**OVERVIEW OF THE MESSENGER MERCURY DUAL IMAGING SYSTEM.** S. E. Hawkins, III, J. D. Boldt, E. H. Darlington, M. P. Grey, C. J. Kardian, Jr., S. L. Murchie, K. Peacock, E. D. Schaefer, B. D. Williams, *The Johns Hopkins University Applied Physics Laboratory, Laurel MD 20723-6099, USA, (ed.hawkins@jhuapl.edu).*

The Mercury Dual Imaging System (MDIS) is part of the science payload to be flown on the NASA Discovery mission MESSENGER [1]. MDIS is comprised of wide- and narrow-angle cameras sensitive to visible wavelengths. The MEcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft will be launched in the spring of 2004 aboard a Delta 2925H-9.5 rocket. MESSENGER will arrive at Mercury in the spring of 2009 to begin its year-long mission to study the planet. Prior to Mercury orbit insertion, the two Mercury flybys will provide imaging opportunities in addition to those during the mission orbital phase. Mission goals are to produce a global monochrome map at 250-m average resolution or better and a color map at 2-km average resolution or better. The success of MESSENGER is strongly tied to developing a capable and robust spacecraft and science payload with minimal mass [2].

Mercury's eccentric orbit poses a challenge to the design of the spacecraft, with the intensity of the solar radiation varying from about 4.6–10.6 times the total irradiance falling on the Earth. Because of this severe thermal environment, a sunshade protects the spacecraft from direct solar illumination, but strongly constrains its range of pointing. To compensate for this limited pointing capability, the dual cameras of MDIS are mounted on either side of a rotating platform, pivoted about a common axis as shown in Fig. 1. The two cameras will be

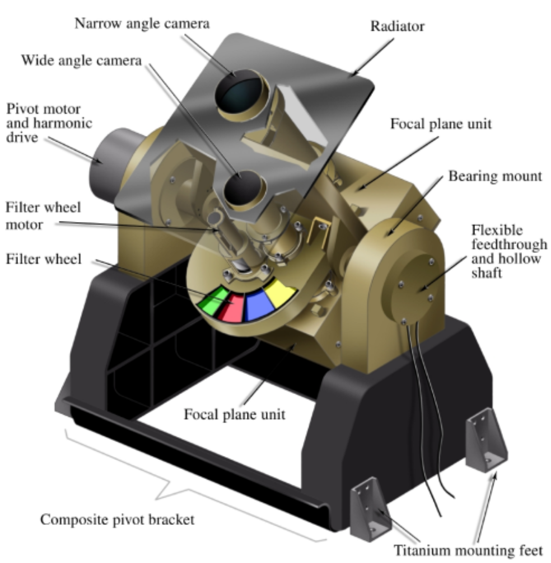


Figure 1: Artistic rendering of MDIS.

co-aligned to within the pointing accuracy of the spacecraft of 0.1°. The pivot platform design enables the instrument to acquire optical navigation (OpNav) images and star field calibrations, and greatly increases opportunities to image key features with minimal impact on spacecraft pointing. The nominal scan range of the platform is $-40°$ in the sunward direction to $+50°$ planetward.

The wide-angle camera (WAC) has a 10.5° field-of-view (FOV) and consists of a refractive telescope using a dogmar-like design having a collecting area of 48 $mm^2$. A 12-position multispectral filter wheel provides color imaging over the spectral response of the CCD detector (395–1040 nm). Ten spectral filters are defined to cover wavelengths diagnostic of different surface compositions and have bandwidths from 10–40 nm. A medium-band filter provides fast exposures for high resolution imaging, and the last filter is panchromatic for OpNavs. In order to achieve diffraction limited image quality, residual chromatic aberration is removed by varying the optical thickness of each filter, optimized for the center wavelength of the filter's passband, as was done for the the Multi-Spectral Imager on the NEAR Shoemaker spacecraft [3]. The narrow-angle camera (NAC) has a 1.5° FOV and uses a reflective design with a single medium-band filter with a passband identical to the one used in the WAC (650–850 nm). Both cameras have identical detector electronics contained in a modular focal plane unit (FPU). Due to thermal constraints, only one camera will operate at a time.

Protective covers for optical components are very desirable during ground-based testing, launch, and trajectory maneuvers requiring large thruster burns. However, due to the severe mass limitations on MESSENGER, a conventional protective cover for MDIS was not practical. Instead, the critical first optic of each telescope can be protected by rotating the platform 180° from nadir, such that both cameras look downward into the deck. This innovative approach ensures a circuitous path for any particulate or molecular contamination. Small incandescent bulbs are mounted in the base of the bracket to facilitate testing of the instrument in its stowed configuration.

The base of the pivot assembly is made of an advanced composite material (graphite/cyanate ester fabric pre-preg). This was chosen to match the material of the instrument deck, thus eliminating mechanical stresses due to differences in differential coefficients of expansion. The composite bracket assembly is thermally isolated from the spacecraft and the pivot platform. A rotary actuator is located on one side of the bracket, containing a stepper motor, resolver, and harmonic drive assembly. The stepper motor contains redundant windings so that the two fully redundant data processing units (DPUs) can independently control the motion of the pivot, enhancing the overall reliability of the pivot mechanism.

The MDIS harmonic drive has a 100:1 gear-reduction resulting in an output step resolution of 0.075°. Harmonic drive gear reducers provide very precise pointing and high torque ratios at lower mass than comparable conventional gear systems. These devices use a radial motion to engage the teeth of a flexspine and a circular toothed spline, rather than the rotating motion of other gear systems. This motion allows for very high gear ratios and near zero-backlash performance. The baseline plan to move the pivot mechanism is to count pulses sent to the stepper motor. A low resolution resolver ensures no steps are missed during motion. Calibration of each output step of the pivot mechanism prior to launch, will provide absolute pointing knowledge of the pivot position to $\lesssim 100$ $\mu$rad, essential for elevation determination from stereo imaging.

The bracket opposite the pivot actuator supports a bearing mount and a flexible diaphragm. A rotary feedthrough passes through a hollow shaft and provides all power, clocking control, and data to the two FPUs, the filter wheel and its position sensor, and the heaters and temperature sensors on the pivot platform. Connections to the platform from the two redundant DPUs pass through an interface adapter box, mounted to the bracket and just below the rotary feedthrough. The adapter box switches between the DPUs in a master/slave configuration and converts the low-voltage differential signals from the DPU to single-ended signals. This approach limits the number of circuits needed to pass through the rotary interface. The $<$1 W dissipated in the adapter box gets conducted into the spacecraft deck through a thermal strap.

The two FPUs with their CCD detectors are passively cooled. Because the instrument payload is protected from direct solar illumination by the spacecraft sunshade, the thermal environment of the instruments is largely benign with the exception of short intervals during the 12-hour orbital period. The thermal design takes advantage of the eccentric orbit of MESSENGER around Mercury by radiatively cooling the pivot platform during most of an orbital period using a 0.022 $m^2$ radiator. Near periapsis, the thermal flux radiated from the planet will be absorbed by this radiator and the instrument is designed such that the latent heat of the pivot platform does not allow the temperature of the cameras to rise above the maximum operating temperature of $-10^\circ$C. During the remainder of the orbit, the radiator cools the pivot platform and thermostatically controlled heaters limit the minimum operating temperature to $-40^\circ$C. There are two redundant survival heaters coupled to the pivot platform, with the setpoint for one configured to switch-on at the MDIS low operating temperature, effectively making it an operational heater. Each image will include four columns of dark reference elements in order to correct for variations in operating temperature.

In order to minimize mass, defocusing, and misalignment effects resulting from operating over a wide range of temperatures, the pivot platform and most of the components are made of magnesium. The two shafts supporting the rotating platform are made of titanium, selected for its relatively poor thermal conductivity. The instrument deck and the bracket will remain near room temperature. The entire instrument and bracket assembly are covered with multilayer insulating blankets.

The design of the detector electronics is based on the CONTOUR/CRISP instrument, and is identical for both the wide- and narrow-angle cameras. Because of the mass constraint on MESSENGER, the FPU electronics have been further miniaturized. The highly capacitive CCD is driven by custom designed hybrid circuits which significantly increase the component density in the FPU. A field-programmable gate array in each FPU provides the necessary clocking and control for each camera. The detector is an Atmel TH7888A CCD array with 1024$\times$1024 pixels with built-in antiblooming control. The fill factor for the 14$\times$14 $\mu$m pixels is 71%. The maximum frame rate is 1 Hz with a frame transfer time of 3 ms.

Optical navigation using MDIS is critical to the success of the MESSENGER mission. To increase the low-light sensitivity, the maximum exposure is approximately 9.9 s with a readout time of $\lesssim$1 s. Typical exposures will be $\sim$100 ms. An autoexposure algorithm similar to that used on NEAR [3] will also be used regularly.

Although the peak of the quantum efficiency of the CCD is only about 18%, the expected signals at Mercury are large. We have assumed a reflectance spectrum for Mercury to be the same as a laboratory spectrum of the Apollo 16 lunar sample 62231 [4]. Telemetry limitations constrain MDIS rather than signal strength. The FPU electronics perform a correlated double sample of each pixel then digitize it to 12-bits resulting in a 12 Mb full image. At the expected acquisition rates of $\sim$100 images/day, the two 8 Gb solid-state recorders (SSR) on board would be filled in less than two weeks. MESSENGER is not equipped with a high gain antenna, and so downlink opportunities are less frequent. To reduce the image downlink, yet minimize the effect on the science return, a number of imaging and compression modes are utilized.

On-chip pixel binning of 2$\times$2 and 4$\times$4 are available within the FPU. To simplify the interface between the FPU and the DPU, the binned and non-binned images appear identical in size by padding invalid pixels in the binned images with dummy values. A valid pixel gate is passed to the DPU to indicate when a pixel should be saved from within the serial data stream. Once the data are transferred to the DPU, they can be streamed directly to the SSR, or compressed in hardware using a variety of 12-to-8 bit lookup tables, differencing of adjacent pixels, and/or the FAST algorithm. These data are then sent to the SSR over a high speed link. The spacecraft's main processor (MP) can read both the hardware-compressed images as well as the raw images from the SSR. The MP can then perform additional binning, extract image subframes, and use much more sophisticated compression algorithms to substantially reduce the total downlink.

## References

[1] S. C. Solomon et al. The MESSENGER mission to Mercury: Scientific objectives and implementation. *Planet. Space Sci.*, in press.

[2] A. G. Santo et al. The MESSENGER mission to Mercury: Spacecraft and mission design. *Planet. Space Sci.*, in press.

[3] S. E. Hawkins, III et al. Multi-Spectral Imager on the Near Earth Asteroid Rendezvous Mission. *Space Sci. Rev.*, 82(1–2):3–29, 1997.

[4] F. Vilas. Surface composition of Mercury from reflectance spectrophotometry. In *MERCURY*, pages 59–76. University of Arizona Press, Tuscon, 1988.