MER/Pancam Data Processing User's Guide

Jim Bell*, Jonathan Joseph and Jascha Sohl-Dickstein (Cornell University)

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1. Introduction

This document (a) describes the calibration procedure that is applied to MER/Pancam raw Science Experiment Data Records (EDRs) in order to generate radiometrically calibrated Science Reduced Data Records (RDRs), and (b) provides additional ancillary information about Pancam and Pancam data that may be useful to scientists or engineers working with the data. The MER/Pancam calibration procedure ("pipeline") consists of, at present, seven steps: (1) 8-bit to 12-bit decoding; (2) bias subtraction; (3) dark current subtraction; (4) "shutter" (frame transfer) smear subtraction; (5) correction of pixel-to-pixel responsivity variations (*i.e.*, "flatfielding"); (6) radiance calibration; and (7) conversion to integer format. Some of the steps are optional depending on what processing was done on-board and how the image was compressed for transmission to Earth.

*To whom correspondence should be addressed: jfb8@cornell.edu

2. Pancam Description

What follows is an abbreviated discussion of the Pancam instrument, focusing on aspects of the detector and electronics that are most relevant to calibration. For a more detailed description of the Pancam instrument, see Bell *et al.* (2003).

There is a left and right Pancam on each rover. Each of the four Pancams uses a 1024x2048 frame transfer CCD detector. One half of the pixels (1024x1024) are used as the active imaging area and the other half, which is masked from illumination, is used as a storage/readout area (Fig. 1). At the start of each exposure, any charge accumulated on the detector is flushed. At the end of the nominal exposure time, charge accumulated in the imaging area is rapidly shifted (shift time = 5.12 ms) to the adjacent masked area. During the readout process, the charge is clocked out, row by row, into a horizontal serial register for subsequent amplification and digitization. The readout rate is 5 ms per row, leading to a total readout time of approximately 5 s per full frame.

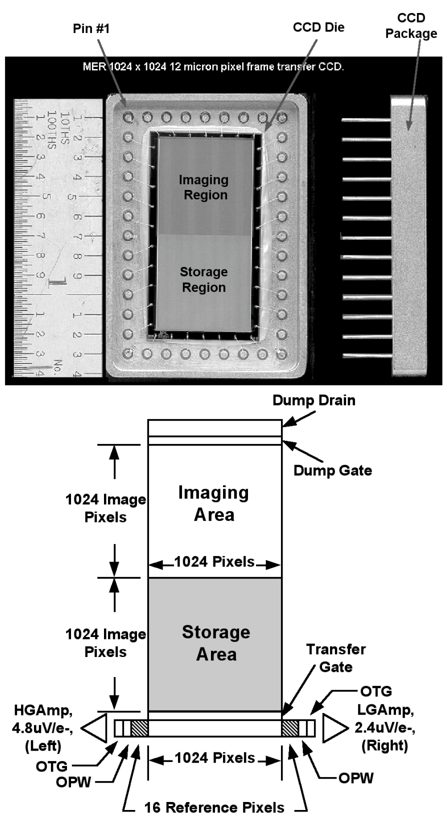

Figure 1. MER CCD package and schematic representation.

Due to the confined space on the camera bar, the left Pancam is rotated 180 degrees relative to the right Pancam. The images stored in the EDRs, however, have already been rotated so that "up" in the image (higher row number) corresponds to "gravitational up" in the scene. As a result, effects such as transfer smear (see below) appear to be in opposite directions in the left and right images. In order to simplify the calibration code, images are first rotated (if necessary) so that decreasing row number is towards the readout serial register. In this document, the direction toward the serial register will be referred to as "down" or "downstream" in CCD space. After all calibration steps are performed, the image is rotated back to its original (real-world) orientation for RDR generation.

Because the rapid transfer of charge from the active region to the masked region is not instantaneous, a small amount of additional charge accumulates as the charge is shifted downstream row-by-row. As the charge is shifted, a given row ***n*** will pick up an additional component of charge from each downstream row (***1*** to ***n-1***) that is proportional to the amount of light incident on that row. This additional charge accumulation is referred to as **electronic shutter smear**. The same amount of additional charge also accumulates during the flush operation immediately preceding the image exposure.

Shutter smear (along with any dark current that accumulates during the readout phase) may be removed on-board by subtracting a zero-exposure image that is taken just before or after the desired image. Alternately, an analytical shutter smear removal algorithm may be applied after the fact. This algorithm can always be applied to full-frame images (either full-resolution or down-sampled). In order to determine the smear component for a pixel at a given row/column, the image value must be known for all downstream row pixels in the same column. Therefore, if images have been sub-framed in rows, the analytical shutter-smear removal algorithm can only be applied if the sub-frame starts at row 1 in CCD space. This will be either the top or bottom of the real-world image depending on the camera. Because of this limitation, on-board shutter subtraction is usually performed when sub-framed images are taken.

3. Calibration Procedure

Raw Pancam images are downlinked from Mars in packetized telemetry and converted to EDRs by the MDOT and MIPL groups at JPL. The raw Data Number (DN) values stored in the images are directly proportional to the radiance that was incident on the detector through each desired filter, modulated by a variety of correctable instrumental effects. The goal of calibration is to reconstruct the true incident radiance using a combination of pre-flight and in-flight test and calibration data to remove the instrument effects. Here is how that process is done for the Pancam Science RDRs released through the PDS:

3.1. 8-bit to 12-bit Resampling.

The Pancam signal is originally sampled with 12 bits per pixel (0-4095 DNs), but the data may be scaled to 8 bits per pixel prior to downlink using one of several look-up tables (LUT) stored on-board the rover. The shape of the LUTs used by Pancam is approximately a square-root function, with a 1-to-1 mapping for low DN values and a many-to-1 mapping for high DN values. Because Poisson noise in detectors like CCDs goes as the square root of the number of electrons detected, the square-root nature of the LUTs provides a way to decrease the number of bits downlinked without statistically significant loss of information (*i.e.,* the noise is not quantized). In this first calibration step, if a 12 to 8 bit LUT was used to scale the data prior to downlink, we simply apply an inverse 8 to 12 bit LUT to restore the Pancam data to its original 12 bit (linearly proportional to radiance) format. Appendix **A** contains the inverse LUTs used for the Pancam instrument.

3.2. Bias Subtraction.

The horizontal serial register on the Pancam CCD contains an additional 32 pixels (16 "prefix" pixels to the left of the main CCD columns, and 16 "suffix" pixels to the right). These reference pixels are read out with each image row, and can be optionally saved to a file for downlink, if desired. When a reference pixel image containing these data is downlinked, it may be used to determine the row-dependent bias level for its associated image, so that the bias may be removed. If a usable reference pixel image is not available, a temperature-dependent model developed from pre-flight calibration data and in-flight performance data is used to remove the bias (Bell *et al.*, 2003).

For our initial calibration, if the reference pixel file is not returned for a specific image, but reference pixel files were returned for the same camera for a different image in the same sequence, then the reference pixel data that is closest in time to and in the same sequence as the image being calibrated is used to remove the bias. If there is no reference pixel data available for the entire sequence then the current approach is to use the model to remove the bias.

3.3. Dark Current Subtraction.

Thermal noise induces electron liberation in most semiconductor detectors, producing a temperature-dependent "dark current" in the devices even in the absence of illumination. This dark current accumulates in both the active (imaging) and masked (frame transfer) regions of the CCD, though the rate of accumulation is different in the two regions (Bell *et al.*, 2003). The temperature dependent models of the dark current in these two regions calculated during pre-flight characterization of the CCDs is used to subtract out the dark current from the images during calibration. For this release of archived data products, only the "initial pixel-by-pixel dark model" as described in the Pancam Calibration Report (Bell *et al.*, 2004a) has been implemented.

The files containing the dark current coefficients are named:

mer_ccd_<ccd>_dark_<region>_coeffs_<ver>.img

where,

ccd = (3 integer) MER CCD identifier. Flight Pancams are:

103: Spirit right Pancam.

104: Spirit left Pancam.

114: Opportunity right Pancam.

115: Opportunity left Pancam

ver = (2 integer) Version identifier providing uniqueness for book keeping.

3.3.1. ***Masked Area Dark Current subtraction***. When the image is in the masked region of the CCD, it gets read out line by line over the course of about 5 seconds. As this happens, the charge is shifted row-by-row until it is shifted into the horizontal serial register and read out. During this time, a given image pixel accumulates a small amount of dark current from each

CCD element in the same column with smaller row number. However, because the amount of time each image pixel spends in the masked region is the same from image to image, regardless of exposure time, it is sufficient to simply model the total dark current accumulation (as a function of temperature) within the entire masked area based on pre-flight calibration measurements – as opposed to modeling the dark current accumulation rates for each individual CCD pixel in the masked region.

If shutter subtraction was done on-board, then the dark current from the zero-exposure image, which should be essentially the same as for the non-zero exposure image, will already have been subtracted, and thus this calibration step can be skipped. Otherwise, the temperature-dependent dark current model for the CCD (Bell *et al*., 2003) is used to compute and subtract the dark current that accumulated during the image readout phase.

3.3.2. ***Active Area Dark Current subtraction***. During image integration, even as light is falling on the active region of the CCD, the thermal-noise-induced "dark current" will be accumulating as well. The temperature-dependent rate of dark current accumulation in the pixels of the active region of the CCD was modeled during the pre-flight characterization of the CCDs (Bell *et al*., 2003) and this model is used to determine and subtract the dark current component that accumulated during image integration. There is no onboard correction for the active region dark current, so this step is always performed during image calibration. In-flight dark current measurements through the solar filters were acquired at different temperatures over the course of both rover missions, and these data are being used to validate and refine the dark current subtraction model. A slightly improved dark model is being developed and will eventually be described and applied in a future data release.

3.4. "Shutter" Smear Subtraction.

After the image integration phase is done, the charge in the CCD is rapidly shifted from the active region of the CCD to the masked region of the CCD. Because there is no physical shutter to block out the light as the charge is shifted row by row under the mask, those rows that are still within the active region are still accumulating signal from the scene. The additional charge that is accumulated during this shifting process is called the "shutter smear". Each row accumulates some additional charge from each downstream row until it reaches the masked region, resulting in a linear "ramp" of additional scene-dependent charge added to each image.

An equivalent amount of charge is also accumulated during the flush prior to image integration as the CCD transfers charge in the opposite direction (upstream). Prior to integration, all the charge is transferred upstream and off the "top" of the CCD. As each row is shifted off the top, the bottom row has zeros shifted into it. As the zero-charge rows are shifted into the active region, though, they begin to accumulate charge. When the flush is done, all rows of the CCD have only the charge they have accumulated since they began shifting through the active region.

A particular row will shift through exactly the same rows (and for the same amount of time) on its way upstream prior to integration as it shifts through downstream once integration is complete. Hence, if the illumination in the scene does not change over the duration of the exposure, the shutter smear component prior to integration as the buffer is flushed will be the same as the shutter smear component after the integration as the charge is transferred to the masked region. As a result, if shutter correction was not done onboard, and the shutter smear needs to be calculated analytically, it is sufficient to perform the calculation for one of those transfers and double the result.

In order to analytically remove the shutter smear for a given row, it is necessary to know the component of the signal that results from light from the scene for all of the downstream rows. As a result, analytical shutter smear removal can only be done on full-frame (either full resolution or down-sampled) images or sub-framed images that start at row 1 in CCD space. The algorithm we use to calculate the shutter smear for a given row is recursive and uses the following equations:

$$scene(n) = signal(n) - smear(n)$$

$$smear(n) = 2\sum_{i=1}^{n-1}\left(scene(i)/exposure\right)\cdot 5\mu\text{sec}$$

$$smear(1) = 0$$

The smear is calculated and removed on a row-by-row basis, starting at row 1 and progressing upstream through row 1024.

3.5. Correction of Pixel-to-Pixel Responsivity Variations.

When the MER-Pancam instrument is presented with a spatially uniform scene, the signal measured by the detector is non-uniform. In general, the non-uniform detector response is a result of either intrinsic responsivity variations among the individual pixels, or induced responsivity variations caused by optics, filters, or other effects like dust specks on a lens.

Normalized flat field files (mean value = 1.0) were generated for each possible filter/CCD combination (Bell *et al.*, 2003, 2004a), except for the neutral density 5 solar filters L8 and R8, which could not be adequately illuminated during pre-flight calibration to obtain flatfield images. The standard deviations for these flat field values have also been saved and can be used in error propagation. The flat field and standard deviation image files use the following naming convention:

Flat field image: MER_FLAT_SN_<ccd>_<eye><filt>_V<ver>.IMG

Standard deviation image: MER_FLAT_STDDEV_SN_<ccd>_<eye><filt>_V<ver>.IMG

where,

ccd = (3 integer) MER CCD identifier described above;

ver = (2 integer) Version identifier providing uniqueness for book keeping;

eye and **filt** are the same as described below in the Pancam file naming conventions.

The appropriate flat field file is chosen based on the camera and filter used to take the image, and the image being calibrated is divided by the appropriate flat field image. For the solar filters L8 and R8, no flat field correction is yet being performed.

3.6. Radiance Calibration.

Absolute calibration of Pancam images is required in order to generate true-color data products or to extract spectra from surface units to compare directly with laboratory mineral and mineral mixture spectra. Towards this end, images are converted to units of radiance incident on the detector, in $W/m^2/nm/sr$, as sampled at the effective wavelength of the filter used.

In general, the radiance incident on the detector, L, is related to the average DN value measured by the camera via a radiance conversion coefficient, K(T), such that

$$L = K(T) \bullet \text{dn\_per\_s} \quad (6.1),$$

where

$$dn\_per\_s = [\text{corrected DN from section 5}] / [\text{exposure time}] \quad (6.2),$$

T is the CCD temperature of the camera, and the functional form of the temperature dependence of K is assumed to be:

$$K(T) = K_0 + K_S \bullet T \quad (6.3)$$

The linear nature of the responsivity versus temperature relationship was determined from pre-flight calibration observations over a wide range of Pancam flight operating temperatures (Bell *et al.*, 2004a). The responsivity coefficients K_0 and K_S are calculated for each camera/filter combination by performing a linear fit to values of K(T) derived during pre-flight calibration. The derived values for K_0 and K_S that are being used for the current PDS-released Pancam Science RDRs are published in Bell *et al*. (2003) and they can also be found in the file **default_responsivity_constants.txt**.

The mathematical technique used to derive individual values of K(T) from calibration data is described below. For further details on experimental setup and data gathering techniques see Bell *et al*. (2004a).

In the case of the Pancam standalone camera sphere calibration data, L equals the integrating sphere radiance, Sp(λ) in $W/m^2/nm/sr$ at the effective wavelength for the filter used, presented to the camera for an image. Therefore,

$$L = Sp(\lambda_{eff}) \quad (6.4)$$

so that

$$Sp(\lambda_{eff}) = K \bullet dn\_per\_s \quad (6.5)$$

where dn_per_s is understood in this case to refer to the mean value of (DN/sec) for the approximately 10 to 50 images of the integrating sphere obtained during calibration at each camera/filter/temperature combination, divided by the exposure time used for those images.

$Sp(\lambda_{eff})$ values are derived from data obtained during thermal vacuum calibration where the voltage output of a NIST calibrated diode was recorded at 50 nm intervals between 350 and 1100 nm. These voltage readings were converted to absolute radiances using a diode calibration performed at the JPL standards lab.

Next we could just divide $Sp(\lambda_{eff})$ by dn_per_s to get K, but this assumes that the input spectrum on Mars (sunlight) will be the same shape as the spectrum of the integrating sphere in the lab, and we know this to be false based on the sphere diode measurements. However, this method can be used to generate approximate radiance coefficients for validation of the more rigorously-derived coefficients described below.

To be more rigorous, we need to proceed as follows: Let Rp(λ) be the responsivity of the camera system as a function of wavelength, in unknown units, from the normalized monochromator-derived Pancam geology filter profiles (Section 3.3.8 in the Pancam Calibration Report of Bell *et al.,* 2004a). Also let Rk(λ) = C • Rp(λ) be the responsivity of the camera system as a function of wavelength in known units [(DN/sec/nm) / ($W/m^2/sr/nm$)]. First we need to find Rk. We start with:

$$\text{dn\_per\_s} = \int \{ Sp(\lambda) \bullet Rk(\lambda) \} \, d\lambda \qquad (6.6)$$

and thus:

$$\text{dn\_per\_s} = \int \{ Sp(\lambda) \bullet C \bullet Rp(\lambda) \} \, d\lambda \qquad (6.7)$$

C is the only unknown, and it's a constant so we can pull it out . . .

$$C = \text{dn\_per\_s} / \int \{ Sp(\lambda) \bullet Rp(\lambda) \} \, d\lambda \qquad (6.8)$$

And so we have:

$$Rk(\lambda) = Rp(\lambda) \bullet \text{dn\_per\_s} / \int \{ Sp(\lambda') \bullet Rp(\lambda') \} \, d\lambda' \qquad (6.9)$$

and thus we know the camera responsivity in general as a function of wavelength.

On Mars, however, the input source will not be the integrating sphere, but it will be sunlight filtered through and scattered by the martian atmosphere and then modulated by the reflectivity of the Martian surface. We used Pathfinder IMP data (Maki *et al.,* 1999) to generate a "typical" input radiance spectrum, St(λ), expected from average bright regions on Mars. Based on past experience, we can assume that the actual radiance measured by Pancam, Sa(λ), will be some scalar multiple of this typical spectrum, such that Sa(λ) = a • St(λ), where a is a unitless scaling constant. So subtituting this source instead of the sphere into equation (6.6) above, on Mars we will have:

$$\text{dn\_per\_s} = \int \{ a \bullet St(\lambda) \bullet Rk(\lambda) \} \, d\lambda \qquad (6.10)$$

or

$$a = \text{dn\_per\_s} / \int \{ St(\lambda) \bullet Rk(\lambda) \} \, d\lambda \qquad (6.11)$$

Since the input radiance L = a • St(λ_{eff}) (equation 6.4, on Mars), then

$$a \bullet St(\lambda_{eff}) = K \bullet dn\_per\_s \qquad (6.12)$$

(from equation 6.5), and thus K = a • St(λ_{eff}) / dn_per_s and substituting into equation 6.11:

$$K = St(\lambda_{eff}) / \int \{ St(\lambda) \bullet Rk(\lambda) \} \, d\lambda \qquad (6.13)$$

Thus, equation 6.13 provides a rigorous way to estimate the radiometric conversion coefficients on Mars, using equation 6.9 to determine the camera responsivity, and an assumed "typical" Mars radiance spectrum as input.

3.7. Conversion to Integer Format.

Finally, the floating point results of radiance calibration are stored in a short-integer format PDS file. This is achieved by using the RADIANCE_OFFSET and RADIANCE_SCALING_FACTOR keywords.

$$integer\_value = \mathrm{round}\big((float\_value - RADIANCE\_OFFSET)/RADIANCE\_SCALING\_FACTOR\big)$$

To retrieve the floating point value:

$$float\_value = RADIANCE\_OFFSET + integer\_value \cdot RADIANCE\_SCALING\_FACTOR$$

3.8. Deriving Approximate I/F or Approximate Relative Reflectance.

The archived Pancam Science RDRs can be used to estimate the approximate reflectivity of the scene through each filter by dividing the derived radiances by an estimate of the radiance incident on the scene. Without using a detailed sky diffuse illumination model, the simplest approach is to use the radiance spectrum of sunlight at the top of the Earth's atmosphere, scaled for the appropriate heliocentric distance of Mars at the time of the observations, as the incident radiance spectrum. Table 1 provides such an estimate of the incident sunlight through each Pancam filter, using as the incident radiance the solar irradiance spectrum of Colina *et al*. (1996) divided by π and divided by (1.50 AU)^2 (the average heliocentric distance of Mars during the first 30 sols of the MER missions). Dividing the archived Pancam radiance data by the appropriate value from Table 1 results in a simplistic estimate of the reflectivity of the scene that could provide a useful start towards comparing Pancam spectra to laboratory mineral or mineral mixture reflectivity spectra. However, note that the results will only be approximate: estimated reflectivity spectra derived this way will include additional spectral features induced by the presence of significant (reddening) scattered radiance from the dust-laden martian atmosphere, and the estimated absolute reflectance levels would need to be corrected for the approximately $e^{-\tau}$ effect of attenuation by atmospheric dust.

Table 1. Pancam Radiance to "Approximate Reflectivity" Scale Factors			
Filter	λ_{eff} (nm)	Bandpass (nm)	Scale Factor
Left Camera			
L1	739	338	0.18122
L2	753	20	0.17854
L3	673	16	0.21574
L4	601	17	0.24793
L5	535	20	0.27290
L6	482	30	0.29164
L7	432	32	0.23626
Right Camera			
R1	436	37	0.25896
R2	754	20	0.17825
R3	803	20	0.16015
R4	864	17	0.13942
R5	904	26	0.12464
R6	934	25	0.11813
R7	1009	38	0.10161

An alternate and more rigorous approach being pursued by the Pancam team and used during tactical rover operations planning is to use near-in-time observations of the Pancam calibration target to derive estimated scene reflectances relative to the standard reflectance materials on the target, also known as relative reflectance or R* (Reid *et al.,* 1999; Bell *et al.,* 2003). For flat-lying surfaces like the calibration target, this approach removes the spectral effects of atmospheric dust scattering and absorption and provides absolute reflectance levels to within 5-10%. However, this approach requires the use of a photometric model of the calibration target standard reflectance materials as well as a model of the spectral effects of the time-dependent airborne dust deposition on the target. The approach can also benefit from the use of a sky illumination model to estimate and separate the diffuse *vs*. direct sources of illumination. These and other refinements are being pursued (Bell *et al.,* 2004b) for possible incorporation of derived I/F files in future Pancam PDS data releases.

4. Pancam (and other MER camera) File Naming Convention

4.1. Pancam Science EDRs and RDRs

Each MER Raw Experiment Data Record (EDR) can be uniquely identified by incorporating into the product filename the Rover Mission identifier, the Instrument identifier, the Starting Spacecraft Clock count (SCLK) of the camera event, the data Product Type, the Site location, the rover Position within the site, the Sequence number, the camera Eye, the spectral Filter, the product Creator identifier and a Version number.

MER Camera filename convention:

<scid><inst><sclk><prod><site><pos><seq><eye><filt><who><ver>.<ext>

where,

scid = (1 integer) MER rover Spacecraft Identifier.

```
Valid values:
2: Spirit = MER-A = MER-2
1: Opportunity = MER-B = MER-1
```

inst = (1 alpha character) MER science instrument identifier.

```
Valid values for MER camera instruments:
P - Pancam
N - Navcam
F - Front Hazcam
R - Rear Hazcam
M - Microscopic Imager
E - EDLcam (Descent Imager)
```

sclk = (9 integers) Starting Spacecraft Clock time.

This is the number of seconds since January 1, 2000 at 11:58:55.816 UTC.

prod = (3 alpha characters) Product Type identifier of input data.

Product types are differentiated as having camera-induced distortion removed (geometrically "linearized") or not removed (nominal), and, as being Thumbnail-sized or not.

```
Four special flag characters exist:

   a) Beginning E - Type of EDR, which are raw with no camera model
      linearization or radiometric correction. If no beginning E, then it is
      a Reduced Data Record (RDR).
   b) Ending T - EDR or RDR that is Thumbnail -sized.
   c) Ending L - If no beginning E, denotes an RDR that is Linearized, except
```

for Thumbnail sized RDRs.
d) Ending **N** - If no beginning E, denotes an RDR that is Thumb**N**ail-sized and Li**N**earized .

Valid values for MER camera instrument input data products:

Data Product	Identifier
Full frame EDR	**EFF**
Sub-frame EDR	**ESF**
Downsampled EDR	**EDN**
Thumbnail EDR	**ETH**
Row Summed EDR	**ERS**
Column Summed EDR	**ECS**
Reference Pixels EDR	**ERP**
Histogram EDR	**EHG**

site = (2 alphanumeric) Site location count (indicates rover's location).

Valid values: **00, 01, 02,...,99, A0, A1,...,A9, AA, AB, etc.**

pos = (2 alphanumeric) Position-within-Site count (indicates rover's position within site)

Valid values: **00, 01, 02,...,99, A0, A1,...,A9, AA, AB, etc.**

seq = (1 alpha character plus 4 integers) Sequence identifier. Denotes a group of images that were all obtained within a single command sequence.

Valid values for character (position 1) in field:
C - Cruise
D - IDD & RAT
E - Engineering
F - Flight Software (Seq rejected)
G - (spare)
K - (spare)
M - Master (Surface only)
N - In-Situ instr. (APXS, MB, MI)
P - PMA & Remote Sensing instr. (Pancam, Navcam, Hazcam, MI, Mini-TES)
R - Rover Driving
S - Submaster
T - Test
W - Seq triggered by a Communications Window
X - Contingency
Y - (spare)
Z - SCM Seqs

Valid values for integers (positions 2 thru 5) in field:
0000 thru **4095** - Valid Sequence number, commanded by Ground

If **P** in character position:
0000 through **0499** - Misc. imaging setup/parm sequences
0500 through **0999** - Unallocated, for possible future use
1000 through **1499** - Hazcam sequences
1500 through **1999** - Navcam sequences
2000 through **2899** - Pancam sequences

```
2900 through 2999 - MI sequences
3000 through 3999 - Mini-TES sequences
4000 through 4095 - Misc. PMA actuation seqs (deploy, etc.)
```

eye = (1 alpha character) Camera eye.

```
Valid values are:
L - Left camera eye
R - Right camera eye
M - Monoscopic (non-stereo camera)
N - Not Applicable
```

filt = (1 alphanumeric) Spectral filter position.

```
Valid values are an integer range of 0-8
(0 = no filter or N/A , 1 thru 8 are valid filter positions).

 Pancam Filter Positions:
 Wavelength (and bandpass) in nm at -10 C
 -----------------------------------------------------------
 LEFT CAMERA                RIGHT CAMERA
 -----------------------------------------------------------------
 1. 739  (338 - EMPTY)      1. 436  (37 - SP)*
 2. 753  (20)               2. 754  (20)
 3. 673  (16)               3. 803  (20)
 4. 601  (17)               4. 864  (17)
 5. 535  (20)               5. 904  (26)
 6. 482  (30)               6. 934  (25)
 7. 432  (32 - SP)*         7. 1009 (38 - LP)*
 8. 440 Solar ND5** (20)    8. 880 Solar ND5** (20)

*  SP indicates short-pass filter; LP indicates long-pass filter
** ND5 indicated 10^-5 neutral density coating
 -----------------------------------------------------------------

Microscopic Imager "Filter" positions:

1.  MI window/cover closed (500-700 nm response)
2.  MI window/cover open (400-700 nm response)
```

who = (1 alpha character) Product Creator indicator. Valid values are:

```
C - Cornell University
F - USGS at Flagstaff
M - MIPL (OPGS) at JPL
S - SOAS at JPL
X - Other
```

ver = (1 alphanumeric) Version identifier providing uniqueness for book keeping.

```
Valid values: 1, 2, 3, ... 9, A, B, ... Z
```

ext = (4 alpha characters) 3-character PDS product type extension following a "." character.

```
Valid values for nominal operations camera data products:
IMG - Camera image EDRs and RDRs (PDS labeled).
JPG - JPEG compressed (no PDS label).
_n.JPG - Scaled and JPEG compressed, where n is 2 for 1/2
        scale, 4 for 1/4 scale, or 8 for 1/8 scale (no PDS
        label). The filenames for these products are not PDS
        compliant, being longer than the 27.3 PDS
        nomenclature.
```

Example:

```
2P123456789EFF0103P2210L2C1.IMG

Spirit MER-A ("2"), Pancam instrument
("P"), SCLK 123456789 ("123456789"),
Raw Full-Frame image ("EFF"), Site 1 ("01"),
Position 3 ("03"), Sequence P2210 ("P2210"),
left Eye ("L"), Filter position 2 ("2"), produced by
Cornell U. ("C"), product version 1 ("1"),
PDS format image (".IMG").
```

4.2. Important Note About Pancam "Science" vs. "Operations" EDRs

There are three flavors of raw Pancam images that are being released to the PDS archive, and it is important for scientists planning to do quantitative work with the Pancam images to understand the difference. Specifically, there are raw 8-bit "Operations" EDRs (sometimes called "OPGS EDRs"), raw 12-bit "Operations" EDRs, and raw 12-bit "Science" EDRs (sometimes called "SOAS EDRs"). **Anyone interested in doing quantitative work starting with the raw Pancam images must use the Science EDRs**. This is because we almost always used 12 to 8 bit Look-Up Table (LUT) scaling on the Pancam images to avoid encoding noise in the downlinked data, and the 8-bit Operations EDRs have not had an Inverse Look-Up Table (ILUT) scaling applied to return the data back to 12 bits. Therefore, the Data Number (DN) values in the 8-bit Operations EDRs represent an approximately square-root encoded representation of the radiance on sensor, rather than a linear representation of that radiance. Using those data instead of the Science EDRs for quantitative work will result in significant errors. The 12-bit Operations EDRs have not been validated by the Pancam team, and so their use for scientific analysis is not recommended.

The Science EDRs can be identified by the occurrence of the character "C" in the filename's <who> field and the number "1" in the <ver> field at the end of the filename, before the 3-letter extension (see Section 4.1 above). The Operations EDRs have the character "M" in the <who> field in the filename. Users who intend to use the Pancam data for quantitative purposes should use the Science EDRs with a "C1" at the end of the filename, before the 3-letter extension.

5. PDS Label Keywords Pertaining to Pancam Radiometric Calibration

The following keywords pertaining to calibration are found in the DERIVED_IMAGE_PARMS group of the PDS label.

SOFTWARE_LANGUAGE : string, programming language that the software is written in (e.g.: IDL)

SOFTWARE_MODULE_NAME : string, name of the primary software module used to generate this product. This is the module to which the parameters (SOFTWARE_PARAMETER_*) and keywords (SOFTWARE_KEYWORD_*) apply.

SOFTWARE_MODULE_TYPE : string, type of module (eg: PROCEDURE, FUNCTION)

(NOTE: in the following keywords, ?? is a 2-digit string: 01, 02, etc). These keywords, if present, describe the parameters and optional keywords passed to the calibration routine.

NUM_SOFTWARE_PARAMETERS : integer, number of positional parameters that were supplied to the generating software. The PDS keywords that contain the values, names and types (if any) will be numbered 01, 02, 03, etc. A PDS keyword named SOFTWARE_PARAMETER_VALUE_?? is required for each software parameter.

SOFTWARE_PARAMETER_VALUE_?? : any valid PDS value, the value of positional parameter.

SOFTWARE_PARAMETER_NAME_?? : string, descriptive name of corresponding parameter.

NUM_SOFTWARE_KEYWORDS : integer, number of keyword parameters that were supplied to the generating software. The PDS keywords that contain the names, values and types (if any) will be numbered 01, 02, 03, etc. PDS keywords named SOFTWARE_KEYWORD_NAME_?? and SOFTWARE_KEYWORD_VALUE_?? are required for each software keyword supplied.

SOFTWARE_KEYWORD_NAME_?? : string, name of supplied keyword.

SOFTWARE_KEYWORD_VALUE_?? : any valid PDS value, the value of the corresponding keyword.

RESPONSIVITY_CONSTANTS : float array, the responsivity constants used in calibrating the image.

RESPONSIVITY_CONSTANTS_FILE : string, name of the responsivity constants file used in calibrating the image.

The responsivity constants filename will follow the following convention:

rc_<scid><eye><filt>_<sclk>_<site><pos><seq>_<ver>.txt where <scid>, <eye>, <filt>, <sclk>, <site>, <pos>, <seq> are as defined for EDRs and RDRs in section 4.1 above and in the SIS (and will be the same as the values in the image used to generate the responsivity constants file).

<ver> is a version number of the responsivity constants file, and will increment if a new responsivity constants file is generated from the same image.

FLAT_FIELD_FILE : string array, name of flat-field files used in calibration.

FLAT_FIELD_FILE_DESCRIPTION : string array, description of corresponding flat field file (eg. “flat field image”, “flat field standard deviation image”)

ZERO_EXPOSURE_IMAGE : string, name of zero-exposure image subtracted during calibration to account for shutter smear and masked-region dark current. Only set if a zero-exposure image product was used during on-ground calibration. Not set when on-board shutter-subtraction is done.

REFERENCE_PIXEL_IMAGE : string, the product ID of the reference pixel image used to remove bias during calibration. Not set if no reference pixel image was returned in the same image sequence. If a reference pixel image is not available, the modeled bias is used.

BIAS_COEFFS_FILE : string, name of bias coefficients file used in calibrating the image.

BIAS_COEFFS_DESCRIPTION : string, description of corresponding bias coefficients file.

INVERSE_LUT_FILE : string, name of inverse-lookup-table file used in calibration. If raw images are already 12-bit (have not been LUT-ed) then no inverse-LUT file is used.

DARK_CURRENT_FILE : string array, names of dark current files used in calibration.
DARK_CURRENT_FILE_DESCRIPTION : string array, description of corresponding dark current files (eg. "Shutter dark coefficients image.", "Active dark coefficients image.").

INPUT_IMAGE : string array, images used to generate this RDR. For Radiometrically calibrated RDR’s, this will be the name of the raw RDR.

6. References

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7. APPENDIX A

Pancam 8-bit to 12-bit Inverse Look-up Table #1

8 bit	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit
0	20	**32**	95	**64**	288	**96**	607	**128**	1054	**160**	1629	**192**	2331	**224**	3161
1	21	**33**	99	**65**	296	**97**	619	**129**	1070	**161**	1649	**193**	2355	**225**	3189
2	22	**34**	103	**66**	304	**98**	631	**130**	1086	**162**	1669	**194**	2379	**226**	3217
3	23	**35**	108	**67**	312	**99**	644	**131**	1102	**163**	1689	**195**	2403	**227**	3245
4	24	**36**	112	**68**	321	**100**	656	**132**	1119	**164**	1709	**196**	2428	**228**	3273
5	25	**37**	117	**69**	329	**101**	668	**133**	1135	**165**	1730	**197**	2452	**229**	3302
6	27	**38**	121	**70**	338	**102**	681	**134**	1152	**166**	1750	**198**	2477	**230**	3330
7	28	**39**	126	**71**	346	**103**	694	**135**	1169	**167**	1771	**199**	2501	**231**	3359
8	30	**40**	131	**72**	355	**104**	707	**136**	1185	**168**	1792	**200**	2526	**232**	3388
9	31	**41**	136	**73**	364	**105**	720	**137**	1202	**169**	1813	**201**	2551	**233**	3417
10	33	**42**	141	**74**	374	**106**	733	**138**	1220	**170**	1834	**202**	2576	**234**	3446
11	35	**43**	147	**75**	383	**107**	746	**139**	1237	**171**	1855	**203**	2602	**235**	3475
12	36	**44**	152	**76**	392	**108**	760	**140**	1254	**172**	1877	**204**	2627	**236**	3505
13	38	**45**	158	**77**	402	**109**	773	**141**	1272	**173**	1898	**205**	2652	**237**	3534
14	40	**46**	164	**78**	412	**110**	787	**142**	1290	**174**	1920	**206**	2678	**238**	3564
15	42	**47**	170	**79**	422	**111**	801	**143**	1308	**175**	1942	**207**	2704	**239**	3594
16	45	**48**	176	**80**	432	**112**	815	**144**	1326	**176**	1964	**208**	2730	**240**	3624
17	47	**49**	182	**81**	442	**113**	829	**145**	1344	**177**	1986	**209**	2756	**241**	3654
18	49	**50**	188	**82**	452	**114**	843	**146**	1362	**178**	2008	**210**	2782	**242**	3684
19	52	**51**	194	**83**	462	**115**	857	**147**	1380	**179**	2030	**211**	2808	**243**	3714
20	54	**52**	201	**84**	472	**116**	871	**148**	1398	**180**	2052	**212**	2834	**244**	3744
21	57	**53**	207	**85**	483	**117**	886	**149**	1417	**181**	2075	**213**	2861	**245**	3775
22	60	**54**	214	**86**	493	**118**	900	**150**	1435	**182**	2097	**214**	2887	**246**	3805
23	63	**55**	220	**87**	504	**119**	915	**151**	1454	**183**	2120	**215**	2914	**247**	3836
24	66	**56**	227	**88**	515	**120**	930	**152**	1473	**184**	2143	**216**	2941	**248**	3867
25	69	**57**	234	**89**	526	**121**	945	**153**	1492	**185**	2166	**217**	2968	**249**	3898
26	72	**58**	242	**90**	537	**122**	960	**154**	1511	**186**	2189	**218**	2995	**250**	3929
27	76	**59**	249	**91**	549	**123**	976	**155**	1530	**187**	2213	**219**	3022	**251**	3960
28	80	**60**	257	**92**	560	**124**	991	**156**	1550	**188**	2236	**220**	3050	**252**	3991
29	83	**61**	264	**93**	572	**125**	1007	**157**	1569	**189**	2260	**221**	3077	**253**	4023
30	87	**62**	272	**94**	583	**126**	1022	**158**	1589	**190**	2283	**222**	3105	**254**	4055
31	91	**63**	280	**95**	595	**127**	1038	**159**	1609	**191**	2307	**223**	3133	**255**	4083

Pancam 8-bit to 12-bit Inverse Look-up Table #2

8 bit	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit
0	0	**32**	75	**64**	268	**96**	587	**128**	1034	**160**	1609	**192**	2311	**224**	3141
1	1	**33**	79	**65**	276	**97**	599	**129**	1050	**161**	1629	**193**	2335	**225**	3169
2	2	**34**	83	**66**	284	**98**	611	**130**	1066	**162**	1649	**194**	2359	**226**	3197
3	3	**35**	88	**67**	292	**99**	624	**131**	1082	**163**	1669	**195**	2383	**227**	3225
4	4	**36**	92	**68**	301	**100**	636	**132**	1099	**164**	1689	**196**	2408	**228**	3253
5	5	**37**	97	**69**	309	**101**	648	**133**	1115	**165**	1710	**197**	2432	**229**	3282
6	7	**38**	101	**70**	318	**102**	661	**134**	1132	**166**	1730	**198**	2457	**230**	3310
7	8	**39**	106	**71**	326	**103**	674	**135**	1149	**167**	1751	**199**	2481	**231**	3339
8	10	**40**	111	**72**	335	**104**	687	**136**	1165	**168**	1772	**200**	2506	**232**	3368
9	11	**41**	116	**73**	344	**105**	700	**137**	1182	**169**	1793	**201**	2531	**233**	3397
10	13	**42**	121	**74**	354	**106**	713	**138**	1200	**170**	1814	**202**	2556	**234**	3426
11	15	**43**	127	**75**	363	**107**	726	**139**	1217	**171**	1835	**203**	2582	**235**	3455
12	16	**44**	132	**76**	372	**108**	740	**140**	1234	**172**	1857	**204**	2607	**236**	3485
13	18	**45**	138	**77**	382	**109**	753	**141**	1252	**173**	1878	**205**	2632	**237**	3514
14	20	**46**	144	**78**	392	**110**	767	**142**	1270	**174**	1900	**206**	2658	**238**	3544
15	22	**47**	150	**79**	402	**111**	781	**143**	1288	**175**	1922	**207**	2684	**239**	3574
16	25	**48**	156	**80**	412	**112**	795	**144**	1306	**176**	1944	**208**	2710	**240**	3604
17	27	**49**	162	**81**	422	**113**	809	**145**	1324	**177**	1966	**209**	2736	**241**	3634
18	29	**50**	168	**82**	432	**114**	823	**146**	1342	**178**	1988	**210**	2762	**242**	3664
19	32	**51**	174	**83**	442	**115**	837	**147**	1360	**179**	2010	**211**	2788	**243**	3694
20	34	**52**	181	**84**	452	**116**	851	**148**	1378	**180**	2032	**212**	2814	**244**	3724
21	37	**53**	187	**85**	463	**117**	866	**149**	1397	**181**	2055	**213**	2841	**245**	3755
22	40	**54**	194	**86**	473	**118**	880	**150**	1415	**182**	2077	**214**	2867	**246**	3785
23	43	**55**	200	**87**	484	**119**	895	**151**	1434	**183**	2100	**215**	2894	**247**	3816
24	46	**56**	207	**88**	495	**120**	910	**152**	1453	**184**	2123	**216**	2921	**248**	3847
25	49	**57**	214	**89**	506	**121**	925	**153**	1472	**185**	2146	**217**	2948	**249**	3878
26	52	**58**	222	**90**	517	**122**	940	**154**	1491	**186**	2169	**218**	2975	**250**	3909
27	56	**59**	229	**91**	529	**123**	956	**155**	1510	**187**	2193	**219**	3002	**251**	3940
28	60	**60**	237	**92**	540	**124**	971	**156**	1530	**188**	2216	**220**	3030	**252**	3971
29	63	**61**	244	**93**	552	**125**	987	**157**	1549	**189**	2240	**221**	3057	**253**	4003
30	67	**62**	252	**94**	563	**126**	1002	**158**	1569	**190**	2263	**222**	3085	**254**	4035
31	71	**63**	260	**95**	575	**127**	1018	**159**	1589	**191**	2287	**223**	3113	**255**	4073

Pancam 8-bit to 12-bit Inverse Look-up Table #3

8 bit	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit	**8 bit**	12 bit
0	0	**32**	76	**64**	271	**96**	594	**128**	1045	**160**	1626	**192**	2336	**224**	3175
1	1	**33**	80	**65**	279	**97**	606	**129**	1062	**161**	1647	**193**	2361	**225**	3204
2	2	**34**	84	**66**	287	**98**	618	**130**	1078	**162**	1667	**194**	2385	**226**	3232
3	3	**35**	88	**67**	295	**99**	630	**131**	1094	**163**	1687	**195**	2409	**227**	3261
4	4	**36**	93	**68**	304	**100**	643	**132**	1111	**164**	1708	**196**	2434	**228**	3289
5	5	**37**	98	**69**	312	**101**	655	**133**	1127	**165**	1729	**197**	2459	**229**	3318
6	7	**38**	102	**70**	321	**102**	668	**134**	1144	**166**	1749	**198**	2484	**230**	3347
7	8	**39**	107	**71**	330	**103**	681	**135**	1161	**167**	1770	**199**	2509	**231**	3376
8	10	**40**	112	**72**	339	**104**	694	**136**	1178	**168**	1791	**200**	2534	**232**	3405
9	11	**41**	117	**73**	348	**105**	707	**137**	1196	**169**	1813	**201**	2559	**233**	3435
10	13	**42**	123	**74**	357	**106**	721	**138**	1213	**170**	1834	**202**	2585	**234**	3464
11	15	**43**	128	**75**	367	**107**	734	**139**	1230	**171**	1856	**203**	2610	**235**	3494
12	17	**44**	134	**76**	376	**108**	748	**140**	1248	**172**	1877	**204**	2636	**236**	3523
13	19	**45**	139	**77**	386	**109**	762	**141**	1266	**173**	1899	**205**	2662	**237**	3553
14	21	**46**	145	**78**	396	**110**	775	**142**	1284	**174**	1921	**206**	2688	**238**	3583
15	23	**47**	151	**79**	406	**111**	789	**143**	1302	**175**	1943	**207**	2714	**239**	3613
16	25	**48**	157	**80**	416	**112**	803	**144**	1320	**176**	1965	**208**	2740	**240**	3643
17	27	**49**	163	**81**	426	**113**	818	**145**	1338	**177**	1987	**209**	2766	**241**	3674
18	29	**50**	170	**82**	436	**114**	832	**146**	1356	**178**	2010	**210**	2792	**242**	3704
19	32	**51**	176	**83**	447	**115**	846	**147**	1375	**179**	2032	**211**	2819	**243**	3735
20	35	**52**	182	**84**	457	**116**	861	**148**	1393	**180**	2055	**212**	2845	**244**	3765
21	37	**53**	189	**85**	468	**117**	875	**149**	1412	**181**	2077	**213**	2872	**245**	3796
22	40	**54**	196	**86**	478	**118**	890	**150**	1431	**182**	2100	**214**	2899	**246**	3827
23	43	**55**	202	**87**	489	**119**	905	**151**	1450	**183**	2123	**215**	2926	**247**	3858
24	46	**56**	210	**88**	500	**120**	920	**152**	1469	**184**	2146	**216**	2953	**248**	3889
25	50	**57**	217	**89**	512	**121**	935	**153**	1488	**185**	2170	**217**	2981	**249**	3921
26	53	**58**	224	**90**	523	**122**	951	**154**	1507	**186**	2193	**218**	3008	**250**	3952
27	56	**59**	232	**91**	534	**123**	966	**155**	1527	**187**	2217	**219**	3036	**251**	3984
28	60	**60**	239	**92**	546	**124**	982	**156**	1547	**188**	2241	**220**	3063	**252**	4016
29	64	**61**	247	**93**	558	**125**	998	**157**	1566	**189**	2264	**221**	3091	**253**	4047
30	68	**62**	255	**94**	570	**126**	1013	**158**	1586	**190**	2288	**222**	3119	**254**	4079
31	72	**63**	263	**95**	582	**127**	1029	**159**	1606	**191**	2312	**223**	3147	**255**	4095