two DCAs each to give a total swath width of 4048 pixels, and the red channel has ten DCAs to provide a swath width of 20,264 pixels.

The 50 cm diameter primary mirror has a dual arch construction for low mass and high rigidity. The optical system provides a diffraction limited modulation transfer function (MTF) on 12 µm pixels for all 14 HiRISE detectors. The color filters are located 30 mm from the detectors for all three channels. This distance avoids problems due to stray light and multiple reflections from the filters in the f/24 quasi-collimated beam. A Lyot stop, located between the tertiary mirror and the second fold mirror, ensures excellent reduction of stray light.

Figure 2 HiRISE Telescope Flight Structure (Approximately 70 cm in Diameter by 1.4 m in Length)

Distortions in the large field of the red channel are very small. As HiRISE points at the Mars' surface, a point in the image will remain in a single CCD TDI column with no cross column smear for all CCDs.

The telescope structure is made of graphite-fiber-reinforced composite. This produces a stiff, lightweight structure with low moisture absorption properties and low coefficient of moisture expansion. The negative coefficient of thermal expansion (CTE) of the composite elements, in conjunction with metallic, positive CTE fittings, is tailored to produce near-zero instrument CTE. Figure 2 shows the flight structure.

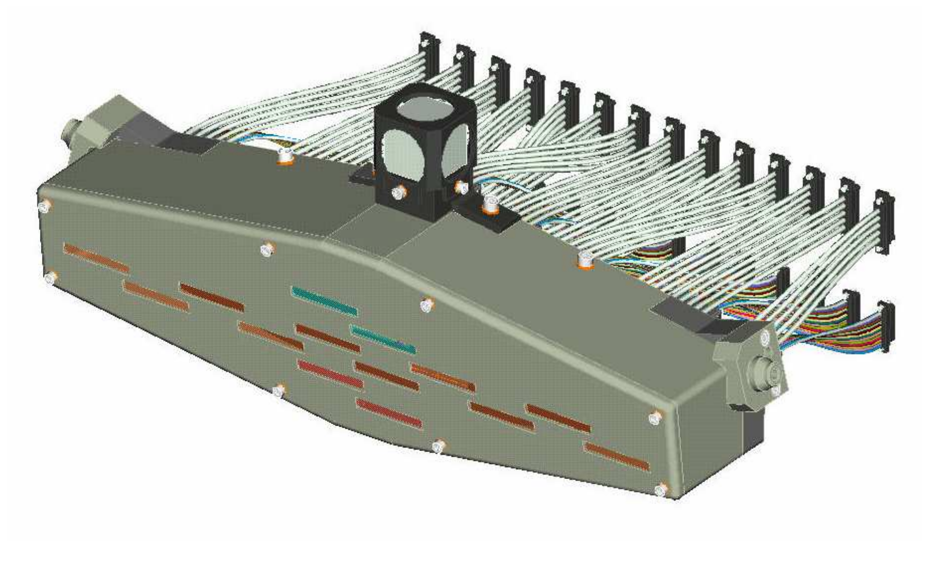

Figure 3 HiRISE Focal Plane Assembly

HiRISE Focal Plane Subsystem (FPS)

The FPS consists of the DCAs, a focal plane substrate of aluminum–graphite composite material, a spectral filter assembly, and CCD processing/memory modules (CPMMs). Each CCD has 2048 12×12 um pixels in the cross-scan direction and 128 TDI elements (stages) in the along-track direction. The 14 staggered CCDs overlap by 48 pixels at each end as shown in Figure 3. This provides an effective swath width of ~20,000 pixels for the red images and ~4,048 pixels for the blue-green and NIR images.

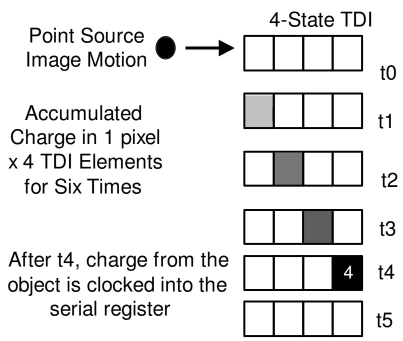

Figure 4 TDI Operation Using a 4-TDI Configuration to Illustrate Charge Accumulation

Using the TDI method increases the exposure time, allowing us to obtain both very high resolution and a high signal-to-noise ratio. As the spacecraft moves above the surface of Mars, TDI integrates the signal as it passes across the CCD detector by shifting the accumulated signal into the next row (line) of the CCD at the same rate as the image moves (see Figure 4). The line rate of 13,000 lines/sec corresponds to a line time of 76 microsec for 250 km altitude. The pixel integration time is set to match the ground velocity so that charge from one image region is sequentially clocked into the next corresponding element in the along-track direction. The imager can use 8, 32, 64 or 128 TDI stages (detector elements in the along-track direction) to match scene radiance to the CCD full well capacity. Spacecraft orientation in yaw will compensate for image smearing during the integration period. A practical limit is reached when residual image smear and spacecraft pointing jitter seriously degrade the required resolution. The 128 lines is the largest number of lines that meets all requirements. Images with higher SNR and lower resolution images will be obtained by binning the signal from adjacent lines and pixels within the CCD, up to a maximum of 16 × 16 pixels.

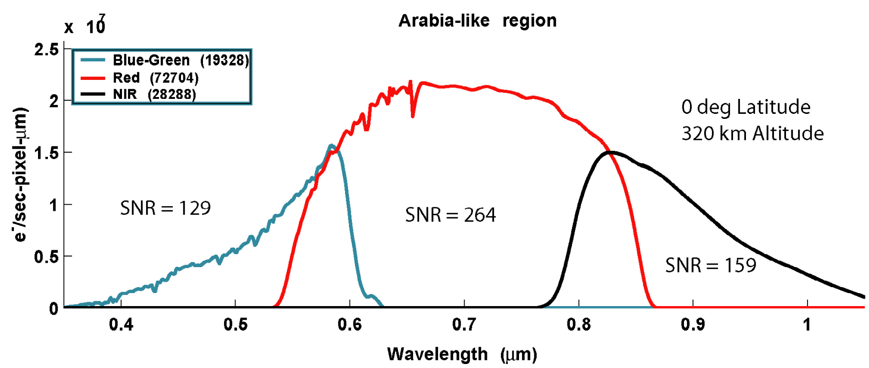

Figure 5 Signal in Electrons as a Function of Wavelength for a Bright Region of Mars

HiRISE Performance

The predicted maximum signal is 76,000 electrons for the red channel at 300 km with no binning. Figures 5 show the expected un-binned SNR capability as a function of spacecraft latitude and regional albedo for the blue-green, red (pan) and NIR bands.

The modulation transfer function is shown in figure 6. Note that the resolution is limited by the aperture response of the pixel, the diffusion in the CCD and the diffraction of the telescope modified by the 18 cm obscuration of the secondary mirror baffle.

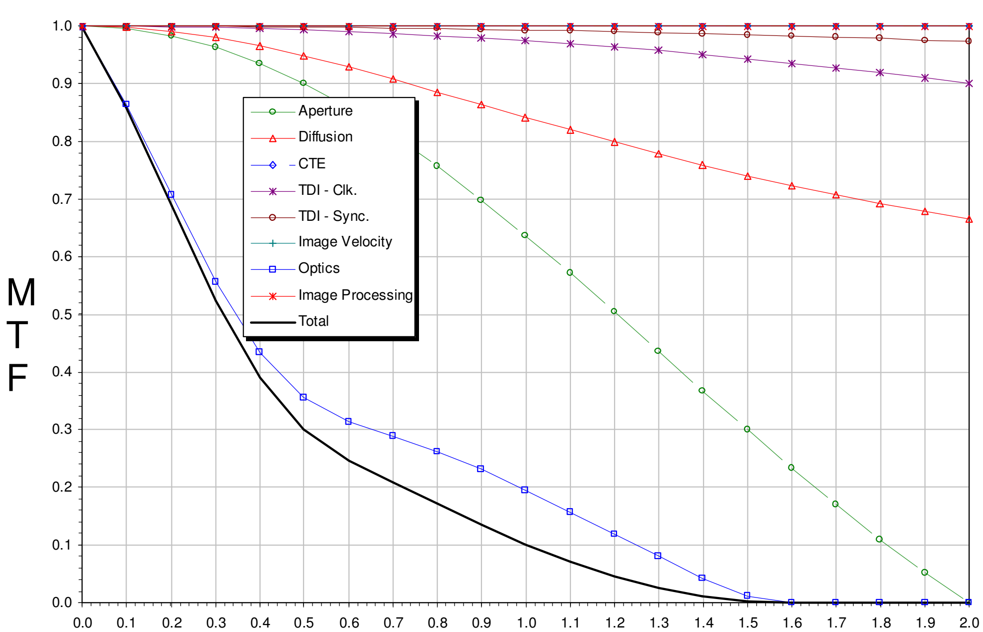

Figure 6 Spatial Resolution Performance. Nyquist is 41.7 lp/mm)

HiRISE Camera Electronics Overview

The CCD Processing and Memory Module (CPMM) electronics approach is to minimize the number of active and passive components that contribute to noise. The obligatory analog signal processing chain between the CCD output amplifier and the 80MSPS 14 bit A/D has been designed so that it adds less noise than the CCD, while being radiation tolerant and reasonably low power. The Digital Correlated Double Sample (CDS) scheme is capable of very high pixels rates, in excess of 16 megapixels per second, while sampling a minimum of twice per pixel.

Each of the 14 CPMM's uses a rad-hard Xilinx Virtex 300E Field Programmable Gate Array (FPGA) to perform the control, signal processing, Look Up Table compression, data storage & maintenance, and external I/O. The FPGA is SRAM based and uses a Flash Serial Programmable Read Only Memory (SPROM) for configuration upon power-up. The SPROM and FPGA are reconfigurable using JTAG, so design changes during development are extremely simple. The JTAG port is available on an external connector to facilitate last minute design changes, if required.

Data System & Operations

Target coordinates for an exposure will be uplinked to the spacecraft, which will then translate the target coordinates into the time at which the spacecraft will fly over the area of Mars to be imaged. At the appropriate moment, a block of commands will be executed that will setup-for and then initiate the exposure. Exposure setup parameters include line time, number of lines, binning factor, number of TDI levels, and the lookup table to be used by the CPMM electronics to convert 14-bit pixel data into 8-bit pixel data. About 5 seconds in advance of the start-time of the exposure, the analog power is turned on

At the prescribed moment, all DCAs begin clocking simultaneously. When the exposure on the last DCA is completed, the analog power is turned off, and the stored pixel data is then readout sequentially from each CPMM to the spacecraft solid-state recorder, in preparation for downlink to the ground. Science data headers accompany the science data so that the science data can be properly interpreted. Optionally, the pixel data can be compressed by a lossless hardware compressor attached to the solid-state recorder.

The nominal high resolution image is 20,000 pixels by 40,000 lines and can take from 4 to 48 hours of transmission time depending on range to earth and compression factors.

Conclusion

In August 2005 the Mars Reconnaissance Orbiter spacecraft will embark on its ambitious journey to explore Mars. The spacecraft will carry an impressive array of instruments including HiRISE, a high-resolution imager that will obtain stunning new images of Mars with a resolution capable of detecting one-meter objects. By April 2003, camera development has reached the hardware stage with the flight optics, flight structure and the custom CCD design being completed. Breadboards of all the flight electronics are in test. Assembly and test of the camera will be completed by June 2004.

Acknowledgments

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