

# Radiometric Calibration of Viking Lander EDR Images

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## 1. Introduction

This document contains a description of the radiometric properties and calibration of the Viking Lander cameras. Each Viking Lander camera had a photosensor array (PSA) consisting of the following twelve photodiodes: four high resolution broadband (0.4 to 1.1 micrometers) diodes; one low resolution broadband diode; six diodes with color and infrared filters; and one diode with a red filter and no amplification for viewing the Sun. A complete description of the camera system is found in the [VOLINFO.TXT](#) file located in the DOCUMENT directory.

This CALINFO.TXT file describes: A) radiometric calibration files; B) conversion from digital number (DN) to reflectance; C) internal calibration and scan verification images acquired during the mission; D) reference test charts mounted on the Landers; and E) the vignetting function. Data in the CALIB directory are taken from Huck et al. [1975] and are derived from a series of pre-flight component level and end-to-end calibration tests. Descriptions of the radiometric calibration tests are found in Wolf et al. [1977]. Because of the severe sterilization requirements of the Landers and neutron radiation damage from the radioisotope thermoelectric generators on the Landers, changes to the pre-flight calibrations were expected. Calibration and performance of the cameras during the Primary Mission are documented in Patterson et al. [1977] based on internal calibration data from a lamp. These internal calibrations were performed frequently throughout the mission and provided a database for monitoring the radiometric characteristics of the cameras.

Data files in this directory are listed below. For each data file, there is also a detached PDS label file with the same name but an extension of .LBL.

| Data File                    | Label File                   | Description                                                                                             |
|------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------|
| <a href="#">GAINOFF.TAB</a>  | <a href="#">GAINOFF.LBL</a>  | Constants used for converting DN to photodiode output voltage.                                          |
| <a href="#">OPTICS.TAB</a>   | <a href="#">OPTICS.LBL</a>   | Spectral transmittance and reflectance of camera optical components.                                    |
| <a href="#">FILTERxx.TAB</a> | <a href="#">FILTERxx.LBL</a> | Spectral responsivities for photodiodes, where xx indicates the lander and camera number, respectively. |
| <a href="#">PHOTOSEN.TAB</a> | <a href="#">PHOTOSEN.LBL</a> | Physical and electronic data for the photosensors.                                                      |

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## 2. Photodiode Output Voltage

The photodiodes of the Viking Lander camera system generated a voltage proportional to the scene radiance. This voltage was converted by camera electronics into a 6-bit digital number for transmission to Earth. Note that although values of 0 to 63 are possible with a 6-bit number, the maximum value for the Lander cameras was 62 because of camera logic design. On Earth, the transmitted 6-bit numbers were converted to 8-bit numbers by multiplying values by 4 (range 0 to 248).

The photodiode voltage to DN conversion could be adjusted with 6 gain and 32 offset settings. Voltage is computed from DN as follows:

$$v = [(DN/4) * (2^{GN}) / Kg] + (K1 * OFN) - K2 \quad (1)$$

where  $v$  is the photodiode output voltage in units of volts,  $GN$  is the gain number listed in the PDS image label,  $DN$  is the digital number from the image,  $Kg$  is the gain constant,  $K1$  is the offset constant 1,  $OFN$  is the offset number listed in the PDS image label, and  $K2$  is the offset constant 2. Values for  $Kg$ ,  $K1$ , and  $K2$  vary as a function of camera and are found in the file GAINOFF.TAB. The digital number is divided by 4 to convert it to the original 6-bit value. Gain and offset constants vary by a small amount as a function of gain number, offset number, and PSA temperature. These small variations are discussed in Wolf et al. [1977]. The average PSA temperature is listed in the PDS image label.

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### 3. Camera Radiometric Model

The output voltage for a given photodiode is related to scene spectral radiance as follows:

$$v = K * \text{INT} [L(w) * T(w) * R(w) * dw] \quad (2)$$

The symbol  $\text{INT} [ ]$  stands for a definite integral over wavelength ( $w$ ) with limits of zero to infinity, but with practical limits of 0.4 to 1.1 micrometers based on the sensitivity of the photosensor. In equation 2,  $v$  is photodiode output voltage in volts,  $K$  is a constant described below,  $L(w)$  is scene spectral radiance with units of power per projected area per solid angle,  $T(w)$  is the transmittance of camera optics (described below), and  $R(w)$  is the spectral responsivity of a given photodiode (values tabulated in FILTERxx.TAB files). No Sun diode data are listed in the FILTERxx.TAB or PHOTOTSEN.TAB because none are given in Huck et al. [1975]. The Sun diode consisted of a red filter with no amplification [Patterson et al., 1977].

In equation 2, the constant  $K$ , is:

$$K = k_c * R_f * G * ((\pi/4) * B * D_l)^2 \quad (3)$$

where  $k_c$  is a calibration factor to account for uncertainty in the camera model (equation 2), calibration hardware, and test procedures;  $R_f$  is the preamplifier feedback resistance for a given photodiode;  $G$  is the channel (photodiode) gain;  $\pi$  is the constant 3.14159...;  $B$  is the photodiode instantaneous field of view in radians (Note values of  $B$  in PHOTOTSEN.TAB are given in degrees); and  $D_l$  is the diameter of the camera lens. Values for these parameters are tabulated in the file PHOTOTSEN.TAB as a function of camera and photodiode. Values of  $B$  in PHOTOTSEN.TAB were computed from formulas in Huck et al. [1975], and are a function of the photodiode aperture radius, distance between a photodiode and the camera lens, the lens focal length, and the photodiode in-focus object distance. These values are also included in PHOTOTSEN.TAB.

Also in equation 2, the optical spectral transmittance  $T(w)$ , is:

$$T(w) = t_{cw}(w) * t_w(w) * r_m(w) * t_l(w) \quad (4)$$

where  $t_{cw}$ ,  $t_w$ , and  $t_l$  are the transmittances of the contamination cover window, the camera window, and the camera lens, respectively, and  $r_m$  is the mirror reflectance. Note that  $t_{cw}$  is included only if the contamination cover window was in place, which it was for all cameras at the start of the mission. The purpose of the contamination cover was to protect the camera from sand blasting or dust coatings. It was designed to move aside if it became coated. The cover was deployed (i.e., moved out of the optical path) for two cameras during the Extended Mission. It was deployed for camera 1 on Lander 1 during camera event 11F252 on VL 1 Sol 470. The cover for camera 2 on Lander 2 was also deployed during camera event 22G255 on VL 2 Sol 593. Analysis of images taken before and after deployment indicates that there was no significant coating on the covers. The contamination covers remained in place for the other 2 cameras during the entire mission.

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### 4. Reflectance at Sensor

The scene reflectance averaged over the wavelength range of a photodiode,  $r$ , can be computed using the following equation:

$$r = V_s / M \quad (5)$$

where  $V_s$  is the photodiode voltage generated from the scene and  $M$  is the voltage from a normally illuminated Lambertian surface with unit reflectance at the same heliocentric distance. Reflectance computed with equation 5 is a radiance factor defined as the ratio of the scene radiance to the radiance of a Lambertian surface of unit reflectance illuminated normally at the same heliocentric distance [Hapke, 1981].

In equation 5, the quantity  $M$  is a function of camera, photodiode, time, and whether the contamination cover window was in place:

$$M = [(D_0/D)^2 * K / \pi] * \text{INT} [F(w) * T(w) * R(w) * dw] \quad (6)$$

where  $D_0$  is the mean Mars-Sun distance of 1.52 AU;  $D$  is the Mars-Sun distance at the time of the image;  $K$  is the constant from equation 2;  $F(w)$  is the solar spectral irradiance at 1.52 AU;  $T(w)$  is the optical transmittance from equation 4;  $R(w)$  is the photodiode responsivity; and  $w$  is wavelength.

The reflectance computed with equation 5 does not account for atmosphere contributions of attenuation and diffuse illumination. Several authors have reported on ways of dealing with the atmosphere using the brightness of shadows in the scene and optical depth measurements made with the Sun diode [e.g., Arvidson et al., 1989; Guinness et al., 1987; and Guinness, 1981].

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### 5. Scan Verification and Internal Calibration Images

The Viking Lander camera systems had two modes of monitoring the mechanical and radiometric performance during the course of the mission. These modes were known as scan verification and internal calibration. The scan verification was used to check the performance of mechanical

scanning in azimuth and elevation. Two pinlights were mounted inside the post that the camera saw when in the park position. During a scan verification command, the camera imaged the two pinlights by scanning in azimuth and elevation. The positioning of the two lights produced an hourglass pattern. Because of small differences in placement of the lights relative to the camera, the pattern is unique to each camera. Comparison of scan verification images acquired during the mission to images taken before launch provided a test of the scanning mechanisms. Scan verification images acquired during the mission revealed that there were no significant scanning errors for both landers.

The internal calibration used an internal light source to monitor the radiometric operation of the cameras. The light for internal calibration was the same kind of light as the ones used for the scan verification mode. The internal calibration light was mounted in the interior of the camera in such a way that external light could be blocked during the internal calibration. The calibration light was cycled on and off 16 times during an internal calibration sequence. During each cycle, one photodiode was exposed to the light. Data for each photodiode were collected over four scan lines while the light was cycling on and off. The sequence during the four lines was as follows:

line 1 - entire line with ambient illumination

line 2 - first half with lamp off to sample dark current, second half with lamp warming up

line 3 - first half lamp continues to come on; second half lamp is at full power

line 4 - lamp is off and data collected with ambient illumination

The nominal sequence of photodiode measurement during the 16 cycles of an internal calibration was as follows: UND, UND, IR1, Red, BB3, BB4, IR3, Blue, Survey, UND, IR2, Green, UND, Sun, BB1, BB2. Note UND means that no photodiode was used during that cycle. Internal calibrations were always done immediately before or after another image. Internal calibration images showed that there was no significant degradation of the BB1, BB2, BB3, BB4, Survey, and color diodes, but that the IR diodes degraded [Patterson et al., 1977].

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## 6. Reference Test Charts

Each Viking Lander had three reference test charts, which contained a set of patches for radiometric, color, and spatial resolution calibration. Specifically, each chart had a series of 11 gray patches of varying reflectance, a blue, green, and red patch for color balancing, three sets of tribar patterns with different spatial frequencies, and two patches coated with paint that darkened when exposed to ultraviolet radiation. Data on the reflectance properties of the individual patches on the reference test charts can be found in Wall et al. [1975].

The three reference test charts were mounted on the lander deck. Two charts were oriented so that they were directly viewed by one of the cameras (i.e., normal to the camera line of sight and about 1 meter from the camera). The third reference test chart was mounted in the center of the back of the lander deck so that it could be seen by both cameras. This third chart also contained a set of ring magnets that were part of the magnetic properties experiment.

The surfaces of the charts acquired thin coatings of dust during the mission. The magnets also acquired magnetic particles during landing and remained about the same throughout the mission. The patches of ultraviolet sensitive paint degraded with time [Moore et al., 1987; Zent et al., 1980; Hargraves et al., 1979].

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## 7. Vignetting Function

The contamination cover window had a small metal frame that caused a vignetting effect (decrease in brightness) at elevation angles above about +25 degrees. The amount of darkening increased with increasing elevation angle. The vignetting effect also varied with a given photodiode because of the relative position of each photodiode in the photosensor array. Wolf et al. [1997] and Patterson et al. [1977] show examples of the vignetting effect as plots of relative brightness as a function of elevation angle. These graphs can be used to correct image reflectance estimates for the vignetting effect. The vignetting effect was no longer observed when the contamination covers were deployed on camera 1 on Lander 1 and camera 2 on Lander 2 (see Section 3 above).

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