USERS GUIDE

THE IMAGER FOR MARS PATHFINDER

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CHAPTER 1

THE IMAGER FOR MARS PATHFINDER CAMERA SYSTEM

PHYSICAL DESCRIPTION

The Imager for Mars Pathfinder (IMP) is a binocular CCD-based camera using a Loral 512 x 512 CCD. The camera resembles a 4 by 8 inch cylinder with the long axis aligned horizontally to the plane of the lander. Shown in **Figure 1** is a cutway line drawing of the camera system. For simplicity most details are not shown. The outer skin of the camera is aluminum painted with white thermal control paint to minimize daytime heating excursions of the camera head and to reduce glints. Inside the cylinder the primary structure is a Titanium optical bench that runs the center length of the camera. All the major camera assemblies are mounted on the optical bench. The upper portion of the bench supports the optical path. The optical components will be described in detail below, but physically the components of the upper half of the optical bench include two each of the window assemblies, the combined fold mirror and baffle assemblies, the half-moon baffles (not shown in the cutway), and the filter wheels. All these assemblies are aluminum. The optical path is combined in the center of the camera at the Titanium optical housing which contains the lens assemblies and a prism that turns the light path upwards toward the CCD. The CCD is mounted in the focal plane facing downward in the top of the optical housing. Separating the two light paths at the CCD is a blackened knife-edge baffle. The active surface of CCD is mounted and aligned to within one millimeter of knife-edge splitter baffle to minimize cross-talk between the eyes. The details of the CCD are described below. The final major component of the upper optical bench is the CCD pre-amplifier board which is connected to the CCD by a length of ribbon cable (not shown) and mounted behind the left fold mirror.

The bottom half of the optical bench mounts the filter wheel motor and drive assembly. The two twelve position filter wheels are fixed on a single drive shaft and driven by a single four-pole stepper motor. The motor has a three to one gear reduction to accomplish one revolution of the drive shaft in three revolutions of the motor. The two wheels are fixed on the same drive shaft and always position the same filter pairs into the optical path. The reason for the fixed wheels is first to minimize moving parts and second to protect the CCD. While we had two independent optical paths, the original design had a single filter wheel in only one light path. There was some concern that the unfiltered eye would have to be shuttered to protect the CCD and minimize scattered light while the “filtered” eye was doing solar observations. The addition of a shutter mechanism threatened to add more moving parts and potentially dangerous failure mechanisms. The simplest solution was to add an additional filter wheel with filters that were matched for their mode of observation so that solar observations are done with solar filters in both eyes. This approach had the added benefit of doubling the number of available filter positions. The wheels are also equipped with a zero position sensor. Although the motor is generally reliable, during calibration there were instances where the wheel would position between filters. If this occurs the IMP Flight Engineer can command the wheel to the reset to the zero position and verify the position with telemetry. The other feature in the bottom hemisphere of the IMP are the five pressure relief holes in the front bottom cover that are shaped like a grin (a one-micron dust filter covers the holes on the inside of the canister). The electronic connections for commands, power, and telemetry exit the camera head on the left side and are gathered into a cable that is bonded to the camera yoke and the mast. The cable is provided with a service loop to permit azimuth and elevation rotations.

The camera cylinder is mounted on a U-yoke supported on each end by gimbal bearing assemblies. The bearing assemblies have been designed to be resistant to dust encroachment and to operate at temperatures of -100°C. The elevation stepper motor is mounted on the right gimbal. The IMP has a “safe” position pointed straight down with the eyes protected by a “box” of brushes. Brushes making up three sides of the box are bonded to the yoke and the fourth side is made up of the brushes bonded in the “eyebrow” position above the eyes of the camera. This was designed to protect the IMP windows during flight and during possible Martian dust storms. The elevation motors can point the IMP in any position from the “safe” position at -90° to straight up at +90°. The elevation assembly is equipped with hard stops and limit switches at the extremes of the range to prevent the camera from revolving around the elevation axis and fouling the telemetry cable. Because the IMP is looking over a mast, a yoke, and a tip plate assembly, the lowest angle that any view of non-IMP features can be obtained is -67°.

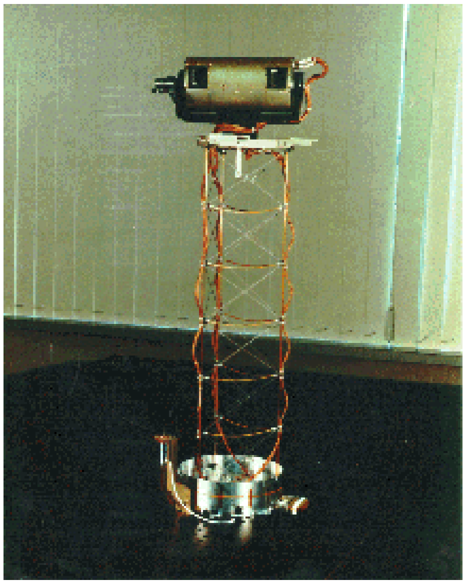


Figure 2: The IMP on its extendible mast.

The Yoke assembly is attached to a cylindrical azimuth gimbal assembly. Inside the cylinder is the azimuth motor and the azimuth bearing assembly. This assembly is also design to be resistant to dust infiltration. The azimuth assembly also has a hard stop and limit switches to prevent multiple revolutions of the camera. The base of the azimuth gimbal assembly bolts onto the IMP extendible mast designed and built by AEC Able Engineering. The mast is shown in **Figure 2**. The interface between the camera and the mast is a three-pronged “tip plate”. The tip plate has tapped mounting holes in each of the three ends. Originally two flat field targets were to be mounted for calibration. However it was determined that sky flat fields can produce better results and the targets were removed to reduce mass and improve the field of view. The only item mounted on the tip plate is the “yoke” magnet provided by the Orsted Laboratory. This is part of the magnetic properties experiment and is a single magnet designed to accumulate airborne dust. Since the magnet is approximately 5 centimeters from the IMP eyes, viewing of this magnet is done with a diopter lens that provides pixel resolutions of 150 microns. The mast is an open lattice of fiberglass stiffened by wire that pops up 79 cm above its stowed position. This puts the camera at approximately 1.5 meters above the Martian surface and extends Pathfinder’s horizon to 3.4 kilometers on a featureless plane. The mast is stowed in an aluminum canister and is deployed by its own strain energy.

Deployment is by a JPL-provided pyrotectic bolt, positioned inside the lower half of the canister, that will be fired during the afternoon of Sol 1. The camera is locked against shocks from launch and landing by the IMP "launch lock" assembly. This fixture attaches to the side of the mast canister and fixes the camera by a spring-loaded pin through the right elevation gimbal. The pin is released by a wax pellet actuator that is activated shortly after landing. The camera can also be freed from the launch lock by firing the mast deployment pyro and allowing the camera to lift off the restraining pin. The camera and mast assembly is attached to the Pathfinder Lander by 6 screws and two positioning pins.

OPTICS AND THE OPTICAL PATH

Shown in **Figure 3** is a schematic of the IMP optical path detailing the optical components of the camera system. The orientation of the figure is approximately the same as Figure 1 for comparison and locating the optical elements. The "eyes" have a field of view of 14.4° in the horizontal and 14.0° in the vertical. At the bottom of each eye is an adjustable front window baffle to control the light falling on the outside of the CCD chip. In the IMP Flight Model, the right window baffle was not needed and was removed. The IMP windows are recessed two centimeters from the edge of the eye and made of 5 millimeter-thick high-quality fused silica glass. There is no provision for active dust removal from the windows. Behind the window the light encounters the fold-mirror assembly and is turned 90° toward the center of the camera. Stray light is restricted by baffles in the fold mirror assemblies and by "half-moon" shaped baffles in front of the filter wheels. The light path next encounters the IMP optical filters which are described in detail in the next section. After the filters the light enters the optical housing by way of the lens units. The lenses are modified f/10 Cooke triplets, designed with rad hard glasses and stopped down to f/18 with a 1.04 mm aperture. The light path is then folded an additional 90° toward the CCD assembly. The light path then passes the knife-edge spitter baffle and falls on the CCD.

The optical system has a toe-in that varies slightly with the wavelength of the observation. For filter wheel position 5, the stereo filters centered on 670 nanometers, the toe-in is 13.05° in the left eye and -24.68° in the right eye. This provides complete viewing overlap at 4 meters distance and assure maximum stereo performance in the zone 2-10 meters from the spacecraft. The effective pixel resolution is 0.981 milliradians per pixel in the left eye and 0.985 milliradians per pixel right eye. Details of the optical performance of the IMP are listed in Chapter 2 of this guide and in the IMP calibration report available electronically on the IMP home page http://lpl.arizona.edu.

FILTERS

In the optical path of each eye is a twelve-position filter wheel, giving the investigation a total of 24 filter positions. The IMP filters were designed and fabricated by Barr Associates and consist of coatings sandwiched between two substrates of high-quality glass. The substrates are bonded together by an aluminum ring that seals the optical coatings. The individual filters are 12 millimeters in diameter and are spring-mounted in the filter wheels. The IMP group has two one-inch diameter witness filters for each filter. These filters can be made available by agreement with Peter Smith for ground-based observational programs. Four wheel positions (eight filters) are used for atmospheric investigations and eight wheel positions (15 filters and a diopter lens) are used for geological/stereo investigations. The atmospheric filters are designed for direct observations of the sun through the Martin atmosphere and include neutral density coatings that reduce transmission to less than 0.1%. The geology positions include three wheel positions for stereo viewing that have the same filter in each eye and one position that has a diopter lens to allow close-up viewing of the magnet mounted on the camera tip plate. This provides a total of twelve separate geology wavelengths for visible and near-IR spectroscopy. Details on the spectral shapes of the filter transmissions can be provided by the IMP group. The solar filters have one common wavelength in each eye giving seven separate wavelengths for direct solar atmospheric spectral observations. A listing of IMP filter characteristics and wheel positions is shown below in **Table 1**.

LEFT EYE			**Filter**	**RIGHT EYE**			
Center (nm)	**FWHM**	**Trans (%)**	**Position**	**Center (nm)**	**FWHM**	**Trans (%)**	**Application**
440	35	60	0	**440**	35	60	Stereo Geology
450	5	0.08	1	**670**	5	0.04	Solar
885	5	0.1	2	**947**	45	0.03	Solar
925	5	0.1	3	**935**	5	0.1	Solar
935	5	0.1	4	**990**	5	0.08	Solar
670	20	70	5	**670**	20	70	Stereo Geology
800	20	70	6	**750**	20	70	Geology
860	20	70	7	**Diopter Lens**			Geology
900	30	70	8	**600**	20	70	Geology
930	30	70	9	**530**	30	70	Geology
1000	35	60	10	**480**	30	60	Geology
965	35	60	11	**965**	35	60	Stereo Ranging & Geology

Table 1: IMP Filter Positions

CCD SYSTEM AND IMP ELECTRONICS

The IMP CCD system was provided by the Max Planck Institute for Aeroonomy (MPAe) located in Lindeau Germany. It is based on a 512x512 Loral CCD with anti-blooming and was originally developed for the European Space Agency's Hugyens Probe Descent Imager and Spectral Radiometer (DISR). The IMP greatly benefited by the engineering and testing that had already gone into the development of the DISR. The system consists of the camera mounted CCD and pre-amplifier board, and the CCD-readout board mounted in the Pathfinder VME electronics enclosure. A block diagram detailing the relationship of the system components are shown in **Figure 4**.

The CCD is divided into three major areas, two active areas corresponding to the right and left eyes, and a covered readout zone. The features of the CCD are shown in **Figure 5**. The two eyes are identical 248x256 pixel sub-arrays and are separated by a 12 pixel “dead zone” to minimize cross-talk. The remaining 512x256 sub-array is the readout zone that allows the CCD to electronic shutter. Pixel well capacity is between 1,000 (DN=40) and 125,000 (DN=4095) electronics. The CCD is linear in the range between 40-4095 DN to less than 1%. In imaging, the charge accumulated by the active sub-arrays is initially moved to the covered sub-array in approximately 0.5 milliseconds. Once the imaging charge has been moved, the DN’s are readout into the frame buffer board. The readout process takes approximately 1.25 seconds and the data is digitized to 12-bits. Other features of the CCD include a 8 pixel-wide covered dark strip, 4 pixels of “null pixels”, and a two pixel wide border on each edge of the CCD. The dark strip was designed to be covered with an opaque film and provide a dark current standard with every image. However, problems with the film deposition have resulted in a wavelength dependent light leak that are most prevalent in the IR filters. Details of the extent of the light leaks are in the IMP calibration report available electronically on the IMP home page http://lpl.arizona.edu/. The four null pixels allow estimation of the dark current contributed by the serial register to the image as it is read out. The pixels are 23 microns square, but 6 microns of one side are occupied by the anti-blooming gates, so the active area of a pixel is 17x23 microns. Shown in **Figure 6** are the expected exposure times as a function of wavelength and solar zenith angle for Mars solar distance and an optical depth of 0.3.

IMP STEPPER MOTORS

The drive motors and gearheads for the IMP azimuth and elevation gimbals were designed and built by the American Technology Consortium of Camarillo, California. The motors are dual phase drive, 45° step and deliver 12 inch-pounds of torque at room temperature. They are equipped with a three-stage reducing gearhead with a total gear ratio of 81.3 to 1. This produces a step size of in azimuth and elevation of 0.5535°. There are 646 total motor steps in azimuth and 332 in elevation. A single image is 25.3 by 26 steps. The standard step rate is set at ten steps a second. Changes to the stepping rate will require changes in the IMP camera parameter table. This will not be done on a routine basis and any suggested changes need to be strongly justified.

The stepper motor drive system has an angular "play" (backlash) which produces an uncertainty in pointing accuracy of approximately 1.2° in azimuth and 0.65° in elevation. The problem is that the tolerances in the motor and the three-stage gear reduction build up to the point where within the final position of the IMP it is possible to have approximately 1.2° of play (in azimuth for example) that is not restrained by the motor’s magnetic detent. The uncertainty rises from where within that range the IMP will come to rest. If there is a force acting in a predictable direction on the IMP, that force will move the IMP to one side or the other of the 1.2° range. Experience has shown that for azimuth we can use the IMP power/telemetry cable as a drag force, and thus increase pointing accuracy to approximately 0.1°. The basic pointing rules for accuracy in azimuth are that small movements of the camera result in the 1.2° uncertainty. Large movements of more than 80 motor steps where the final direction is clockwise will drag the IMP cable sufficiently to preload the motor system for accurate pointing. For images that require high precision in pointing, it will be necessary to make a camera slew of >80 steps and approach the desired location from a clockwise direction. The error in motor backlash is discussed in Chapter 2 and there is a figure that summarizes calibration results for the magnitude of error over the range of IMP movements.

CALIBRATION TARGETS

The IMP has two radiometric calibration targets mounted on the lander and four sets of color calibration targets (5 colors each) mounted next to each magnetic properties array and each radiometric target. A radiometric target and a set of color "chips" are shown in **Figure 7** and the locations of the targets on the Pathfinder Lander are detailed in **Figure 8**. There are two additional sets of color targets mounted on the rover All calibration targets were made by casting either paint pigments or common ferrous oxides in a matrix of GE transparent silicone binder (RTV655). The molds were bead-blasted with 30-micron glass beads to produce a nearly Lambertian surface on the castings. Although these materials were selected for their resistance to degradation from UV-radiation, the strong UV environment on Mars can cause some spectral changes. Our testing shows that the rate of change drops off sharply after a few weeks equilivient exposure with the color of the targets stabilizing after a few more weeks of exposure. The targets were irradiated for approximately 110-equilivant Martian days to stabilize the spectral behavior.

The pigments for the 5 colors comprise three iron oxides: hematite (red) maghemite (redish-brown), and goethite (yellow) and two additional color reference targets are Green (chromium dioxide paint pigment) and Blue (cobalt blue paint pigment). Reflectance spectra of the color targets are available from the IMP group The radiometric targets are a bullseye target consisting of an outer black ring, then a gray ring, a white ring, with a black-painted shadow post in the center. Pigments used for the radiometric targets were: Rutile (TiO_2 , white), carbon black (black), and a mixture of rutile and carbon black (gray). The radiometric targets are

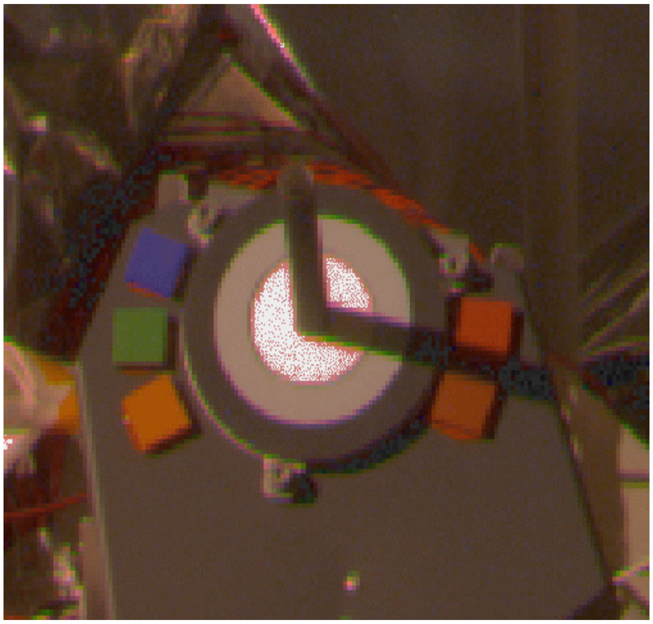


Figure 7: IMP radiometric target and color chips.

mounted on an aluminum fixture that also holds the shadow post. This fixture is bolted to the spacecraft. The Color chips are bonded to the spacecraft.

DATA STREAM AND COMPRESSION

Commanding the camera system is accomplished through a sequence of commands that are time tagged and stored in RAM. These commands can either be from already stored sequences or newly generated sequences that have been uplinked to respond to changing mission conditions. The structure and content of the imaging commands will be discussed in detail in Chapter 3.

The IMP data stream begins on the active image area. Before an imaging is commanded the anti-blooming gates are dropped to clear charge in the active area. The exposure begins when the anti-blooming gates are raised and the CCD begins to accumulate electrons in the pixel charge wells. At the end of the set exposure time the image is transferred row by row to the storage area in the covered portion of the chip. This takes less than 0.5 milliseconds. During the time it takes to accomplish the transfer additional electrons build up in the active area, producing a longer exposure in the last row transferred than the first. This is the electronic shutter effect that can be removed by on-board processing as part of the IMP imaging command structure. The storage area is than read out to the IMP Frame Buffer Board (FBB). The FBB contains sufficient memory for the storage of one set of left and right IMP images. The data stays in the FBB only long enough to allow the Pathfinder AIM computer to recognize its existence and to read it to main memory. Once in the AIM computer the image is processed as required in the imaging command. This includes performing dark, flat, and electronic shutter corrections, sub-framing as necessary, and compression.

Several types of data compression are included in the IMP software package. Lossless compression using the Rice algorithm developed at JPL will be the workhorse for the IMP images as long as we have a data rate of several thousand bits per second. For non-science or low data rate scenarios a lossy compression using a modified JPEG compressor developed at the Technical University of Braunschweig will normally be used. Other methods of conserving downlink resources include sub-framing the image, row and column averages, and pixel averaging. Examples of this are most of the atmospheric science images of the Sun which will be returned as 30x30 pixel blocks centered on the Solar disk. Row and column averages will be used for sky images, as this gives the gradient and the edges of cloud features, but not the high resolution of an image. Pixel averaging can be used were full resolution is not needed. The limitation on pixel averaging is that the blocks of pixels averaged can be no larger than 9x9. Also, these methods can be used in combinations for highest compression.

Each IMP scene can use 4 calibration images to correct for internal camera behavior. These are the zero-exposure image, dark, zero-exposure dark, and flat field. Note that only one image, the actual scene exposure, is required for any given scene to be corrected, since the other exposures can be generated from software based on previous exposures.

After processing the image is stored in a APID for eventual downlink. The APID’s are AIM storage buffers for the downlink queue. Their structure imposes two major limitations on science options: First, the APID’s, from the IMP operations point of view have only two operations, they can be read out sequentially or erased. No other operations are possible Imaging data that goes into an APID comes out in the same order. We cannot search an APID and just downlink those images or sequences that we want. Also we cannot selectively erase unwanted data from an APID. The entire APID is cleared, or noting is erased. Second, there are only a limited number of APID's available to IMP and this number cannot be increased during the mission. Each APID is assigned to a particular instrument or type of measurement. IMP has 4 APID's for science data, one for rover support, two for mission related imaging and one for engineering data. These are the only APID's formatted in the ground support system to accept IMP data. Downlink priorities for the APID's are set by the Pathfinder project with input (but not control) from the science team. The operation result is that we have to be very careful how we structure the storage of data. High priority data needs to be stored in a APID that will be downlinked promply. Backup data needs to be stored in a low-priority APID and, if not needed, erased. Any data stored in a low priority APID is likely to be lost rather than expend the bandwidth necessary to downlink a large percentage of a low priority APID. Remember that the data is read out of the APID sequentially so that any low priority data that went into an APID first, comes out first. If the team wants rapid access to critical data, the readout will depend on what is in front of that data in the APID.

DOWNLINK LIMITATIONS:

The standard IMP product will be a single image consisting of header that contains the time-tagged command information, a unique image identifier, and an array of the DN's produced by that image. The major constraint on IMP data sets is the downlink resources available to Pathfinder. Optimistic scenarios put the downlink data rate at approximately 5000 bits per second for several hours per day. The standard planning assumption is that total daily downlink may reach 28 Mbits per day, assuming good DSN locks and good solar panel performance. However, science cannot expect all of this downlink bandwidth. Approximately 4 Mbits/day of engineering data will have to be accommodated and the engineering data often has higher downlink priority than the science. Downlink resources are the scarce factor in the Pathfinder Mission and it is a very limited science downlink budget that the Science Team will spend. Shown in **Table 2** is a chart detailing the “bit costs” for different types of imaging. A single uncompressed IMP image can be as large as 0.788 Mbits and it would take only 35.5 full uncompressed IMP images to use up an entire days downlink. Without compression and intelligent planning, the downlink bottleneck can easily become a serious problem for IMP science.

CHAPTER TWO

CAMERA PARAMETERS

This section summarizes measured IMP parameters so that a user composing command sequences for data collection, or a user of the data after it has been taken, will have a conception of the camera performance levels.

STRAY LIGHT MAP

Stray light is unwanted light which reaches the focal plane. This light adds data numbers to pixels in the image which do not result from the optical intensity of the part of the scene which should geometrically correspond to those pixels. Stray light is measured by taking images in the presence of a light source of known intensity and geometry. The data numbers which exceed system noise in pixels outside the image of the source are attributed to stray light. A mosaic of images taken around 4π steradians with a single fixed light source is a stray light map. For the IMP, a smaller set of pointing directions (about +/- 40° from the optical axis) can possibly contribute to stray light due to the camera entrance window geometry. The limits to stray light measurement are system noise and scattered room light. These limits are extended by increasing exposure time with angle away from the light source, and by constructing appropriate light baffles. The source subtended 6 milliradians. A set of baffling was used as shown in Figure 1. In addition to sealing the system from room reflections, the IMP itself was baffled with black material formed to follow the camera contours. The extreme darkness of the stray light map frames 50° from the source indicates that the baffling is sufficiently effective to permit measuring stray light at less than one part in 100,000.

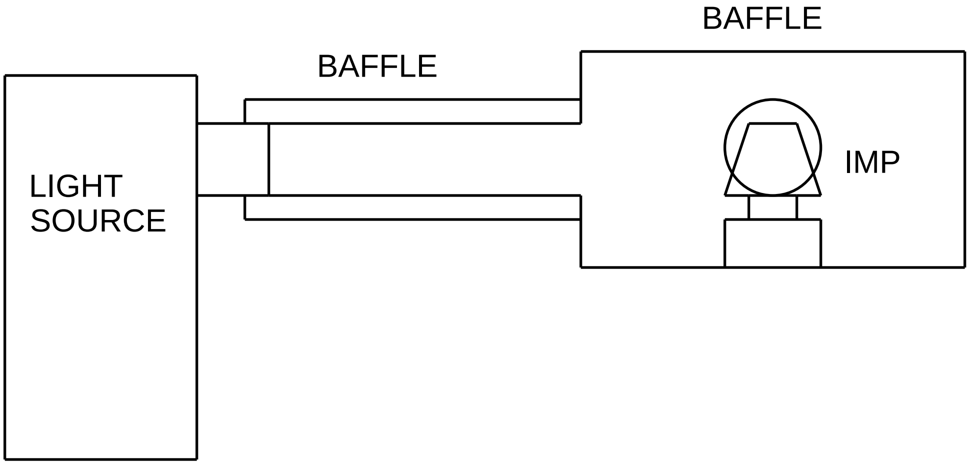


Figure 1. Stray Light Mapping Equipment

The resulting stray light map, compiled from the calibration data, is shown below. Each plot represents a vertical or horizontal slice of the total stray light map for each eye.

LIGHT SCATTERED INTO THE FIELD OF VIEW

The IMP images over a field of view about 14.3° wide using the active area of the detector array. Light from a somewhat larger full angle (about 80 degrees) enters the camera window directly. This overfilling of the field of view by an extended scene (e.g., the Mars surface) results in additional light entering the camera outside the field of view. The amount of stray light appearing within the field of view due to illumination outside the field has been measured for the IMP. Data was collected at 1 mm intervals from contact between the integrating sphere exit port to a separation of 50 mm.

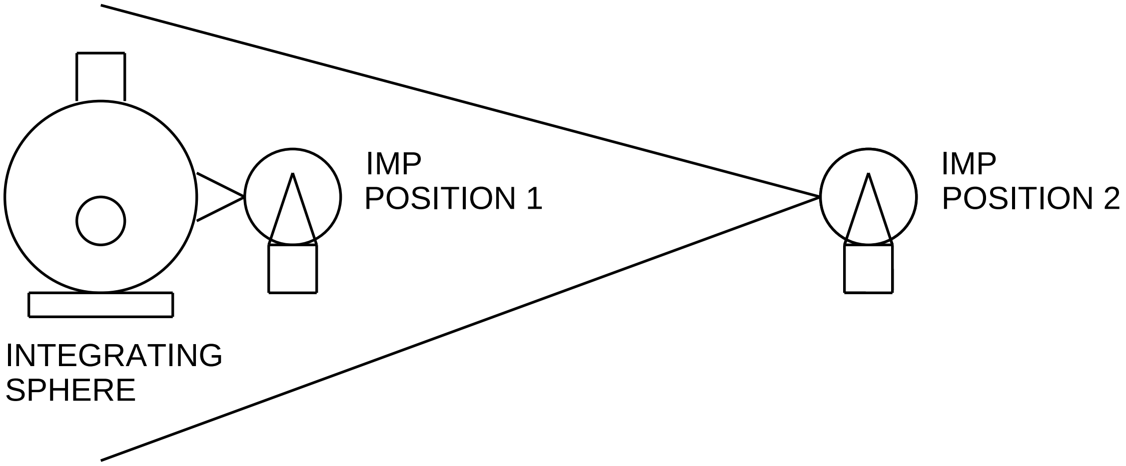
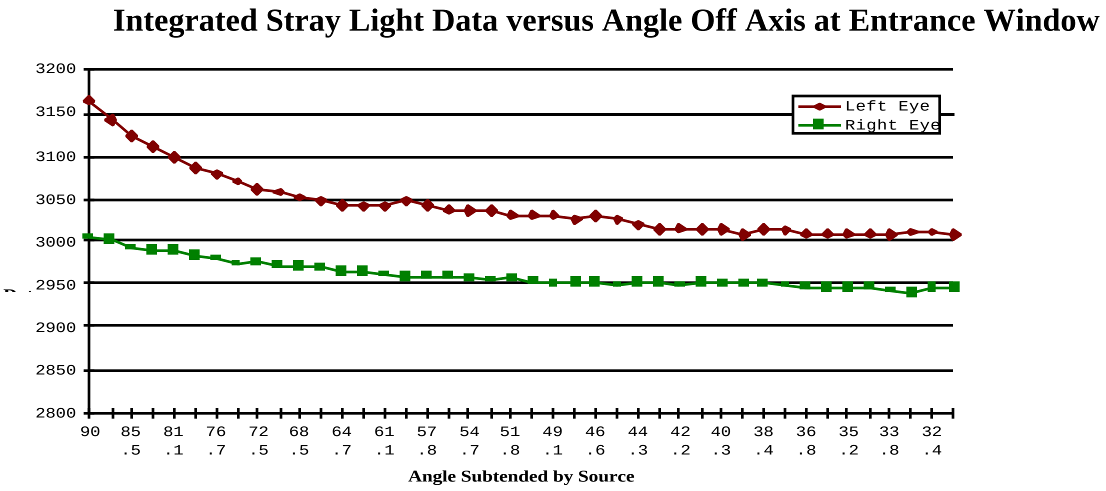


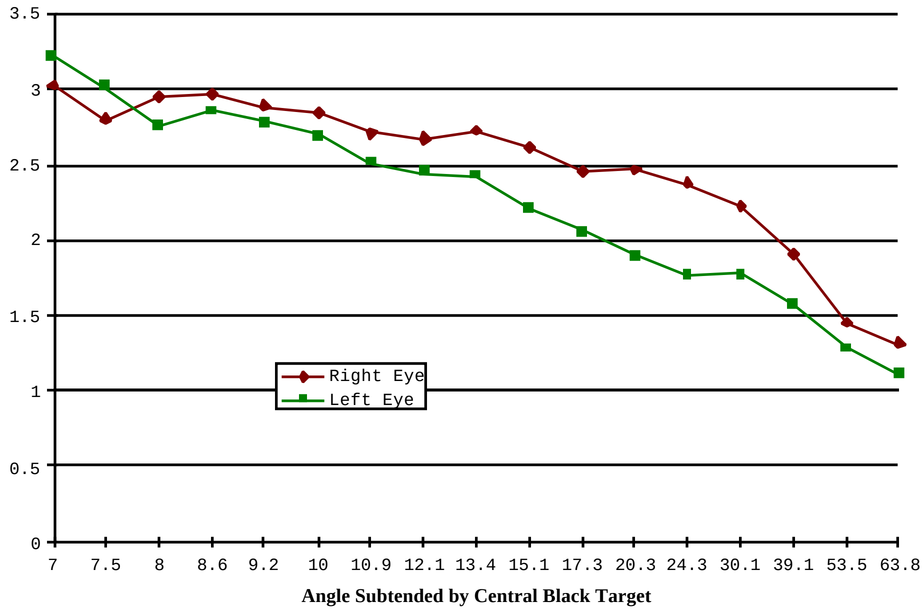
Figure 2. Flat Field as a Function of Distance.

The plot below shows how the integrated stray light due to overfilling the field of view increases with scene subtense half angle at the entrance window. Completely overfilling the field results in integrated stray light of 5.03% in the left eye, and 2.12% in the right eye.


Integrated Stray Light Data versus Angle Off Axis at Entrance Window

FORWARD SCATTERED STRAY LIGHT DETECTION.

The forward scattered stray light was integrated by using a large white target with a small black area in the center. In the absence of forward scattered stray light, the black center portion of this target should image near the level of dark current. Thus, by looking at the number of data counts in the black region versus the white region of the target, the forward scattered stray light may be measured. As the target approached the camera from the distance at which it just filled the field of view, the size of the black area increased (ie the angle which it subtended). This caused a decrease in the amount of forward scattered light into the center of the field of view. The integrated forward scattered light at the center of the field of view is about 3% in each eye.



Light Scattered into the Field of View

BAD PIXEL MAP

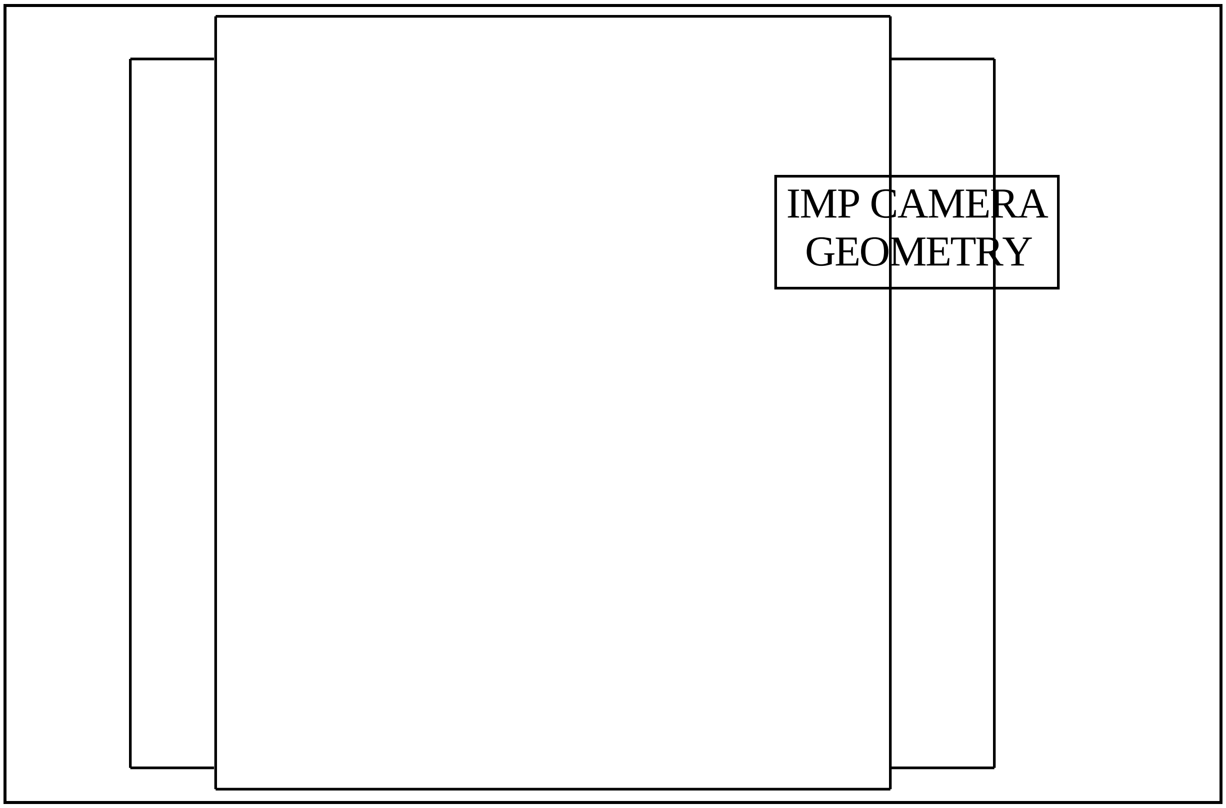
The bad pixel map can be categorized into three groups of pixels: hot strip, high variability, and vignetted pixels. Hot strip pixels have higher than average dark currents but they also fail either the variability or linearity test or both. The camera images also contain some corner pixels which have such severe vignetting that their variability is an order of magnitude greater than the average pixel. Thus, they can not be flat fielded with any accuracy. The vignetting is due to the front edge of the fold mirror mount interfering with the edge of the beam. Finally, some pixels have highly fluctuating dark currents, or fail the linearity test Their standard deviation in ten flat sample ranges from 1.63% to 6.6%. The cause of their high variability is not known.

The following table lists all three types of bad pixels. In the figure that follows, bad pixels are indicated as black, and the origin from the table data is taken at the lower left hand portion of each image.. The most critical filter for bad pixels was found to be filter 0. It had the largest no of bad pixels by any criteria. The total number of bad pixels for the left eye is 12 and the right eye is 92.

IMP BAD PIXEL TABLE

	Left Eye	Right Eye
Hot Strip	(none)	(187,0 to 43)
		(188,0 to 43)
Severely Vignetted	(245,255)	
	(246,255)	
	(247,248 to 255)	
High Variability	(186,189)	(84,21)
	(227,52)	(92,123)
	(191,163)	
	(211,63)	

GEOMETRIC PARAMETERS



Toe-In

Filter (Wavelength)	Left Eye (Q_L)	Right Eye (Q_R)	
0 (440 nm)	12.44	-24.66	radians
5 (670 nm)	13.05	-24.68	radians
11 (965 nm)	12.55	-24.45	radians

Lens-to-Fold-Mirror Distance

	Left Eye (V_L)	Right Eye (V_R)	
Baseline to Entrance Pupil	0.0623	0.0623	meters

Stereo Baseline

	Left Eye	Right Eye	
Half Baseline (W)	0.075	0.075	meters

Lens-to-CCD Distance

	Left Eye (h_L)	Right Eye (h_R)	
Exit Pupil to Focal Plane	0.0234	0.0234	meters

Detector Spacing

	Left Eye	Right Eye	
Pixel Spacing	2.30E-5	2.30E-5	meters/pixel

Image Scale

	Left Eye	Right Eye	
Scaling (theta)	0.000981	0.000985	radians/pixel

Stereo Alignment

Filter (Wavelength)	Toe-in:Left Eye	Toe-in:Right Eye	Boresight	
0 (440 nm)	12.44	-24.66	-0.82	radians
5 (670 nm)	13.05	-24.68	-0.13	radians
11 (965 nm)	12.55	-24.45	-0.13	radians

GEOMETRIC DISTORTION MAP.

The distortion is under 0.05 milliradians per pixel, and unmeasurable. Please see Appendix C of the Calibration Report for details.

POINTING ACCURACY AND REPEATABILITY

Raw pointing accuracy data from JPL system tests indicate pointing errors of 1.5° in azimuth. Using the azimuth backlash pointing rules and determining the coordinate frame offsets allows reducing this by an order of magnitude to 0.15°. The elevation backlash is not so predictable. The overall pointing error is about +/-0.65°.

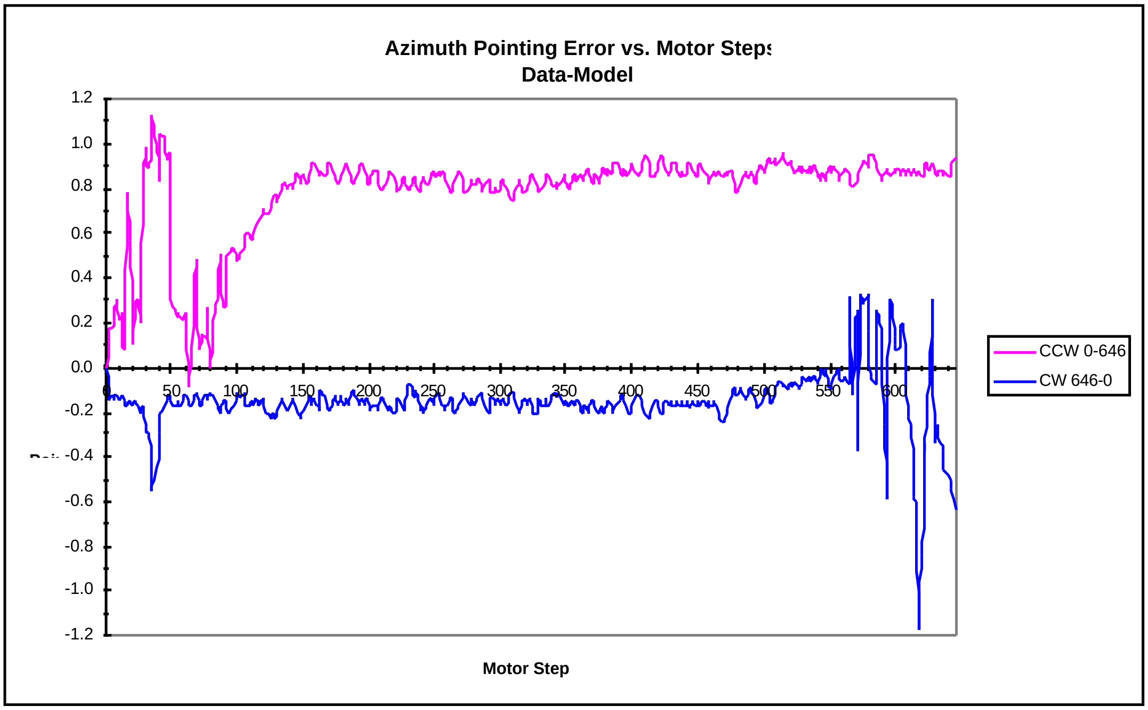


Figure shows the observed error from AZ two step pointing data going from 0 motor counts to 646 motor counts and then returning.

Dark Current

The dark current is an exponential function of temperature and a linear function of integration time. The dark current is the sum of currents produced in the CCD active imaging area, the frame storage for readout area, and the serial readout register, added to the hardware offset. The dark current is about 30 data numbers per second at 22 C, and is below 1 DN/sec at -20 C. The scaling factors which give the time and temperature dependencies for the average dark current are:

$$DN = A_D t e^{B_D T} + A_S e^{B_S T} + A_N e^{B_N T} + 16.0$$

OFFSET = 8.7 DN:

$A_D = 3.016$
$B_D = 0.105$
$A_S = 2.845$
$B_S = 0.105$
$A_N = 2.28$

$B_N = 0.105$

CHAPTER 3

IMP COMMANDS AND SEQUENCES

IMP COMMANDS:

Most members of the Science Team will not routinely prepare IMP commands. The building of commands and sequences will be restricted to a few members of the science team and the JPL operations staff. Team members will, however, be providing inputs for commands and sequence construction. The inputs will need to correspond to the established formats and allowable ranges for the commands. In this chapter we will review the structure of an IMP imaging command, how the commands fit into sequences, and how sequences are executed on the spacecraft.

The IMP command structure and commands are described in the Pathfinder Flight Software document (D-12500, PF-200-7.2a) pages 168-201. Most of the IMP commands are not applicable to science team activities and will not be discussed here. The relevant commands are those that command the camera to take and process imaging data. There are five commands that initiate imaging: IMP_IMAGE_AZ_EL, IMP_IMAGE_LCLGRD, IMP_IMAGE_LCLVEC, IMP_IMAGE_OBJECT, IMP_IMAGE_VECTOR. These “IMP_IMAGE” commands all have the same basic structure and differ primarily in the method for determining camera pointing coordinates. In the following section I will review the command structure of IMP_IMAGE_AZ_EL and then specify the differences between it and the other imaging commands.

An IMP imaging command is a formatted string of up to 18 16-bit words that specifies the parameters that can vary with each image for mode, type, location, processing, and storage. An example of a command string is:

```
        IMP_IMAGE_AZ_EL("IMPIMG",20,8002416,"AUTO",3,"RIGHT","IM",254,114,40
00,2500,0,5,"ARLCT",TRUE,TRUE,TRUE,TRUE,FALSE,FALSE,FALSE,FALSE,0,255,0,255
,12,0,2,2)
```

The location of the parameters in this string corresponds to the order of parameters listed below. The command also relies on additional parameter values that don’t vary with imaging, set in the IMP Flight Software Parameter Table for allowable ranges of operation and the definition of modes of operation. The FSW Parameter Table is read into RAM and can be changed by uplink if necessary. For the IMP_IMAGE_AZ_EL there are 30 possible parameters in the command string. This command initiates a single image to be taken using absolute azimuth and elevation motor counts as the coordinate system. As such it does not rely on the FSW or Lander for any pointing or target information. The absolute pointing begins at the azimuth and elevation hard stops and moves by pulsing motor steps from those locations. As part of the command the following parameters must be specified:

cmdtyp: IMPIMG, DRKCUR, FLTFLD, ATMOS This specifies the type of imaging commanded. This can be a normal image (IMPIMG), a dark current for the dark current correction table, a flat field for the flat field correction table, or an atmospheric image. The atmospheric image has an extra processing step that confirms that the image contains the sun. If the sun is not imaged then the frame is not stored.

apid:	The APID number specifies the downlink storage buffer for this image data. The specification of an APID (given the downlink priorities set by the Project) will determine how soon, if ever, this data is downlinked.
imgid:	Image ID. In the uplink the image ID is always even. Since every imaging command produces two images, the left frame takes the even image ID and the right frame takes the next odd ID. As a result all odd numbered images will be right frames and all even numbered images will be left frames.
exptyp:	Exposure type for the image. The allowable parmeter set is: NONE, MANUAL, PRETMD, AUTO, INCR. A no exposure is for configuring the camera prior to the start of imaging or a reboot. Manual exposure sets the time for a single exposure. Pre-timed uses the exposure time of the previous image. Auto exposure takes several test images and processes them to check the levels against parameters that are set later in this command sequence. It adjusts the exposure time until the scene is within the set requirements. Only one image is produced and saved to an APID from a set of test auto exposures. Until we understand the operation of the IMP on the surface of Mars and have analyzed the imaging data, most of the commands will use auto exposure. Incremental use the last auto-exposure setting to start a new auto exposure series. It has the advantage of using the experience of the previous settings to save time on finding the appropate exposure time.
expcnt:	"Exposure Count" sets the maximum number of exposures to take for AUTO or INCR. Typical values are 2 to 5.
Frmtyp:	"Frame type" specifies the which frames to extract from the CCD. Since the IMP provides a left and right frame with each exposure, this allows the trashing of an unwanted frame. Allowable values are LEFT, RIGHT, HLEFT, and BOTH. The HLEFT flag activiates a half exposure which results in only a left frame. A full exposure always produces both left and right frames.
dwnlod:	An IMP image also includes a dark strip and null pixel data. This flag allows the specification of which data to write to an APID. Since Pathfinder is so downlink limited dark strips should be downlinked only with necessary. Null pixels are typically not downlinked **Table 2** details the bit costs of each imaging action and the dark strip bits. Note that for some subframes the dark strip bits can be as much as three times the actual data bits.
azimth:	This specifies the azimuth location in motor counts from the hard stop for the center of the image. Allowable values are 0 to 650.
elevtn:	This specifies the elevation location in motor counts from the lower hardstop for the center of the image. Allowable values are 0 to 332

inttim:	Specifies the integration time for manual exposure and the starting argument for auto exposure. The IMP can expose in 0.5 millisecond increments from 0.0 to 32767.5 milliseconds.
datact:	Data cut number used for auto exposure. This value is used with the pixel fraction number specified later in the command stream. The data cut is the DN minimum value of the highest fraction of pixels specified by the fixel fraction number. For example a data cut of 2000 and a pixel fraction of 10% means that 10% of all pixels must have DN above 2000.
fltrnm	The filter position number specifying the filters to be used. Table 1 details the filters that correspond to each filter position. There are 12 positions and they are numbered 0 to 11.
pixfrc	Pixel fraction number used for auto exposure. This value is used with the data cut number specified previously in the command stream. The data cut is the DN minimum value of the highest fraction of pixels specified by the fixel fraction number. For example a data cut of 2000 and a pixel fraction of 10% means that 10% of all pixels must have DN above 2000.
cmptyp	Type of compression to be used on the data. Compression options available for the IMP were discussed in chapter 1. This command specifies three types of compression: Rice, JPEG (using either Huffman tables or arithmetic), and LCT (Least Cosine Transform). The JPEG and LCT can be specified as a compression ratio or a quality factor and both can use either Huffman or arithmetic. The Rice compressor is used for lossless compression. Parameters for the value of the quality factor or compression ratio are set later in the command stream.
shtflg	Shutter flag to turn on the automatic removal of the electronic shutter effect from the image.
badpix	Bad Pixel flag for the automatic replacement of bad pixels on the image before downlink.
darkcr	Dart current correction flag for automatic processing of the image using the current dark current correction table.
flatfd	Flat field correction flag for the automatic processing of the image using the current flat field correction table.
hstgrm	Histogram flag. This uses the image to create a histogram of the DN values. Only the histogram will be stored and downlinked.
sumflg	Row and Column sum flag. This uses the image to create a row and column sum of DN values. Only the sums are stored and downlinked. This is intended to be used with solar images to further enhance the effective compression over the small subframes typically used.

sqrflg	Flag for enabling the square root compressor. This uses a square root algorithm to reduce a 12 bit pixel down to 8 bits prior to additional compression being performed. The primary use is to reduce the noise component of the pixel value. This way the normal compressors are not attempting to compress as much noise and can be more effective.
sfrmfg	Sub-frame flag. This indicates that only a sub-frame of the image will be downlinked. The next four parameters specify the size of the subframe and are only used if this flag is set to TRUE.
minrow	Minimum row for the sub-frame
maxrow	Maximum row for the sub-frame
mincol	Minumum column for the sub-frame
maxcol	Maximum column for the sub-frame
cmpdtv	Values for the quality factor or compression ratio to be achived if the compression type set in cmptyp requires a ratio or factor. Allowable values for the quality factor are a percentage between 1-99 and for the compression ratio it is a range from 2-255.
qtable	This specifies the quantization table index for JPEG compression.
pxbwth	The final two parameters allow for averaging pixels in an IMP image. This command specifies the x-averaging factor that can be between 1 and 9.
pxbhit	For pixel averaging this specifies the y-averaging factor that can be between 1 and 9.

The IMP imaging commands IMP_IMAGE_LCLGRD, IMP_IMAGE_LCLVEC, IMP_IMAGE_OBJECT, IMP_IMAGE_VECTOR vary from IMP_IMAGE_AZ_EL in how the location of the center of the imaged area is specified.

IMP_IMAGE_LCLGRD initiates a single image using the local grid coordinates supplied by the Pathfinder computer. The Pathfinder will establish as soon as possible a local grid system based on a local level coordinate system. This command and the IMP_IMAGE_LCLVEC command will image using this system. The parameters gridx, gridy, and gridz specify the imaging location in the local coordinates. The flight computer performs the transforms necessary to put those coordinates into motor steps.

IMP_IMAGE_LCLVEC initiates a single image by specifying a unit vector in the local level-based coordinate system. The new parameters for this type of pointing are vectrx, vectry, and vctrz.

IMP_IMAGE_OBJECT: The flight computer maintains the time-variable location of a number of “objects” such as the Sun, the Earth, and standard stars. By specify the object parameter the computer will supply the current coordinates necessary for imaging the object.

IMP_IMAGE_VECTOR: Initiates a single image to be taken using a unit vector in the camera head based system. This allows the commanding of an image using only a vector from the camera head. The new parameters for this command are vectrx, vectry, and vctrz.

Four other IMP commands should be mentioned. The IMP_CCD_HEATER command turns on the heater for the CCD. This is intended to minimize the temperature excursions during imaging by warming the chip up in the morning. This way more images are obtained at a consistant CCD temperature, reducing the need for frequent dark current updates. The IMP_INITIALIZE command is intended to reset the position of the IMP by moving the gimbal and filter wheel motors to a known position. This will be used by the IMP Instrument Engineer if the gimbal drives drop steps and miss their intended position or if the filter wheel comes to rest between filters. IMP_PWR_WINDING command heats the gimbal motors and gearheads without moving. This allows the IMP Instrument Engineer to respond to the possibility that the cold Martian night will freeze the lubricant in the gimbal drive system.

USING IMP COMMANDS:

To command the camera, IMP commands are strung together chronologically into an image SEQUENCE. A particular observation (imaging an area of the landing site in several filters, for instance) is given a sequence name, and the sequence begins its life as ASCII file containing the particular IMP commands of interest. These ASCII files are called Spacecraft Activity Sequence Files, or SASFs. SASFs can be generated manually with a simple text editor, or with a Graphical User Interface (GUI) editor such as SIMP. Once the SASF has been created it is sent to the JPL Operations team. The operations team runs the SASF through a sequence generation process which checks the SASF for errors, tests the sequence in the testbed, and creates a description of the sequence (see below). The sequence is then radiated to the spacecraft and executed.

In addition to the SASF, the Sequence of Events (SOE) is generated for managing the sequence and the resulting downlink. The SOE is a full description of the sequence, including execution times. SOE files are generated by the operations team and it is highly recommended that the SOE be used as the reference document for a particular observation and not the SASF.

The first 4 digits of the 10-digit Image ID are reserved for the 4 digit sequence name. For instance, any image from sequence S0022 must contain an image ID which begins 0022xxxxxx. By convention the last 6 digits increase chronologically. Reminder: the last digit is automatically EVEN for left-eye images and ODD for right-eye images. Therefore, remember to increment the Image IDs by at least 2 for each image command.

Listed below is a selected list of IMP related sequences. See these for detailed information concerning sequence format.

S0001	Pre-deploy Red and IR panorama
S0002	Rover Deployment panorama
S0005	Radiometric Calibration Target (Lower)

S0008	Mission Success panorama
S0022	Airbag Assessment panorama
S0030	Predeploy 5-color panorama (quadrant #1)
S0031	Predeploy 5-color panorama (quadrant #2)
S0032	Predeploy 5-color panorama (quadrant #3)
S0033	Predeploy 5-color panorama (quadrant #4)
S0062	Magnetic Plate (upper)
S0068	Windsock pairs
S0072	Rock Multispectral
S0071	APXS Site images