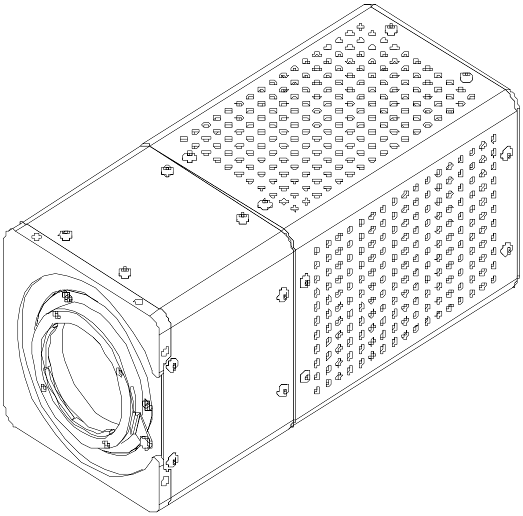
# Trillium

## TR-36, TR-37, TR-38

### Programmable, High-Speed, Color Line Scan Cameras



# Camera User's Manual

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DALSA
technology with vision

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DALSA is an international high performance semiconductor and electronics company that designs, develops, manufactures, and markets digital imaging products and solutions, in addition to providing semiconductor products and services. DALSA's core competencies are in specialized integrated circuit and electronics technology, software, and highly engineered semiconductor wafer processing. Products and services include image sensor components; electronic digital cameras; vision processors; image processing software; and semiconductor wafer foundry services for use in MEMS, high-voltage semiconductors, image sensors and mixed-signal CMOS chips. DALSA is listed on the Toronto Stock Exchange under the symbol "DSA". The Company has its corporate offices in Waterloo, ON and over 1000 employees world-wide.

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TRILLIUM USER'S MANUAL

# Contents

CHAPTER 1

# 1.0 Introduction to the Trillium

## 1.1 Camera Highlights

### Precision

- Prism beamsplitter gives 3 color outputs from common optical axis for superior color registration
- Pixel-by-pixel FPN and PRNU correction and color balancing by integrated signal processing
- Separate data channel for each color (red, green, blue)
- Low image lag and high blue response

### Programmability

- Camera self-calibration and self-color balancing: camera can adapt to changing lighting conditions
- Simple ASCII protocol can control virtually all camera functions, including line rate, exposure period
- Permanent PC connection not required; customizable power-up configuration
- Programmable pushbutton and configurable inputs to trigger almost any camera function without PC connection

### Performance

- 1024 or 2048 pixels, 14µm x 14µm
- 25MHz per output data rate, 8-bit output from 10-bit digitization
- Line rates to 21kHz (1k resolution) or 11kHz (2k resolution)
- EIA-644 (LVDS) data format
- Antiblooming and exposure control

### Usability

- Camera-mounted diagnostic display
- Test pattern output for debugging
- Grab reference lines through RS232 without the need for a frame grabber
- 12V – 15V Single input voltage
- CE compliant

# Description

The Trillium cameras represent a significant advance in the power, precision, and flexibility of color line scan imaging. With unmatched performance and an unprecedented array of programmable diagnostic and signal processing features, the Trilliums break new ground.

The camera's superior performance starts with a precisely-aligned beam-splitting prism with interference filters to separate red, green and blue inputs from a common optical axis with superior transmission efficiency. This common optical axis approach provides higher fidelity images than interdigitated color imagers without the buffering complexities of trilinear imagers. And the prism's interference filters provide sharper transitions, lower out-of-band transmission, and higher in-band transmission than the absorption filters typical of other color imaging approaches.

Three high-performance DALSA line scan sensors collect high-quality image information from the prism and pass it to integrated signal processing circuits which perform pixel-to-pixel correction for FPN, PRNU, and color balance. This allows the camera to adapt to variations in the intensity and spectra of the application's light source. 10-bit digitization circuits output the most significant 8 bits. An embedded controller handles communication and diagnostic functions.

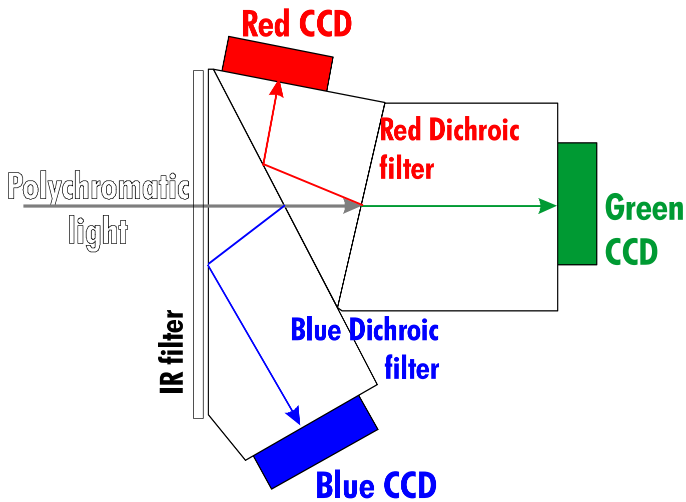
The camera's simple ASCII communications protocol allows you to configure and program virtually all camera functions through an RS232 serial interface, but the camera need not be connected to a PC permanently. Trillium's non-volatile memory can remember its configuration for subsequent power ups; you can also return to user-specified or factory defaults. The camera can also adapt to complex situations, performing user-configured functions at the touch of the camera-mounted pushbutton, or upon receiving combinations of the four user-configurable inputs.

To speed setup and system debugging, the camera offers a seven-segment diagnostic LED; the camera can also output a test pattern to help track the path of data through an acquisition system.

# 1.2 Image Sensors

The Trillium uses three high-performance DALSA line scan image sensors. They are available in a range of pixel sizes and resolutions with 100% fill factor. A beamsplitting prism separates the red, green, and blue components of polychromatic light using dichroic filters for selective transmission and reflection.

***Figure 1. Beamsplitting prism***



# 1.3 Camera Performance Specifications

***Table 1. Trillium Performance Specifications***

| Physical Characteristics | Units | |
|---|---|---|
| Size (excluding lens) | mm | 88.9 x 88.9 x 218.4 (3.5 x 3.5 x 8.6”) |
| Mass (excluding lens) | kg | 1.44 |
| Power Dissipation | W | <16 |
| Sensor-to-Sensor Alignment (x,y) | µm | ±10 |
| Regulatory Compliance | CE: EN55022:1988 class A / CISPR-22 IEC 1000-4-2:1995, 1000-4-3: 1995, 1000-4-4: 1995 | |
| Time to calibrate | | |
| Exposure Control (EC) off | sec. | 3 |
| Exposure Control (EC) on | sec. | 4 |

| Operating Ranges | | Units | Min | Max | Notes |
|---|---|---|---|---|---|
| Data Rate | | MHz | 25 | 25 | |
| Line Rate | 1024 | kHz | 2.0 | 21 | |
| | 2048 | kHz | 2.0 | 11 | |
| Temperature | | °C | 0 | 50 | |
| Temperature drift before recalibration | | °C | | 10 (recommended) | |
| Input Voltage | | V | 11 | 16 | |
| Gain Adjustment (per channel) | | | 1 | 15.98 | 1 |
| RS232 Data Rate | | kbps | 9.6 | 38.4 (default) | |
| Photoresponse Variation across field of view (combining light source variation and lens vignetting) | | Ratio | | 1.8:1 | |

| Electro-Optic Specifications | | Units | Min | Typ | Max | Notes |
|---|---|---|---|---|---|---|
| Factory Set Average Broadband Responsivity | | | | | | 2,4 |
| | Red | DN/(nJ/cm$^2$) | | 4.2 | | |
| | Green | DN/(nJ/cm$^2$) | | 4.2 | | |
| | Blue | DN/(nJ/cm$^2$) | | 4.2 | | |
| Calibration Error | | | | | | 3,4 |
| EC off, all channels | | DN | | 2 | 4 | |
| EC on | Red | DN | | 2 | 4 | |
| | Green | DN | | 2 | 4 | |
| | Blue | DN | | 3 | 7 | |
| Signal to Noise @ 0dB gain | | | | | | 5 |
| | Red | Ratio | 1:300 | 1:370 | | |
| | Green | Ratio | 1:300 | 1:370 | | |
| | Blue | Ratio | 1:240 | 1:320 | | |
| Pk-Pk Noise @ 0dB gain | | | | | | 5 |
| | Red | Ratio | | 4 | 6 | |
| | Green | Ratio | | 4 | 6 | |
| | Blue | Ratio | | 4 | 8 | |
| Output Linearity | | DN | | +0.5/-1.0 | ±1.5 | 6 |
| White Balance | | DN | | ±0.5/-0.7 | +1/-1.5 | 6 |
| Power Supply Current | | | | | | |
| | Vin @ 15V | A | | | 1.06 | |
| | Vin @ 12V | A | | | 1.29 | |

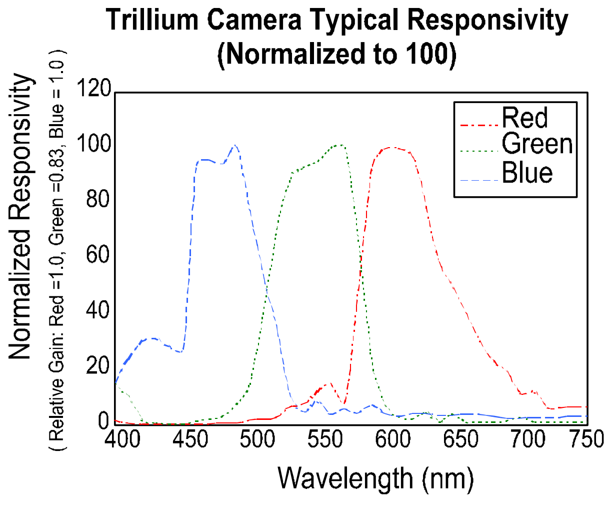
## Notes to Table 1.

DN = Digital numbers (0-255); also known as gray levels.

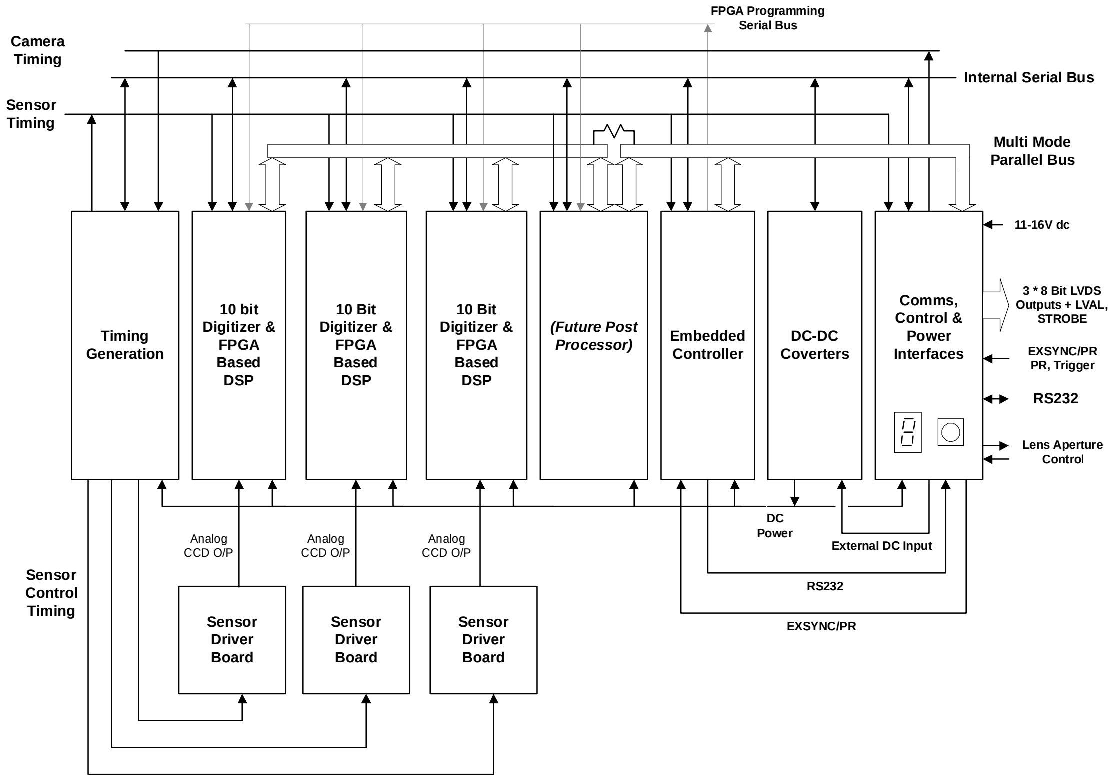
EC = Exposure control.

1. Manual gain adjustment forces uncalibrated operation.
2. With calibration off, using factory settings (these are separate from user defaults settings, both are set during factory calibration).
3. With calibration on, using user default settings, using integrating sphere, and a 10°C drift from time of calibration.
4. Tungsten halogen light source, 3200K bulb temp., and 750nm cutoff filter.
5. Calibration off. Gain for each channel set to 2 (command sg 2, 2, 2).
6. Deviation from ideal, from 10%-90% exposure. Measured after calibration, light intensity 120µW/cm², 4kHz line rate. "Ideal" condition is based on line of best fit through 12 points of data.

***Figure 2.***



## *Figure 3. Trillium Block Diagram*

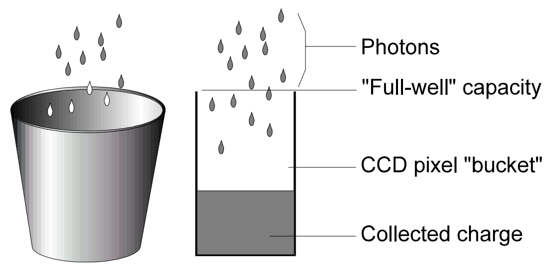


# 1.4 CCD Camera Primer

For more background and detail on how beamsplitter cameras work, see DALSA's "Common Optical Axis Cameras" application note, doc# 03-32-00364

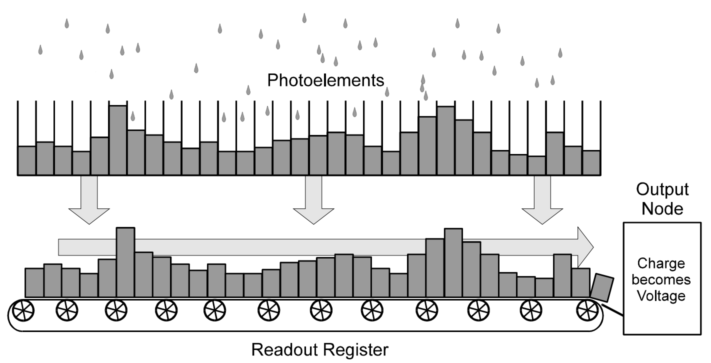
## How CCD Image Sensors Work

In a camera such as the Trillium, a CCD image sensor converts photons (light) into electrons (charge). When photons hit an image sensor, the sensor accumulates electrons. This is called charge integration. The brighter your light source, the more photons available for the sensor to integrate, and the smaller the amount of time required to collect a given amount of light energy.




The way photosensitive elements (pixels) on CCD image sensors collect charge has often been compared to wells or buckets filling with water. From this analogy comes the term "full-well capacity," meaning the maximum charge (number of electrons) a pixel well can hold without "spilling" charge onto adjacent pixels.

As an image sweeps over a line of pixels, the pixels collect charge. At certain intervals, the sensor transfers its collected charge to one or more readout registers, which feed each pixel's charge from the image sensor into an output node that converts the charges into voltages.



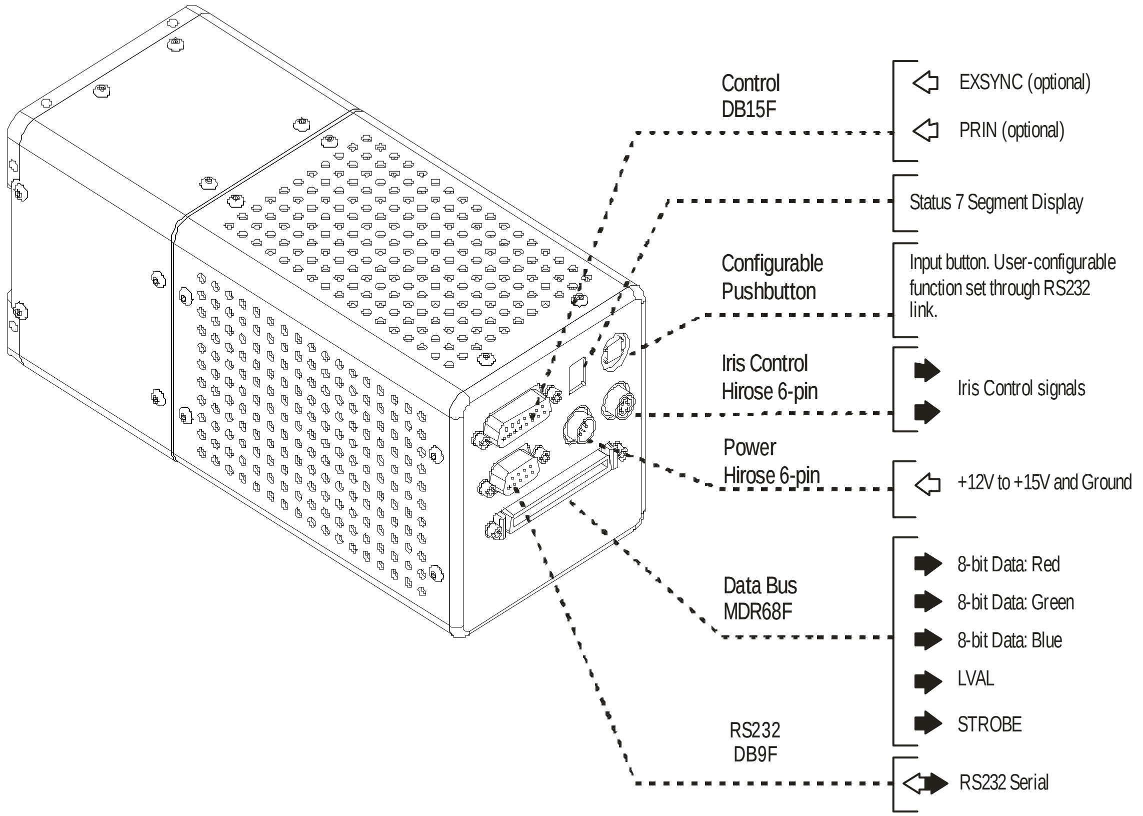

After this transfer and conversion, the voltages are amplified to become the camera's analog output. In digital output cameras, the camera's analog-to-digital (A/D) board converts voltages to digital numbers (0-255 for 8-bit cameras, 0-4095 for 12-bit cameras). These digital numbers are what the camera outputs as data to a frame grabber.

*For more information on terms and concepts from the digital imaging industry, see DALSA's current Databook Glossary, CCD Technology Primer, and Application Notes.*

CHAPTER 2

# 2.0 Camera Hardware Interface

## 2.1 Interface Overview




**Note:** The camera should be protected with a 2A fast-blow fuse between power supply and camera.

# 2.2 Connectors, Pinouts, and Cables

**Data Connector**


**Mating Parts:** Shell: 3M 10368-3280-000-1
68 Pin Male Connector: 3M 10168-6000EC
Cable: 3M 3600B/68

The 68 Pin Male Connector is not specifically for ribbon cables, and, with the proper tooling, can be used to terminate bundled twisted pairs. For systems using bundled twisted pair cables, it may be most cost and time effective to purchase pre-assembled cables already terminated at one end with the MDR connector.

| | Pin | Signal | Pin | Signal |
|---|---|---|---|---|
| | 1 | GND | 35 | GND |
| | 2 | Future use | 36 | Future use |
| | 3 | Future use | 37 | Future use |
| | 4 | Future use | 38 | Future use |
| | 5 | G7 (MSB) | 39 | G7B (MSB) |
| | 6 | G6 | 40 | G6B |
| | 7 | G5 | 41 | G5B |
| Green | 8 | G4 | 42 | G4B |
| | 9 | G3 | 43 | G3B |
| | 10 | G2 | 44 | G2B |
| | 11 | G1 | 45 | G1B |
| | 12 | G0 | 46 | G0B |
| | 13 | Future use | 47 | Future use |
| | 14 | Future use | 48 | Future use |
| | 15 | B7 (MSB) | 49 | B7B (MSB) |
| | 16 | B6 | 50 | B6B |
| | 17 | B5 | 51 | B5B |
| Blue | 18 | B4 | 52 | B4B |
| | 19 | B3 | 53 | B3B |
| | 20 | B2 | 54 | B2B |
| | 21 | B1 | 55 | B1B |
| | 22 | B0 | 56 | B0B |
| | 23 | Future use | 57 | Future use |
| | 24 | Future use | 58 | Future use |
| | 25 | R7 (MSB) | 59 | R7B (MSB) |
| | 26 | R6 | 60 | R6B |
| | 27 | R5 | 61 | R5B |
| Red | 28 | R4 | 62 | R4B |
| | 29 | R3 | 63 | R3B |
| | 30 | R2 | 64 | R2B |
| | 31 | R1 | 65 | R1B |
| | 32 | R0 | 66 | R0B |
| | 33 | STROBE | 67 | STROBEB |
| | 34 | LVAL | 68 | LVALB |

**Note:**
MSB = Most Significant Bit

**Control Input Connector**

| Pin | Signal | Pin | Signal |
|---|---|---|---|
| 1 | Future use | 9 | User3** |
| 2 | Future use | 10 | Future use |
| 3 | User1* | 11 | User1B* |
| 4 | EXSYNCB | 12 | EXSYNC |
| 5 | PRIN | 13 | PRINB |
| 6 | Future use | 14 | Future use |
| 7 | User2** | 15 | User4** |
| 8 | GND | | |


**Mating Parts:** Amphenol hood 17-1657-15 AMP plug 205206-3, AMP pin 745254-7, Belden cable 9807 28AWG (or equiv.)

* User1 is a user-configurable LVDS (differential) input

** User2, User3, and User4 are user-configurable digital inputs with RS232 thresholds

**RS232 Connector**

| Pin | Signal |
|---|---|
| 1 | Data Carrier Detect (not used) |
| 2 | Received Data |
| 3 | Transmitted Data |
| 4 | Data Terminal Ready (not used) |
| 5 | GND |
| 6 | Data Set Ready (not used) |
| 7 | Ready To Send (not used) |
| 8 | Clear To Send (not used) |
| 9 | Ring Indicator (Used if camera wants attention) |


**Mating Part and Cable:** standard off-the-shelf "straight-through" 9-pin serial cable

**Power Connector**

| Pin | Signal |
|---|---|
| 1 | 12 to 15V |
| 2 | 12 to 15V |
| 3 | 12 to 15V |
| 4 | GND |
| 5 | GND |
| 6 | GND |


**Mating Part:** HIROSE HR10A-7P-6S

**Note:** The camera should be protected with a 2A fast-blow fuse between power supply and camera.

**Iris Control Connector**

| Pin | Signal |
|---|---|
| 1 | Pot Pin 1 (GND) |
| 2 | Pot Pin 2 (Wiper) |
| 3 | Pot Pin 3 (+) |
| 4 | Pot Pin 1 (GND) |
| 5 | Motor (-) |
| 6 | Motor (+) |


**Mating Part:** HIROSE HR10A-7R-6S

(complete cable included with lens)

# 2.3 Power Supplies

The camera requires a single input voltage (12 to 15V). Contact DALSA for more information.

When setting up the camera's power supply, follow these guidelines:

- Protect the camera with a 2A fast-blow fuse between power supply and camera.
- Do not use the shield on a multi-conductor cable for ground.
- Use shielded cable for better noise immunity.

See section 1.3 for power requirements.

# 2.4 Control Signal Inputs

The camera accepts differential (LVDS) control inputs on a DB15F connector. All control signals are optional and default to HIGH. If not using these inputs, leave them unconnected.

Standard control signals include EXSYNC and PRIN, but the camera also allows up to four user-defined inputs. These can be used to trigger functions that have been user-defined through the RS232 interface.

LVDS control signals must be supplied from your frame grabber to the camera using twisted pair cable. DALSA recommends shielded cables. Maximum cable lengths depend on environmental factors and EIA-644 limitations. See Appendix A.

> **Note**: The TR-36 also offers a **programmable exposure mode**, in which line rate and exposure period are programmed through the RS232 interface. In programmable mode, an EXSYNC input is not necessary.

## EXSYNC

EXSYNC triggers line readout and controls integration time. It can operate in two different exposure modes: **edge mode** or **level mode**. Exposure mode is selected using the RS232 interface.

In **edge mode**, the falling edge of EXSYNC triggers line readout. The camera integrates light from one EXSYNC falling edge to the next. To control integration time independently from line rate, you must clock the PRIN signal with a LOW to HIGH edge at the desired amount of time before the next EXSYNC falling edge. Restricting EXSYNC to logic HIGH or logic LOW prevents line readout. Minimum high or low time is 100ns.

In **level mode,** the camera integrates light as long as EXSYNC is in logic HIGH, and the falling edge of EXSYNC triggers line readout. For exposure control in this mode, PRIN does not need to be connected. While EXSYNC is LOW, the camera does not integrate light; integration begins on the rising edge of EXSYNC. Minimum EXSYNC low time is 2µs.

**Note:** EXSYNC must not be clocked faster than the camera's specified maximum line rate. To slightly improve offset performance at maximum line rates other than the defaults, see the section "Setting Line Rate (EXSYNC)".

## PRIN

PRIN is an optional signal that can shorten the effective exposure time by resetting the pixels (draining accumulated charge) on the image sensor between EXSYNC-triggered line readouts. PRIN operates differently in different integration modes (**edge mode** and **level mode)**. Exposure mode is selected using the RS232 interface.

In **edge mode**, PRIN provides exposure control if it is clocked go from LOW to HIGH at a specific interval preceding the falling edge of EXSYNC. While PRIN is LOW, the camera does not integrate light; exposure effectively begins on the rising edge of PRIN. If PRIN is kept high, the integration time is maximized; if it is kept low the sensor collects no image information.

In **level mode**, hold PRIN is not necessary for exposure control. In this mode, the camera will ignore PRIN and integrate light only while EXSYNC is high.

PRIN is an optional signal; if not using PRIN, leave inputs unconnected.

## User1 (LVDS)

User1 is a user-configurable LVDS input. It can be used to trigger camera functions that have been previously programmed through the serial interface.

This allows you to trigger camera functions from your frame grabber or other controller.

### User2, User3, User4 (RS232)

These signals are user-configurable single-ended inputs with RS232 thresholds. They can be used to trigger camera functions that have been previously programmed through the serial interface. This allows you to trigger camera functions from your frame grabber or other controller without connecting to a PC.

## 2.5 RS232 Inputs

The camera accepts RS232 inputs on a standard DB9F connector. See Appendix C for protocol and command structure details.

## 2.6 Pushbutton Input

The camera’s pushbutton, located on the upper left corner of the backplate, triggers software commands. The factory default setting is a white light calibration (equivalent to the command **`correction_calibrate 2`**). The button’s function can be customized to any command through the serial interface. See Chapter 3 for details.

## 2.7 Iris Control Outputs

The camera's 6-pin iris control connector is designed to output control signals to a motorized iris. The camera has an embedded controller that can adjust lens aperture from a maximum of f/1.4 to f/22.4 assuming the use of a DALSA-supplied 1K lens. The 2K lens aperture range is f/2 to f/16.

## 2.8 Data Outputs

See section 2.3 for pinouts.

**IMPORTANT:** This camera’s data is valid on the ***rising*** edge of STROBE.

### Digital Data

The camera uses 10-bit ADCs and outputs the most significant 8 bits (one channel for each color) in LVDS format. To clock digital data into the frame grabber, use the camera outputs clocking signals STROBE and LVAL.

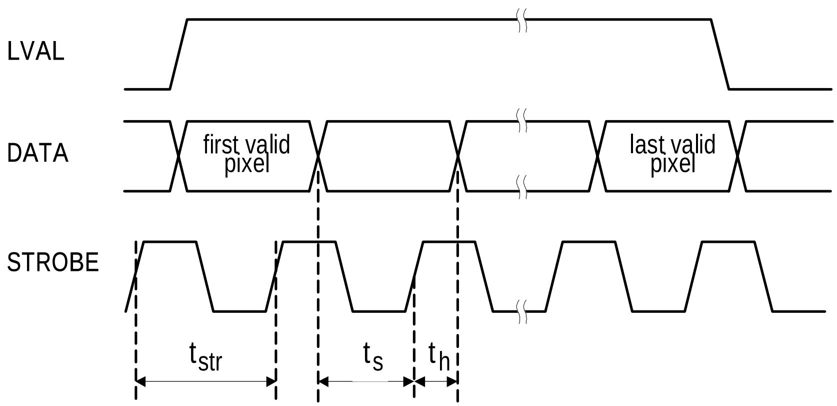
## STROBE

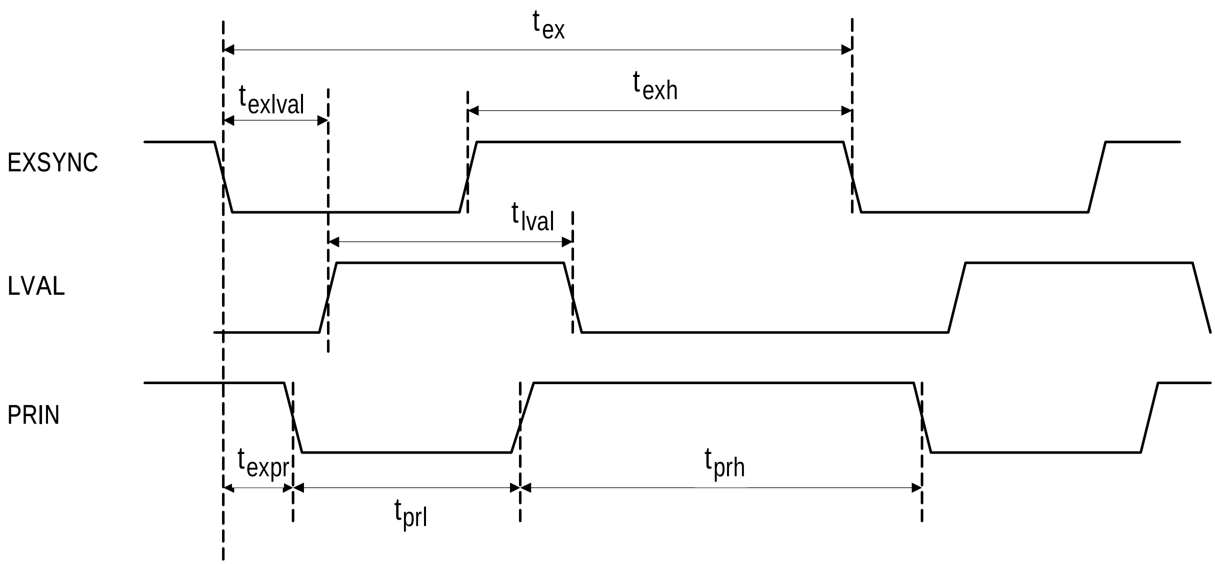
STROBE is a pixel clock signal for digital data. It is continuous, toggling even when data is not valid. Data is valid on the **rising** edge of STROBE.

## LVAL

LVAL high indicates the camera is outputting a valid line of pixels.

# 2.9 Timing



| Symbol | Parameter | | Units | Min. | Nom. | Max. | Notes |
|---|---|---|---|---|---|---|---|
| $t_{str}$ | STROBE period | | ns | | 40 | | 1 |
| $t_s$ | LVAL/Data setup to STROBE rising edge | | ns | 28 | 31 | | |
| $t_h$ | LVAL/Data hold from STROBE rising edge | | ns | 6 | 9 | | |
| $t_{ex}$ | EXSYNC period | 1K | ms | 0.0476 | | 3.33 | |
| | | 2K | | 0.0909 | | 3.33 | |
| $t_{exh}$ | EXSYNC high duration | | % of $t_{ex}$ | 2 | | 95 | 2 |
| $t_{exlval}$ | EXSYNC falling edge to LVAL rising edge | | µs | 2.56 | | 2.76 | 4 |
| $t_{lval}$ | LVAL high duration | 1K | µs | | 40.96 | | |
| | | 2K | | | 81.92 | | |
| $t_{expr}$ | EXSYNC falling edge to PR falling edge hold | | µs | 2 | | | |
| $t_{prh}$ | PR high duration | | % of $t_{ex}$ | 2 | | 95 | 5 |

### Notes on Timing

1. Fixed by internal oscillator.
2. High duration determines CCD integration time with EXSYNC in level mode.
3. $t_{exlval}$ will jitter by 20ns due to the synchronization of EXSYNC with internal camera timing.
4. High duration determines CCD integration time with PRIN in edge mode.

   $t_{prh}$ will jitter by 40ns due to the synchronization of EXSYNC with internal camera timing.

# 2.10 LED Status Codes

See section 3.3.

CHAPTER 3

# 3.0 Software Interface: How to Control the Camera

## 3.1 Overview

All camera features can be controlled through the serial interface. The camera can also be used without the serial interface after it has been set up correctly. Functions available include:

- Controlling basic camera functions such as gain, sync signal source, and exposure
- Performing color balance and camera calibration
- Measuring sensor temperature, supply voltages, and external sync rate
- Capturing video and line statistics
- Generating test patterns for debugging
- Controlling the camera iris

The serial interface uses a simple ASCII-based protocol and the camera does not require any custom software. The complete protocol is described in Appendix C.

For quick help, the camera can return all available commands and parameters through the serial interface. To generate this list, send the command **`help`** or **`?`** to the camera.

> A guide to getting started with your camera is provided in Appendix D.

> See Appendix C for the complete syntax and command reference (including command shortcuts) for the camera's serial interface.

> **Serial Protocol Defaults:**
> 8 data bits
> 1 stop bit
> No parity
> No flow control
> 38.4Kbps
> Camera does not echo characters

# 3.2 Startup

When the camera is first started, it must perform several actions before it is ready for imaging. This startup routine takes less than 10 seconds and follows this sequence:

1. Initializes the camera and all internal hardware.
2. Loads the last settings saved to non-volatile memory, including the last set of video correction coefficients.
3. Sets the iris to the last saved position.
4. Performs a memory test, voltage test, hardware test, and temperature test and reports an error if any occurred.

During startup, the seven-segment on the camera backplate display shows a ‘P’ for processing. After this startup sequence is complete, the camera display will show either a ‘0’ if no error occurred, or an error code if a problem has been discovered.

# 3.3 Status and Error Codes

The 7-segment display on the camera backplate shows status and error codes. If any errors occur in the camera (including communications errors), the camera will also send the error code and its message to the host system through the serial interface.

With only 7 segments, the camera cannot display all error codes; any code greater than 9 will be displayed as 9. See Appendix C for the full list of error codes.

| Status Code | Explanation |
|---|---|
| . (single point) | Internal power test Ok. |
| P | The camera is processing. The camera will delay processing of any new commands until after the processing is complete. After the processing is complete (typically within a few seconds) the ‘P’ code will be replaced with another status or error code. |
| U | The user button has been pressed and the camera is processing. |
| 0 | Ok |
| 1 | Internal camera error. Please report this error code to DALSA. |
| 2 | Video Timeout Error. External or internal sync not functioning. |

| Status Code | Explanation |
|---|---|
| 3 | Unable to program internal FPGAs.  Please report this error code to DALSA. |
| 4 | Validation error programming flash memory.  Please report this error code to DALSA. |
| 5 | One or more of the required supply voltages is out of specification. Please report this error code to DALSA. |
| 6 | The camera temperature is outside the valid operating range. |
| 7 | The camera memory check failed.  Please report this error code to DALSA. |
| 8 | The camera flash memory check failed. Please report this error code to DALSA. |
| 9 | All other failure codes. Detailed in Appendix C. |

**Notes:** Error codes will only be cleared after the error message has been transmitted through the serial port.

# 3.4 Setting Line Rate (EXSYNC)

All commands have short forms. See Appendix C for the complete syntax and command reference.

The camera's line rate (synchronization) generated internally or input from a frame grabber/host system. The source is selected using the **set_sync_mode** ***mode*** or **ssm** ***mode*** command through the serial port (see Appendix C for more details on serial commands, modes, syntax, etc.). When using internally generated sync, the frequency can be programmed using the commands **set_sync_frequency** ***frequency*** or **ssf** ***frequency***, where ***frequency*** is a floating-point number in Hz between 300 and the specified maximum line rate.

For external sync, the control signal EXSYNC determines line rate. See page 17 and section 2.9 Timing.

# 3.5 Setting Exposure Duty Cycle

When the camera generates sync and exposure control internally, the duty cycle can be programmed using the **`set_sync_duty`** ***`percentage`*** or **`ssd`** ***`percentage`***, where ***`percentage`*** is an integer from 0 to 100. 90% means that the camera integrates light for 90% of the period between line readouts.

For external exposure control, use PRIN. See page 17 and section 2.9 Timing.

# 3.6 Controlling Channels Separately

Many of the commands in the communications protocol operate on single channels only. In the protocol, these commands have "Channel" as one of the command parameters. When referring to a channel, the following color mappings apply:

- Channel 1 is Red
- Channel 2 is Green
- Channel 3 is Blue

# 3.7 Setting Gains

Although the camera sets gains automatically during calibration, the camera also allows independent manual control of the gain for each color channel. In this situation, the output will not be calibrated.

To set gains manually, use the **`set_gain`** command and specify each channel's gain setting. **Note: you must always specify parameters for each channel**. The gain ranges are 1-15.98 (floating point numbers). For example, to set Red gain to 4, Green Gain to 3, and Blue gain to 7.5:

```
set_gain 4, 3, 7.5
```

# 3.8 Calibrating the Camera

## Calibration Overview

This camera has the ability to calibrate itself in order to improve the color balance and image flatness. This video correction operates on a pixel-by-pixel basis and implements a two-point correction for each pixel. This correction can reduce or eliminate image distortion caused by the following factors:

- Fixed Pattern Noise (FPN)
- Photo Response Non Uniformity (PRNU)
- Color imbalance
- Lens and light source non-uniformity

For more detail on this camera's calibration and correction algorithms, see DALSA's "Trillium TR-31 Calibration" application note, doc# 03-32-00366.

This video correction can also be used to adjust the gains of the camera and to configure the color balance as required.

The two point correction is implemented such that for each pixel:

$V_{output}$ = PRNU( pixel ) * ($V_{input}$ - FPN( pixel ))

| | | | |
|---|---|---|---|
| where | $V_{output}$ | = | output pixel value |
| | $V_{input}$ | = | input pixel value from the CCD |
| | PRNU( pixel) | = | PRNU correction coefficient for this pixel |
| | FPN( pixel ) | = | FPN correction coefficient for this pixel |

The calibration algorithm is performed in two steps. The fixed offset (FPN) is determined first by performing a calibration without any light. This calibration determines exactly how much offset to subtract per pixel in order to obtain flat output when the CCD is not exposed.

The white light calibration is performed next to determine the multiplication factors required to bring each pixel to the required value (balance target) for flat, white output. The white light calibration also sets the analog gains in the camera appropriately to balance all of the channels.

When performing any camera calibration, random noise must be averaged out to ensure proper sampling. Make sure the sample size for calibration is large enough to average out random noise. The factory default sample size of 64 lines is adequate for most purposes. The command to set the calibration sample size is **`correction_set_sample 64`**. The current value can be read by reading the camera parameters with **`get_camera_parameters`**.

# Digital and Analog Gains

The camera has a number of internal gain stages that are used to balance each CCD in order to obtain white light. These gain stages are briefly described below:

1. **Fixed analog gain.** Each channel has a fixed analog gain stage that is used to compensate for different sensor sensitivities between colors. This gain stage is fixed at the factory on a channel by channel basis.

2. **Variable analog gain.** Each channel also has a variable gain stage that is used to compensate for changing lighting conditions. This stage implements either a 1x, 2x, or 4x gain.

3. **Variable per-pixel digital gain.** Each pixel has a unique gain coefficient (PRNU coefficient) that is used to compensate for PRNU and non-uniform lighting conditions. Each pixel has a maximum gain of 2x, meaning that the light variation across the white image cannot vary by more than 2 to 1.

4. **Variable per-channel digital gain.** Each channel also has a variable digital gain stage that is applied after the video correction. This gain stage has a maximum gain of 2x (in 256 linear steps) and is used in the calibration process.

When the camera performs a white light calibration, it finds the appropriate analog gains and per-pixel digital gains so that each pixel meets a specified target value. If the targets for all three channels are the same, the resulting output will be a completely flat, white image.

The 1x, 2x, and 4x analog gain adjustment plus the digital gain adjustment allows for a 2:1 variation in light non-uniformity across the object plane, plus a further possible 4:1 overall light variation. This allows the camera to perform a white light calibration for a large range of illumination conditions.

**Note:** You can choose to set gain manually using the **`set_gain`** command. As with autocalibrated gain, the camera will adjust the various analog and digital stages to achieve the specified target. But with manual gain settings, the camera’s video correction will be disabled.

# Dark Calibration

Dark calibration is used to remove the fixed analog offset from the video path. When exposure control is disabled, this offset (and FPN) is usually very low. As a result, dark calibration may only be required at first installation or power up, and then stored in the user settings by initiating the **`ws`** command.

With exposure control enabled, FPN can be high if a long integration time is used and/or the ambient temperature is high (see "offset de-rating curve", page 40)

and the dark calibration must be repeated if the camera temperature varies more than 10 C °.

**To perform dark calibration:**

1. Stop all light from entering the camera.
2. Issue the command **`correction_calibrate 1`**. The camera will respond with Ok> if no error occurs.
3. After the calibration is complete, you can save these settings to non-volatile memory so they will be remembered after power-down. To do so, issue the command **`write_settings`**.

## White Light Calibration

White light calibration is more complex than dark calibration because the camera attempts to create a flat white image. This calibration corrects PRNU effects as well as non-uniform lighting and lens vignetting affects.

White light calibration requires a clean, white reference. The quality of this reference is important for proper calibration. White paper is often not sufficient because the grain in the white paper will distort the correction. A more uniform source such as white plastic will lead to better balancing.

The factory default balance target is 94% for all channels. This means that the white light calibration algorithm will ensure that for the white reference, the resulting image will have all pixels set to 94% of saturation (~240DN) after removing random noise. Balance targets can also be set independently for each channel. See page 29.

> **Note:** If your illumination or white reference does not extend the full field of view of the camera, calibration will still be successful for the center portion of the image. However, the camera will send a warning that the illumination level is too low under these conditions.

There are several restrictions that must be met in order for the calibration to succeed. Our testing has shown that these criteria can be easily met with a halogen bulb light source (one bulb for 1k resolution; two for 2k) and a fiber-optic light pipe.

1. At high gain settings, the camera is sufficiently sensitive to detect 60 Hz ambient light flicker which may affect camera performance and calibration results.
2. The light must be bright enough (within the 4:1 range available) so the camera can reach the balance. If the light is not bright enough, then the camera will not produce a flat response to a white surface and the resulting image will be gray.
3. The light must not be too bright (within the 4:1 range available) for the camera to reach the balance. If the camera is at minimum gain and the image sensor is still saturated, the calibration can not be completed.

4. The variance in light intensity across the target must not be more than 2 to 1. Since the maximum per-pixel digital gain is 2x, the camera will not be able to compensate for extremely non-uniform light, and a flat response to a white surface will not be achieved.

These restrictions are all tested within the calibration algorithm and the camera will report an error if any of these conditions could not be met. In this case, the calibration will still complete but the results will not be optimum.

<table>
<tr><th>White calibration without a dark reference, exposure control enabled only at high line rate (see "offset de-rating curve, page 40)</th><th>White calibration with a dark reference, exposure control disabled</th></tr>
<tr><td>1. All calibration is performed with an illuminated white reference. Ensure that the internal or external sync and exposure control signals are characteristic of final operation.</td><td>1. Perform a dark calibration first. The dark calibration’s FPN results are used by the white light calibration algorithm</td></tr>
<tr><td colspan="2">2. Place a white reference in front of the camera.</td></tr>
<tr><td colspan="2">3. Ensure that the light intensity is characteristic of the final imaging environment.</td></tr>
<tr><td>4. Instruct the camera to perform a white light calibration using the command <code>correction_calibrate 3</code>. The camera will respond with Ok> if no error occurs.</td><td>4. Instruct the camera to perform a white light calibration using the command <code>correction_calibrate 2</code>. The camera will respond with Ok> if no error occurs.</td></tr>
<tr><td colspan="2">5. After the calibration is complete, you can save these settings to non-volatile memory so they will be remembered after power-down. To do so, issue the command <code>write_settings</code>.</td></tr>
</table>

**If an error occurs,** adjust the light intensity into the correct range for calibration. Error messages will help to determine how much to increment or decrement the light intensity.

## Returning Calibration Results and Errors

After calibration, you can retrieve the results using the command **`correction_get_results`.** This function returns the analog gain and minimum and maximum digital gains for each channel.

The possible values for the analog gain are 1x, 2x, and 4x. The per-pixel digital gain ranges from 1.00 to 4.00. These values can be used to determine the cause of a calibration failure.

# 3.9 Adjusting Color Balance

Since each channel has an independent balance, the color balance target parameter can be adjusted to suit the application. This allows manual control of color balance and gain level.

The factory default balance target is 94% for all channels. This means that the white light calibration algorithm will ensure that for the white reference, the resulting image will have all pixels set to 94% of saturation (~240DN) after removing random noise.

**Note:** Color balance targets must be set before performing a white light calibration.

The color balance can be changed by modifying the balance target for one or more channels. For instance, to emphasize red in an image, you could use the following balance targets:

Red: 94%
Green: 90%
Blue: 90%

```
correction_set_balance 94, 90, 90
```

This will increase the red response of the camera.

The balance targets can also be changed to adjust the gain of the camera. By setting all of the balance targets a value lower than 94%, the analog and/or digital gains in the camera will be reduced. By controlling the iris when calibrating, it is possible to balance the camera and increase or decrease the camera's gains by performing a white light calibration.

The range for **`correction_set_balance`** parameters is 50-150%. Values greater than 100% are useful if the white reference used is brighter than the "white" levels in the object to be imaged. In this case, values greater than 100% can bring objects' "white" levels up to saturation. Note that if there are large variations in light level across the image, the full 150% may not be attainable.

**Note:** The color balance changes when adjustments are made to the iris due to changes in the angle of incidence at the dichroic filters. The camera should be re-calibrated following adjustments to the iris.

### Activating / Deactivating Video Correction

White light calibration should be performed in the field at least once to compensate for the application-specific lighting conditions.

**Note:** Video correction is disabled if you set gains manually. To re-enable video correction, use the command **`restore_setting`** or **`rs`** if calibration results have been previously stored in the user settings (**`ws`** command), or perform a calibration using one of the **`correction_calibrate`** commands.

## 3.10 Using the Pushbutton

The pushbutton on the camera backplate triggers predefined serial commands. By default, the pushbutton triggers a white light calibration, equivalent to the command **`correction_calibrate 2`**.

If you press the pushbutton during camera power-up, the camera will be forced to factory default settings, including setting the baud rate to 38.4Kbps.

## Programming the Pushbutton

The pushbutton can perform any command available. To change the behavior of the pushbutton, use the command:

```
user_set input, command
```

Input identifies the input number. The camera has the following inputs, which have the following default actions (equivalent to serial commands):

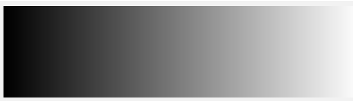
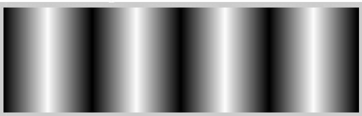
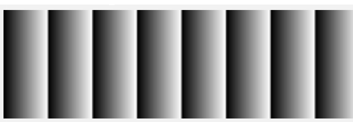
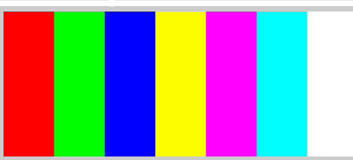
| Input# | Input | Default Command |
|---|---|---|
| 1 | Pushbutton | `correction_calibrate 2` |
| 2 | User1 (LVDS control input) | `set_aperture 0` |
| 3 | User2 (digital input, RS232 thresholds) | `set_aperture 33` |
| 4 | User3 (digital input, RS232 thresholds) | `set_aperture 66` |
| 5 | User4 (digital input, RS232 thresholds) | `set_aperture 100` |

Example: this example sets the pushbutton to perform a dark calibration:

```
user_set 1, correction_calibrate 1
```

# 3.11 Generating Test Patterns

The camera can generate a variety of test patterns to aid in system debugging.

| Pattern | Command | Description |
| --- | --- | --- |
| 1 | **test_set_pattern 1** <br>  | Black to white ramp<br>• All channels (creates gray pattern)<br>• Output levels ramp from 0 to 255<br>• 4 pixels per value for 1k cameras, 8 pixels per value for 2k cameras |
| 2 | **test_set_pattern 2** <br>  | Black to white pyramid<br>• All channels (creates gray pattern)<br>• Output levels ramp from 0 to 255 back to 0<br>• 1 pixel per value<br>• 2 cycles for 1k cameras, 4 for 2k cameras |
| 3 | **test_set_pattern 3** <br>  | Black to white "sawtooth"<br>• All channels (creates gray pattern)<br>• Output levels ramp from 0 to 255<br>• 1 pixel per value<br>• 2 cycles for 1k cameras, 4 for 2k cameras |
| 4 | **test_set_pattern 4** <br>  | Color bars<br>• Output levels toggle between 0 and 255 on each channel<br>• 146 pixels wide for each color bar for 1k, 292 pixels wide for each color for 2k<br>• Color sequence is red, green, blue, yellow, magenta, cyan, white. |
| 5 | **test_set_pattern 5** <br>  | Color ramp<br>• Output levels toggle between 0 and 255 on each channel<br>• 4 ramp sequences for 1k cameras, 8 ramps for 2k<br>• Color sequence is red, green, blue, (repeat) |

Once initiated, test patterns continue until you turn them off.

These commands control test patterns:

| Command | Action |
|---|---|
| **test_set_pattern *number*** | Selects the pattern |
| **test_start** | Start the test pattern output |
| **test_halt** | Stop the test pattern output and return to normal operation |

# 3.12 Returning Video Information through the Serial Port

The camera's microcontroller has the ability to read corrected or uncorrected video from the CCD sensor. This functionality can be used to verify camera operation and to perform basic testing without having to connect the camera to a frame grabber.

This video information can be sampled through the serial port by issuing the following command:

**get_line *channel, sample size***

Sample size indicates the number of lines to average (note that the camera returns only one line, but that line is the average of the sample size). This command will return the pixel values for one channel. Each value is represented as an integer from 0 to 255.

## Generating Statistics

It is also possible to get some simple statistics from a line by issuing the command:

**get_line_statistics *channel, sample size***

This command returns the maximum pixel value, minimum pixel value, and average for one line of video.

If video correction is enabled, both commands will operate on corrected video. If the correction is disabled, the results returned are from raw image data.

## Determining Channel Noise

To determine channel noise, issue the command:

**get_line_noise *channel, sample size***

This command returns an rms noise figure for the selected channel over the number of lines set by the sample size.

**Note:** Camera noise specifications are for no light conditions.

# 3.13 Controlling the Iris

The optional camera lens assembly includes an electronically controlled iris that can be used to adjust the amount of light that reaches the camera CCDs. This iris is controlled through the serial communications port using the command:

**set_aperture *setting***

The aperture setting is an integer from 0 to 100 representing the percentage of light reaching the camera. However, due to hysterisis in the iris drive mechanism, an accuracy no better than 5% can be guaranteed, except for fully open and closed, which is ensured to be repeatable.

Before the iris can be used, it must be calibrated using an illuminated white reference and the **optimize_aperture** command. The command takes several seconds to execute.

To disable the aperture control (e.g. to use a lens without iris control), disconnect the iris and use the **optimize_aperture** command again.

Note that the iris position is saved within the camera. The camera will remember the last iris position and set the iris to this position during startup.

Also note that the color balance changes when adjustments are made to the iris due to changes to the angle of incidence at the dichroic filters. The camera should be re-calibrated following adjustments to the iris.

# 3.14 Monitoring the Camera

## Temperature Measurement

The temperature of the camera can be determined by using the **`verify_temperature`** command. This command will return the temperature of the CCD sensor in degrees Celsius. For proper operation, this value should not exceed 80°C. By default, the camera only checks the sensor temperature once at startup unless it receives the appropriate command.

If the temperature exceeds 80°C, the camera will report an error. Verify that the camera is getting adequate convection cooling (i.e. the camera is not enclosed and the vent holes are not blocked etc.).

## Voltage Measurement

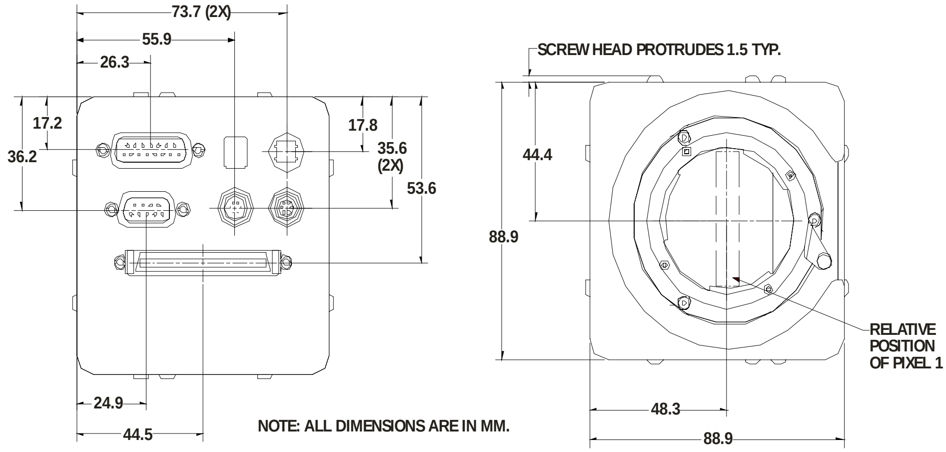
The command **`verify_voltage`** checks the camera's input voltage and internal voltages. If they are within the proper range, the camera returns Ok>. Otherwise the camera returns Fail. Note that the voltage measurement feature of the camera provides only approximate results (within 10%). They should not be used to set the applied voltage to the camera. The purpose of this test is to isolate gross problems with the supply voltages.

CHAPTER 4

# 4.0 Optical and Mechanical Considerations

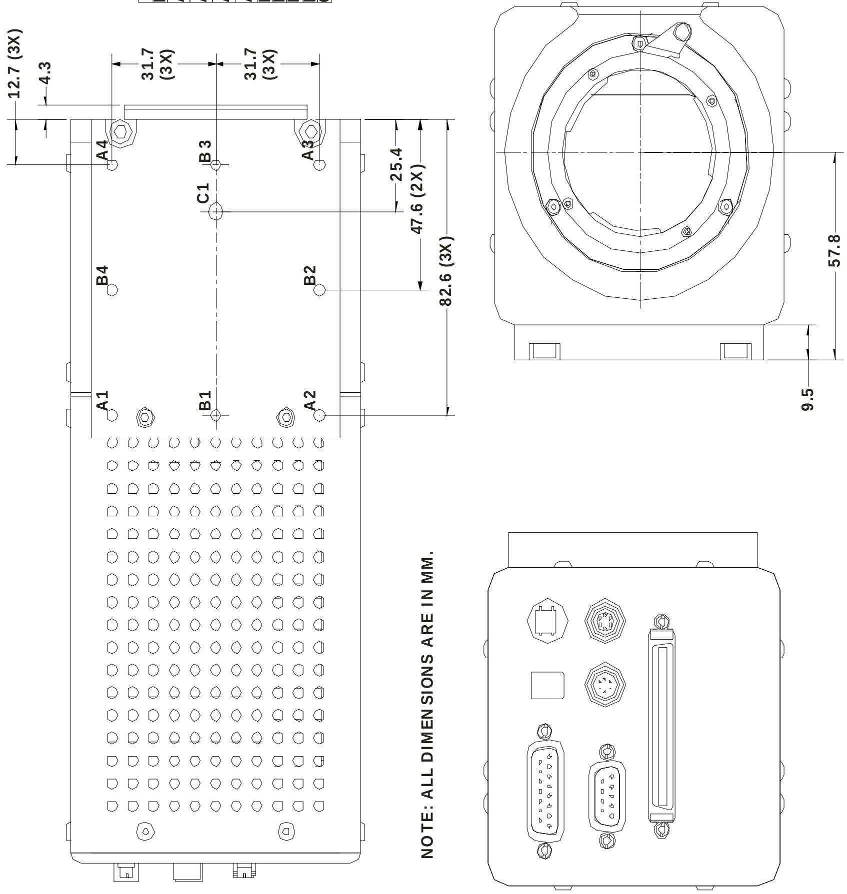
## 4.1 Mechanical Interface

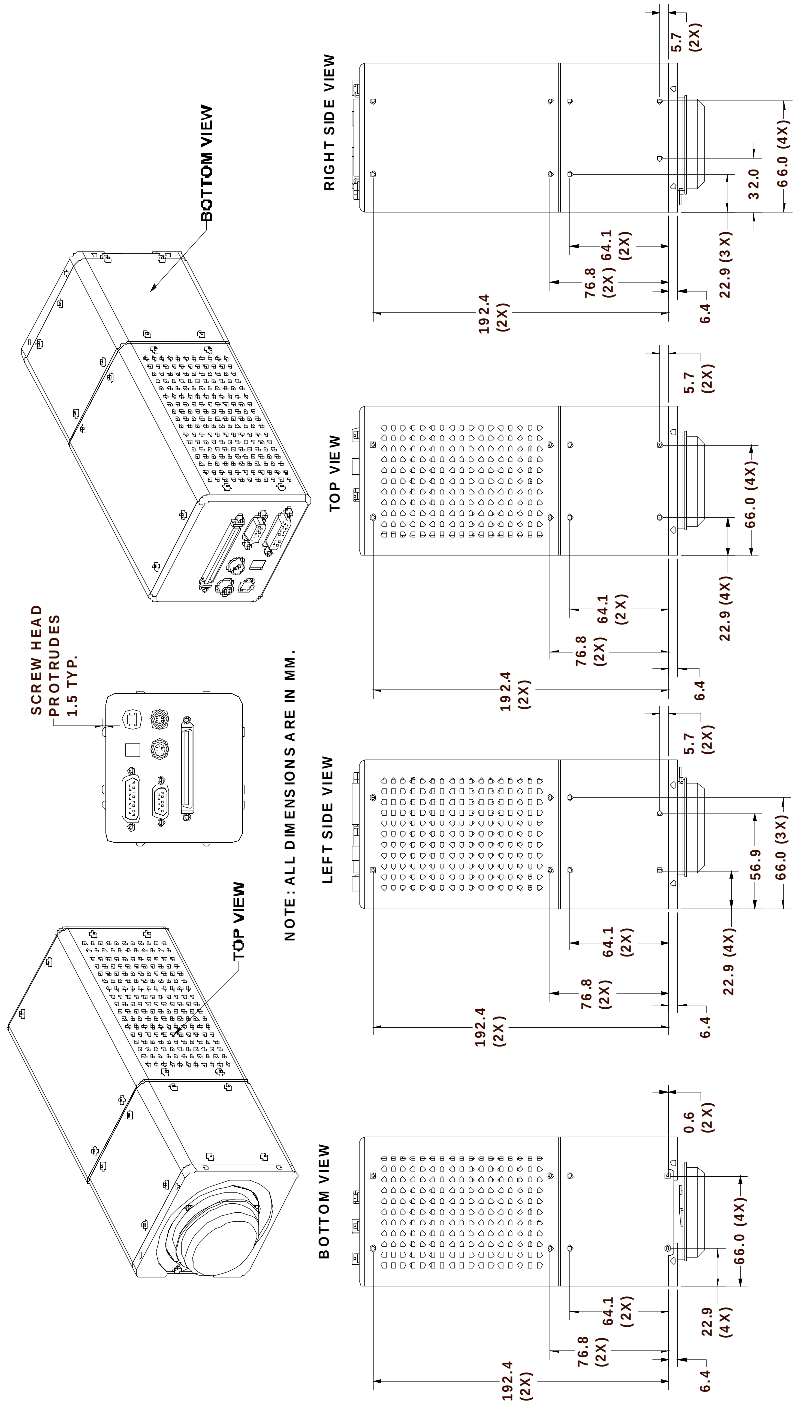
The camera's electronics are housed in an anodized aluminum case.



**Hole Table**

| LOC | SIZE |
|---|---|
| A1 | 8-32 UNC - 2B |
| A2 | 8-32 UNC - 2B |
| A3 | 8-32 UNC - 2B |
| A4 | 8-32 UNC - 2B |
| B1 | M4x0.7 - 6H |
| B2 | M4x0.7 - 6H |
| B3 | M4x0.7 - 6H |
| B4 | M4x0.7 - 6H |
| C1 | 1/4-20 UNC - 1B |

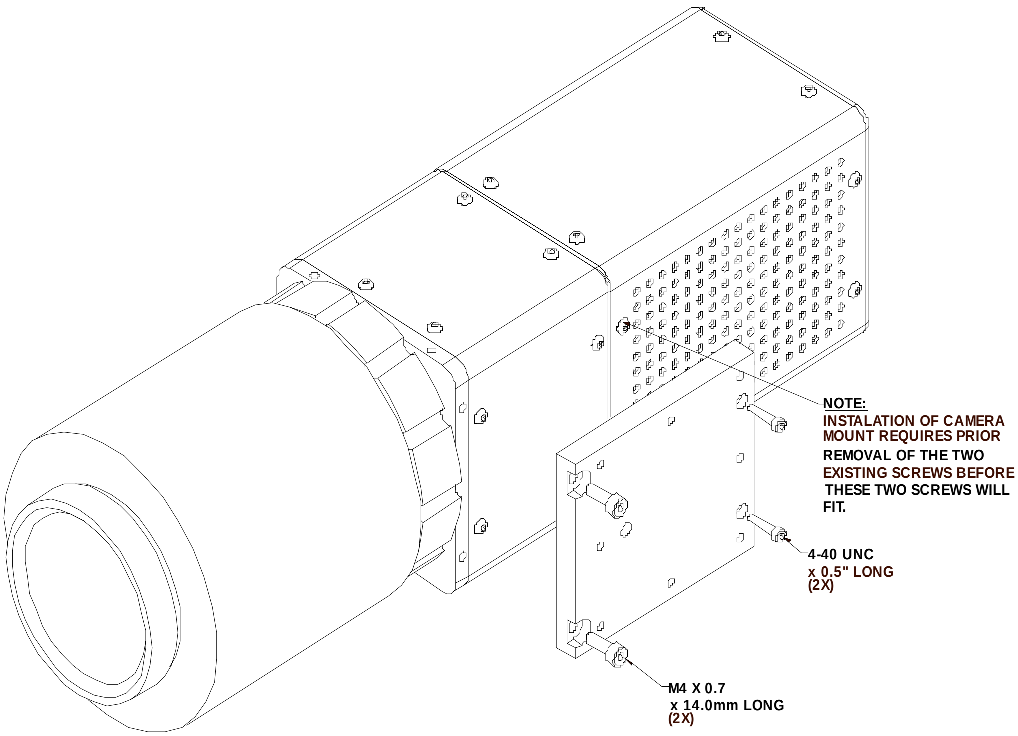



BOTTOM VIEW
TOP VIEW
SCREW HEAD PROTRUDES 1.5 TYP.
NOTE: ALL DIMENSIONS ARE IN MM.
RIGHT SIDE VIEW
TOP VIEW
LEFT SIDE VIEW
BOTTOM VIEW
5.7 (2X)
66.0 (4X)
32.0
22.9 (3X)
64.1 (2X)
76.8 (2X)
192.4 (2X)
6.4
22.9 (4X)
66.0 (3X)
56.9
0.6 (2X)
22.9 (4X)

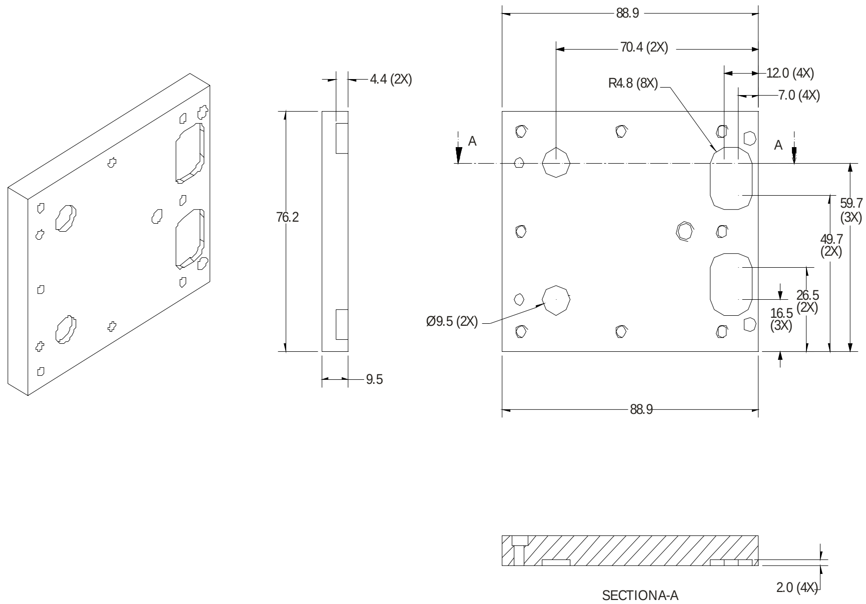
# Mounting

The camera includes a mounting plate that can be attached to any of the camera's four long sides. This plate allows interfacing to other mounting structures.

**Note**
Installation of camera mount requires prior removal of the two existing screws before these two screws will fit.



# Mount Plate


4.4 (2X)
76.2
9.5
88.9
70.4 (2X)
R4.8 (8X)
12.0 (4X)
7.0 (4X)
A
A
59.7 (3X)
49.7 (2X)
26.5 (2X)
16.5 (3X)
Ø9.5 (2X)
88.9
2.0 (4X)
SECTIONA-A

## Environment

The camera and cables should be shielded from environmental noise sources for best operation. The camera should also be kept as cool as possible. Specified operating temperature is 0-50° C. The camera case is vented to allow for convection cooling. Some environments may warrant a cooling fan.

At temperatures below 35°C, convection cooling has proven to be sufficient if a reasonable airflow is maintained around the camera. For higher temperatures, some minimal forced air circulation may be necessary. Requirements can be determined by reading the camera's internal temperature using the **`verify_temperature`** command after the camera has stabilized. For best performance, keep the operating temperature below the de-rating curves.

### De-rating curves

In some applications requiring long integration times, an increase in Charged Conversion Efficiency (CCE) by the IL-P3 sensors may result in large dark offsets, caused by the amplification of temperature generated dark signal integrated over long periods. This effect has an impact on the ability of the camera to correctly calibrate itself. See Appendix E, for further information on the de-rating curve.

**Note:** The de-rating curve applies only to applications requiring long integration times, not necessarily low line rates. For example, a web inspection application where line rates may vary considerably but integration time is limited to a short duration will not experience a dark offset issue.

# 4.2 Optical Interface

## Lenses

For 1k resolutions, images may be obtained with high-quality F-mount lenses (e.g. Nikon NIKKOR 55mm). At present, DALSA cannot recommend commercial lenses for 2k resolutions.

> For more information on lenses and chromatic aberration, see DALSA's "Correcting Chromatic Aberration" application note, doc# 03-32-00363.

### Illumination

The amount and wavelengths of light required to capture useful images depend on the particular application. Factors include the nature, speed, and spectral characteristics of objects being imaged, exposure times, light source characteristics, environmental and acquisition system specifics, and more.

It is often more important to consider exposure than illumination. The total amount of energy (which is related to the total number of photons reaching the sensor) is more important than the rate at which it arrives. For example, $5\mu J/cm^2$ can be achieved by exposing $5mW/cm^2$ for 1ms just the same as exposing an intensity of $5W/cm^2$ for $1\mu s$.

### Light Sources

Keep these guidelines in mind when setting up your light source.

- Halogen light sources generally provide very little blue relative to IR.
- Fiber-optic light distribution systems generally transmit very little blue relative to IR.
- Some light sources age; over their lifespan they produce less light. This aging may not be uniform—a light source may produce progressively less light in some areas of the spectrum but not others. The camera's calibration process can compensate for this degradation, assuming there is still sufficient blue light.

### Filters

CCD cameras can be extremely responsive to infrared (IR) wavelengths of light. To prevent infrared from distorting the images you scan, the camera uses a "hot mirror" or IR cutoff filter that transmits visible wavelengths but does not transmit wavelengths over 700µm. Depending on your application, additional filters may be justified.

## 4.3 EMC Operation

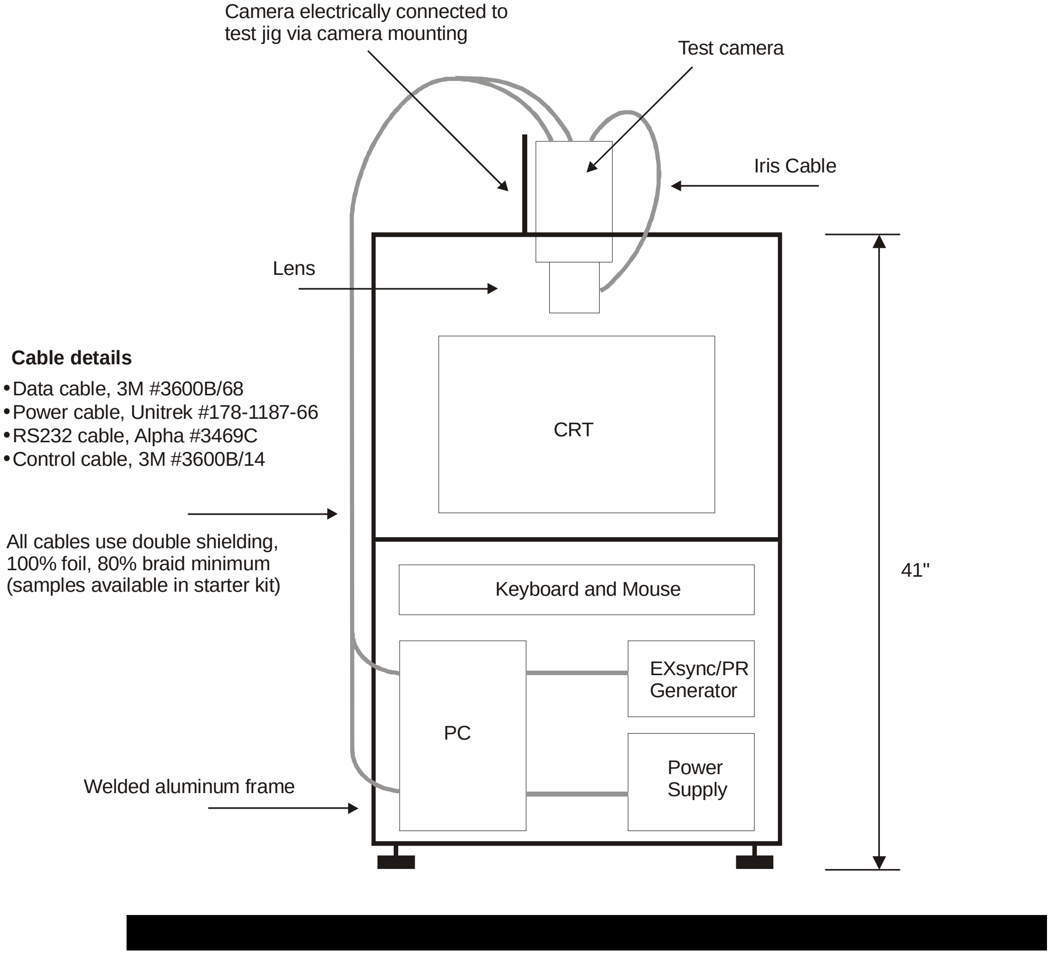
The Trillium has been designed for EMC compliance, including the supplied cables.

Follow these specific guidelines to maximize compliance in your application:

- Keep all cables as short as possible.
- All cables must have 95% coverage shields that include braided wire. Metallic foil shields are insufficient without braided wire.

- Ensure that all cable shields have 360° electrical connection to the connector.
- Electrically connect camera mount to the metal camera support structure.

### *EMC Test Setup for CE Compliance Testing*



CHAPTER 5

# 5.0 Troubleshooting

The information in this chapter can help you solve problems that may occur during the setup of your camera. Remember that the camera is part of the entire acquisition system. You may have to troubleshoot any or all of the following:

- power supplies
- frame grabber hardware & software
- light sources
- operating environment
- cabling
- host computer
- optics
- encoder

## 5.1 Diagnostic Tools

The Trillium has a range of very useful diagnostic capabilities, including the following:

- On-camera LED status code indicator.
- With a 12 – 15V power supply and a RS232 connection, you can capture reference data **without** a frame grabber.
- The camera can output a test pattern for data path/acquisition system debugging.
- Internal diagnostics to verify power, temperature and timing.

# 5.2 Product Support

If the troubleshooting flowchart indicates a problem with your camera, collect the following data about your application and situation and call your DALSA representative.

**Note:** You may also want to photocopy this page to fax to DALSA.

| | |
|---|---|
| **Customer name** | |
| **Organization name** | |
| **Customer phone number**<br>**fax number** | |
| **Complete Product Model Number** (e.g. TR-36-01K25...) | |
| **Complete Serial Number** | |
| **Your DALSA Agent or Dealer** | |
| **Acquisition System hardware** (frame grabber, host computer, light sources, etc.) | |
| **Acquisition System software** (version, OS, etc.) | |
| **Power supplies and current draw** | |
| **Data rate used** | |
| **Control signals used in your application, and their frequency or state** (if applicable) | |
| **Detailed description of problem encountered.** | *please attach description with as much detail as appropriate* |

In addition to your local DALSA representative, you may need to call DALSA Technical Sales Support:

| | North America | Europe | Asia |
|---|---|---|---|
| **Voice:** | 519-886-6000 | +49-8142-46770 | 519-886-6000 |
| **Fax:** | 519-886-8023 | +49-8142-467746 | 519-886-8023 |

# Appendix A: EIA-644 Reference

EIA-644 is an electrical specification for the transmission of digital data. The standard is available from the EIA (Electronic Industries Association). It defines voltage levels, expected transmission speeds over various cable lengths, common mode voltage operating requirements for transmitters and receivers, and input impedances and sensitivities for receivers. The table below gives a quick comparison between EIA-644 and RS422 (another differential standard).

### *Table 2. RS422 vs. EIA-644*

| Parameter | RS422 | EIA-644 |
|---|---|---|
| Differential Driver Output Voltage | ±2-5V | ±250-450mV |
| Receiver Input Threshold | ±200mV | ±100mV |
| Data Rate | <30Mbps | >400Mbps |
| Supply Current, Quad Driver (no load, static)* | 60mA | 3.0mA |
| Prop. Delay of Driver, max.* | 11ns | 3ns |
| Prop. Delay of Receiver, max.* | 30ns | 5ns |
| Supply Current, Quad Receiver (no load, static)* | 23mA | 10mA |
| * based on National Semiconductor DS90C031/2 | | |

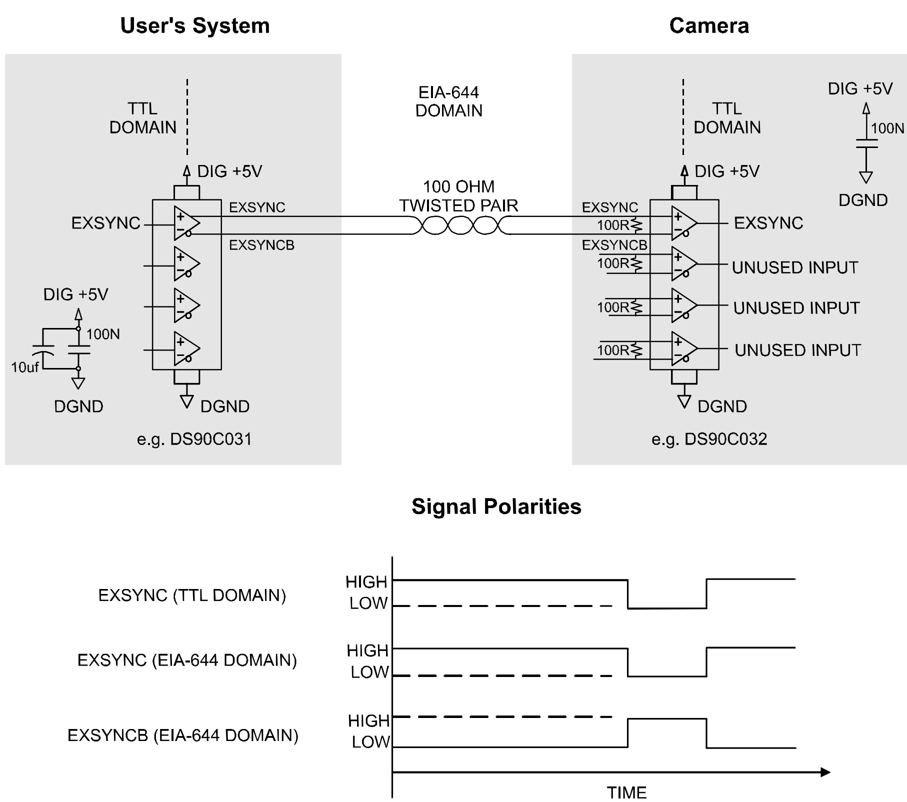
The standard requires that two wires (e.g. twisted pair) be used to transmit one signal in a differential mode. This means that one wire will be logic HIGH while the other wire is logic LOW. Voltage swing between HIGH and LOW is approximately 350mV, with a typical offset of approximately 1.25V. The use of differential signal transmission allows the receiver to reject common mode voltages. This noise rejection improves data integrity and allows cameras to be installed in an industrial environment.

EIA-644-compatible line receivers and drivers are available from many different IC manufacturers in a variety of fabrication technologies such as CMOS and GaAs. The EIA-644 standard does not define specific voltages, so it can migrate from 5V power supplies to 3.3V and sub-3V. DALSA recommends the use of 5V CMOS line drivers and receivers such as National Semiconductor parts DS90C031 quad line driver and DS90C032 quad line receiver.

To achieve full benefit of the common mode rejection, twisted pair cable should be used for all EIA-644 signals. The cable impedance should be 100 Ohms and the cable terminated at the receiving end with a 100 Ohm resistor. All EIA-644 inputs in a DALSA camera are terminated with 100 Ohms between the (+) and (-) of a signal. Figure A-1 (a) shows an example of an EIA-644 transmission.

DALSA indicates the (+) signal by the name of the signal; i.e. EXSYNC, while the (-) signal is indicated by either an overscore over the name or appending the letter B to the end of the name; i.e. $\overline{\text{EXSYNC}}$ or EXSYNCB. The (+) signal has the same sense as the TTL signal which is sent or received; i.e. when EXSYNC in the TTL domain is HIGH then EXSYNC in the EIA-644 domain is HIGH. The (-) signal has the opposite sense of the TTL domain signal and so if EXSYNC TTL is HIGH then EXSYNCB EIA-644 is LOW. Figure 4 shows the relationship.

### *Figure 4. EIA-644 Example*



## Unused EIA-644 Inputs and Outputs

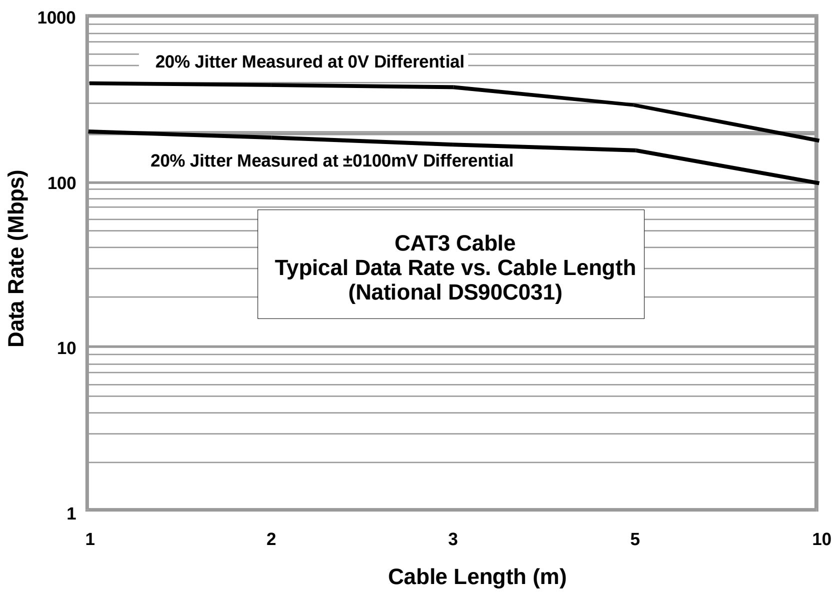
Unused **outputs** should be left unconnected. This will reduce power dissipation within the camera and reduce radiated emissions.

Unused **inputs** should also be left unconnected; EIA-644 chips have fail-safe features that guarantee a known logic state (HIGH) in fault conditions (unconnected, shorted, or unterminated). **Do not connect cables to unused inputs.** Cables can act as antennae and cause erratic camera behavior.

## Cable Lengths

Figure 5 shows a graph of ideal communication data rate vs. cable length for the EIA-644 standard.

### *Figure 5. EIA-644 Data Rate vs. Cable Length*



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# Appendix B: EMC Declaration of Conformity

We, **DALSA Corp.**
**605 McMurray Rd., Waterloo, ON**
**CANADA N2V 2E9**

declare under sole responsibility, that the product(s):

**TR-36-xxxxW (all models)**
**TR-37-xxxxW (all models)**
**TR-38-xxxxW (all models)**

fulfill(s) the requirements of the standard(s)

**FCC Part 15**
**ICES-003**
**EN 55022: 1998**
**EN 55024: 1998**
**EN 61000-6-1: 2001**

This product complies with the requirements of the Low Voltage Directive 73/23/EEC and the EMC Directive 89/336/EEC and carries the CE mark accordingly.

| | |
|---|---|
| Place of Issue | **Waterloo, ON, CANADA** |
| Date of Issue | **18 February 2005** |
| Name and Signature of authorized person | **Hank Helmond**<br>**Quality Manager, DALSA Corp.** |

This Declaration corresponds to EN 45 014.

# Appendix C: Communications Protocol

## C1. Protocol Overview

This protocol defines the complete method used to control the camera via a RS232 serial interface. The communication protocol defines the command format used, as well as the checksum and error handling methods used.

## C2. Protocol Features

- ASCII-based
- Checksum is optional. If it is provided, then the camera's microprocessor will verify it and only proceed if no error occurs.
- Multi-drop communications
- Multiple baud rates
- No autobaud (camera will not respond if the wrong baud rate is chosen)

### Camera Serial Port Defaults

- 8 data bits
- 1 stop bit
- No parity
- No flow control
- 38.4Kbps
- Camera does not echo characters

## C3. Command Format

### Short Form

```
[:ID] a[b][c] [channel] [values...] [#nn]CR
```

## Long Form

```
[:ID] acommand[_bcommand][_ccommand] [parameters...]
[#nn]CR
```

- Carriage return (CR) Ends each command. The linefeed character is optional.
- All values are assumed to be in decimal
- Values in square brackets are optional (or are command specific)
- A simple addition checksum can be used by placing a # key as the last parameter before the carriage return. The checksum is calculated by adding all of the ASCII values of the line up to the # character (including spaces), and then sending it as a 3 digit integer number (from 0-255). The checksum will be calculated using an 8-bit number. All higher-order bits will simply be truncated.
- Command words a, b, and c uniquely specify each command
- Spaces must be placed between all sections, and commas must be placed between all parameters
- There are two methods for entering the commands: In long mode each command is written in its entirety and words are separated by the underscore '_' character. In the short mode, only the first letters of each command are required, and no spaces or underscore characters are permitted.
- The camera will answer each command with either "Ok >" or "Error x: Error Message >". The ">" is always the last character sent by the camera.

# C4. Multi-drop Mode

- If the device ID is present, only cameras with the same character ID will respond to the command (IDs from 0 to 9 and from A to Z).
- All of cameras will ship with a default ID of 0.
- When the camera responds in multi-drop mode, it will send the ID of the camera with the response. For example, when sending a command to camera 2, the camera will respond "2 Ok >".
- In multi-drop mode, a global command can be sent by including the ":" but omitting the camera ID. All cameras will process the command, but will not respond. For example, to begin a camera calibration for all cameras at once enter ": cc 1". None of the cameras will respond. The **`query_busy`** command can then be used to determine when the calibration has been completed.
- A camera's ID can be programmed while in the network by using the **`set_camera_id`** global command. For example, to set the ID to 8 use the command:

```
: set_camera_id 8
```

# C5. Examples

### Example: to set the gain for all channels to 1

```
set_gain 1,1,1
```

or

```
sg 1,1,1
```

### Example: to return the model number of camera 1

```
:1 get_camera_model
```

or

```
:1 gcm
```

### Example: to begin a camera calibration (white light correction)

```
correction_set_sample 64
correction_calibrate 2
```

or

```
css 64
cc 2
```

# C6. Error Handling

- The camera will send "Ok >" to an empty message (i.e. just a CR). This simulates a "command prompt"
- All non-query functions return "Ok >" unless an error occurs
- If an error occurs, the function returns "Error x: Description >" where x is an error code
- Error codes include:

| Code | Description |
|---|---|
| 0 | Ok |
| 1 | Camera error. An internal error was found. Please report this error code to DALSA. |
| 2 | Video Timeout Error. External or internal sync not functioning. |

| Code | Description |
|---|---|
| 3 | Unable to program internal FPGAs. Please report this error code to DALSA. |
| 4 | Validation error programming flash memory. Please report this error code to DALSA. |
| 5 | One or more of the required supply voltages is out of specification. |
| 6 | The camera temperature is outside the valid operating range. |
| 7 | The camera memory check failed. Please report this error code to DALSA. |
| 8 | The camera flash memory check failed. Please report this error code to DALSA. |
| 9 | The camera DSP check failed. Please report error to DALSA. |
| 10 | Camera calibration error. The light level is below the acceptable range for white light calibration. |
| 11 | Camera calibration error. The light level is above the acceptable range for calibration. |
| 12 | Camera calibration error. The white reference variation exceeds 2 to 1. |
| 13 | The calibration requires that the camera operate with exposure control enabled. |
| 14 | Sensor saturation error. One or more pixels will be clipped at 255. |
| 15 | Checksum error. The command was not processed. |
| 16 | Unknown command. |
| 17 | Command could not be completed successfully. |
| 18 | Invalid command format. |
| 19 | Parameters out of range. |
| 20 | Invalid parameters type. |
| 21 | Invalid number of parameters. |
| 22 | Camera ID character is invalid. |
| 23 | Command will invalidate the video correction results. Recalibrate the camera. |
| 24 | Aperture is not responding. |

# C7. Commands

| Command | Short Form | Parameters | Description |
|---|---|---|---|
| correction_calibrate | cc | Calibration Type | Execute a calibration: Calibration type is the type of calibration to perform and can have the following values:<br>0: Clear the calibration coefficients<br>1: Calibration with a black reference<br>2: Calibration with a white reference<br>3: Calibration with a white reference only in exposure control mode |
| correction_get_fpn | cgf | Channel, Pixel | Read the correction coefficient for a specific pixel |
| correction_get_prnu | cgp | Channel, Pixel | Read the PRNU coefficient for a specific pixel |
| correction_get_results | cgr | | Return the results from the last calibration. Also returns the current gains of the camera |
| correction_set_balance | csb | Red value, Green value, Blue value | Set the calibration balance target for all channels as a % of full scale. The values for each channel are independent |
| correction_set_fpn | csf | Channel, Pixel, Value | Write the correction coefficients for a specific pixel |
| correction_set_prnu | csp | Channel, Pixel, Value | Write the correction coefficients for a specific pixel |
| correction_set_sample | css | Sample size | Set the number of lines to average for the calibration |
| get_camera_id | gci | | Get the camera ID |
| get_camera_model | gcm | | Read the camera model number |
| get_camera_parameters | gcp | | Read all of the camera parameters. Note: Sequence of camera parameters may change as new functionality is added to the camera. When possible, use commands specific to the information you want to retrieve |
| get_camera_serial | gcs | | Read the camera serial number |
| get_camera_version | gcv | | Read the firmware version and FPGA version |
| get_line | gl | Channel, Sample size | Get a scan line averaged over x lines |

| Command | Short Form | Parameters | Description |
|---|---|---|---|
| get_line_noise | gln | Channel, Sample size | Get the rms noise for a specific channel |
| get_line_statistics | gls | Channel, Sample size | Get the minimum, maximum, and average for x lines of video |
| help | h | | Display the online help |
| increment_aperture | Ia | Value | Increment the aperture setting by "Value." "Value" can be negative |
| increment_sync_duty | isd | Value | Increment the sync duty cycle by "Value." "Value" can be negative |
| increment_sync_frequency | isf | Value | Increment the sync frequency by "Value." "Value" can be negative. |
| optimize_vpr | ovp | Value | Set the minimum pixel level. Recommended value is 12 |
| reset_camera | rc | | Reset the entire camera (reboot) |
| restore_factory_settings | rfs | | Restore the camera's factory settings |
| restore_settings | rs | | Restore the last settings saved to non-volatile memory by the write_settings command |
| set_aperture | sa | Value | Set the aperture (iris) position from 0-100. 0 = closed, 100 = fully open. Command **`sa 50`** provides 50% of the light of **`sa 100`**. The aperture is accurate within ±5 |
| set_baud_rate | sbr | Rate | Set the baud rate. Valid rates are: 2400, 4800, 9600,19200, 38400 |
| set_camera_id | sci | Serial number, ID | Set the camera ID (0-9 and A-F). If the serial number is given, only that camera will change its ID |
| set_gain | sg | Red value, Green value, Blue value | Set the gain for each channel. The values for each channel are independent. Gain value is specified from 1 to 15.98 as a floating point number |
| set_pretrigger | sp | Pretrigger | Set the pretrigger (either 0 or 8) |
| set_sync_duty | ssd | Duty cycle | Set the internal sync duty cycle for exposure control mode. Returns an error message if value is beyond specified limits |
| set_sync_frequency | ssf | Exsync rate | Set the internal sync rate in Hz |
| set_sync_mode | ssm | mode | Set the line sync mode of the camera: |

| Command | Short Form | Parameters | Description |
|---|---|---|---|
| | | | 1: Internally generated Sync, EC (exposure control) Enabled<br>2: Internally generated Sync, EC Disabled<br>3: Externally generated Sync, Level Mode (Combined EC; see page 17)<br>4: Externally generated Sync, Edge Mode (Separate EC; see page 17)<br>5: Externally generated Sync, EC Disabled<br>6: Free running mode |
| test_halt | th | | Stop test pattern generation and return to regular operation |
| test_set_pattern | tsp | Test number | Set the test pattern used for test pattern generation |
| test_start | ts | | Start the test pattern generation |
| user_get | ug | Input | Get the function of the user input |
| user_set | us | Input, text command | Set the function of the user input number to the specified command. This command will be executed whenever the input is triggered. Note that input #1 is the push button |
| verify_camera | vc | | Check the entire camera |
| verify_memory | vm | | Perform a memory check |
| verify_sync | vs | | Verify that the sync signal is being generated internally (sync modes 1-2) or being supplied externally (sync modes 3-5). Returns an error message if exposure levels exceed the range of 2-95% |
| verify_temperature | vt | | Check the temperature of the camera |
| verify_voltage | vv | | Check the camera voltages and return OK or fail |
| write_settings | ws | | Write all of the user settings to FLASH |

# Appendix D: Setting Up Your Camera

## D1. Overview

A detailed overview of the features used to control your camera is provided in Chapter 3.

In order to get your camera running quickly and smoothly you will need to:

- Check the integrity of the camera, including power supplies and communication links.
- Determine the lighting requirements of your system.
- Calibrate the camera.

The Trillium camera incorporates a number of features that enable you to get your camera running quickly. Much of this evaluation can be done through the serial interface without a frame grabber.

## D2. Checking the Integrity of the Camera

To establish the basic functionality of the camera, you require a 12 or 15 volt power supply and an RS232 serial link.

A cable starter kit, accessory # AC-SU-0500, is available to the first time user. The kit includes a power cable, control cable and data cable, all terminated at one end, plus an RS232 cable. All cables use appropriate shielding to ensure the best EMC performance and signal integrity. Contact DALSA to order.

## Ensuring an Adequate Power Supply

**Important:**
Protect the camera and power cable with a 2AF fuse. Internal protection circuits in the camera rely on this fuse being present.

You must ensure your power source has adequate current capability. At low voltage (6 to 8 volts), the switching supply in the camera draws a current that can be as much as twice the rated current. Some supplies, even though they appear to be rated appropriately, will not come up when the camera is plugged in. Though not harmful to the camera, this low-voltage current draw can cause the power source to reach the external supply current limit before it can reach the specified operating voltage, disabling the camera. You need a power supply that can handle an input surge current of approximately 4 Amps for 10 milliseconds of operation. A 2 Amp power supply running under normal conditions should be sufficient.

## Communicating with the Camera

You communicate with the camera through a serial interface communication package, such as the HyperTerminal program available with Windows© 95 or NT.

If you choose to use the HyperTerminal application, configure the connection's properties (e.g. data bits, stop bits, parity, bits per second, etc.) as described in Appendix C.

Because the camera does not echo characters you send to it, you need to set the "Echo typed characters locally" option, located under the ASCII Setup button on the Settings tab in HyperTerminal.

## Startup

Once you have started your camera and allowed the startup routine to run, the camera displays either a '0' if no error occurred, or an error code if a problem has been discovered. If an error occurs, see Appendix C for a full list of error codes and the response you should take.

## Obtaining Basic Camera Information

**Note:** All commands have short forms. See Appendix C.

Use the following commands to obtain basic camera information:

1. To verify the link with your camera, type a carriage return. The camera should display the '>' prompt.
2. To generate a list of all available commands and parameters, send the command **`help`** or **`?`** to the camera.
3. To verify the serial number, model number, and sensor length, send the command **`get_camera_parameters`**.
4. To execute the same tests performed during power, send the **`verify_camera_command`**. This command can be used anytime.
5. To check that all supplies, including the power source, are within specification, send the command **`verify_voltage`**. When using the power cable supplied with the cable starter kit, the voltage at the camera should measure no more than 300mV below the power source voltage.

# D3. Determining Appropriate Illumination

After ensuring the integrity of your camera, you need to determine the appropriate level of illumination for your system.

The faster your lens, the less illumination you need.

## Establishing Illumination Requirements

Mount the camera in your system with the desired lens. The widest aperture may not give you optimum image quality and you may have to stop the lens down and increase illumination significantly.

The initial object for the camera should be white plastic or PVC with minimal texture or grain. Paper is undesirable as the grain induces significant PRNU after calibration. To assess your illumination requirements:

**Note:** Running the camera from an internally generated sync signal allows for the greatest flexibility while performing the procedure.

1. Set the sync source to internal with exposure control off by sending the command **`set_sync_mode 2`**.
2. Set the maximum desired line rate by sending the command **`set_sync_frequency`** ***`frequency`***, where ***`frequency`*** is the line rate in kHz.
3. Set the gain for each channel to the lowest level by sending the command **`set_gain 1,1,1`**.
4. Determine the response of each channel by sending the command **`get_line_statistics`** ***`#channel`*** **`, 20`**. For example, **`get_line_statisticc 3, 20`**. Where **`20`** is the number of lines used to determine the statistics. Record the average response for each channel and calculate the gain required to achieve approximately 200 DN.
5. Using the gain values determined above, send the **`set_gain`** command again. (Note: 15.98 is the maximum.)
6. Determine the response of each channel by sending the command **`get_line_statistics`** ***`#channel`*** **`, 20`**. The average values reported should be close to 200 DN. If not, adjust the gains appropriately.

You have now established the approximate gains the camera will use when calibrated. The higher the gains, the worse the generated noise level.

## Determining Noise Levels

To determine the noise level generated by the camera at the established gain settings, use the command **`get_line_noise`** ***`#channel`*** **`, 20`**.

The values returned are for RMS noise. Peak to peak noise will be about 5 times this figure. Any extraneous light, particularly from fluorescent fixtures, can affect the noise figure significantly, especially when the gains are high. Try turning lights off in the vicinity of the camera to determine if the noise figures change.

Note that the **`get_line_noise`** command returns slightly higher figures than actually exist on the data port. This is due to a different noise environment existing within the camera while the embedded controller is capturing data.

# D4. Calibrating the Camera

**Note:** If your illumination or white reference does not extend the full field of view of the camera, calibration will still be successful for the center portion of the image. However, the camera will send a warning that the illumination level is too low under these conditions.

To ensure the camera will calibrate successfully, you need to check the camera's response to the white reference:

1. Continuing from the setup above, send the command **`get_line_statistics`** ***`#channel`*** **`, 20`** for each channel. Examine the maximum and minimum values reported. If the maximum values are no greater than twice their associated minimum values, the camera should calibrate successfully.
2. If the ratio of minimum to maximum value reported is greater than 2 times, send the command **`get_line`** ***`#channel`*** **`, 20`** to display a line of pixel data. Examine the displayed data, looking for low values that are causing the unacceptable spread of data. Associate the low light level spots with the illumination system and identify alignment and/or unevenness problems that can be improved.
3. When the minimum to maximum value reported is less than 2 times, you can calibrate the camera.

The factory defaults for the calibration balance targets for all channels are 94%. This means that after calibration the white reference will appear as nominally 240DN for all pixels. These values can be used to compensate for the white reference (see below).

## Calibrating the Camera with Exposure Control Disabled

**Note:** If you can tolerate minor FPN it may be possible to omit, the **`correction_calibrate 1`** command, or perform it less frequently. Usual calibration can then consist of **`correction_calibrate 2`** only.

Calibration can be performed when running from internal or external sync. With the line rate set to the desired calibration frequency, perform the calibration:

1. Reset the correction values by sending the command **`correction_calibrate 0`**.
2. Establish dark conditions by covering the lens.
3. Correct the pixel offsets by sending the command **`correction_calibrate 1`**.
4. Place a white reference in front of the camera, close to the object plane.
5. Ensure that the light intensity is characteristic of the final imaging environment.
6. Establish a flat field by sending the command **`correction_calibrate 2`**.

# Calibrating the Camera with Exposure Control Enabled

Calibration can be performed when running from internal or external sync. With the line rate and exposure control duty cycle set to the desired calibration frequency, perform the calibration:

1. Place a white reference in front of the camera, close to the object plane.
2. Ensure that the light intensity is characteristic of the final imaging environment.
3. Establish a flat field and remove the pixel offsets by sending the command **`correction_calibrate 3`**.

**Note:** for further calibration issues, refer to the "dark offset de-rating curve" section, page 40.

# Reviewing the Calibration Results

To review the results of the calibration, send the command **`get_line_statistics #channel, 20`**. The average values for each channel should be close to 240 DN, and the minimum and maximum values should be within a few DN of the average.

**Note:** increasing the number of lines averaged will reduce the minimum/maximum spread if gains are high. Try a value of 64 to determine if there is a difference.

# Adjusting Calibration to Accommodate the White Reference

If the white in the media you want to image is not equal, in brightness and hue, to the white reference, images could be distorted. To accommodate for different white values use the command **`correction_set_balance`**.

1. Determine the **`correction_set_balance`** parameters by sending the command **`correction_set_balance 100,100,100`**, and calibrate the camera in the desired mode, line rate, and white reference.
2. Place the media to be imaged at the object plane of the camera, ensuring it contains white as you define it.
3. Obtain the image data for the actual white levels recorded by the camera by sending the command **`get_line #channel, 20`**.

**Note:** Depending on what you have available, it may be easier to do this adjustment using your frame grabber and image processing S/W.

4. Examine the value of the white levels.

## White Levels Lower than 254 DN

If the actual white levels are lower than 254 DN for each color, your white reference is brighter than the white in your media and you need to brighten the image by increasing the calibration target levels:

1. Adjust the levels for each channel by sending the command **`correction_set_balance`** ***`{100 * Desired Levels/Actual Levels for each Color}`***.

2. Re-calibrate the camera.

## White Levels Higher than 254 DN

If the actual white levels are higher than 254 DN, your white reference is dimmer than the white in your media and you need to stop saturation by reducing the calibration target levels:

1. Send the command **`correction_set_balance 50, 50, 50`**.

2. Re-calibrate the camera.

3. Obtain the image data for the actual white levels recorded by the camera by sending the **`command get_line #channel, 20`**.

4. Examine the value of the white levels.

5. Adjust the levels for each channel by sending the command **`correction_set_balance`** ***`{100 * Desired Levels/(2 * Actual Levels for each Channel)}`***

6. Re-calibrate the camera

The desired levels for each channel should now be met when imaging the white present in the media.

# Saving your Settings

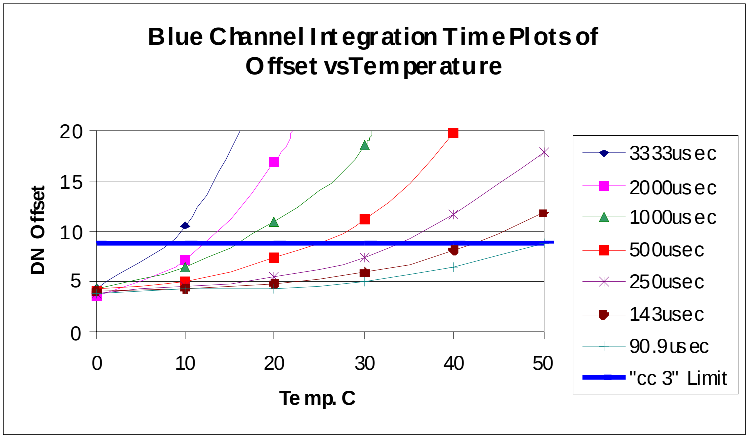
After you have completed the calibration you can save these settings in the camera's non-volatile memory in order to retain them after a power down/up cycle. To save your settings, send the command **`write_settings`**.

# Appendix E: Dark Offset De-rating Curve

## D1. Overview

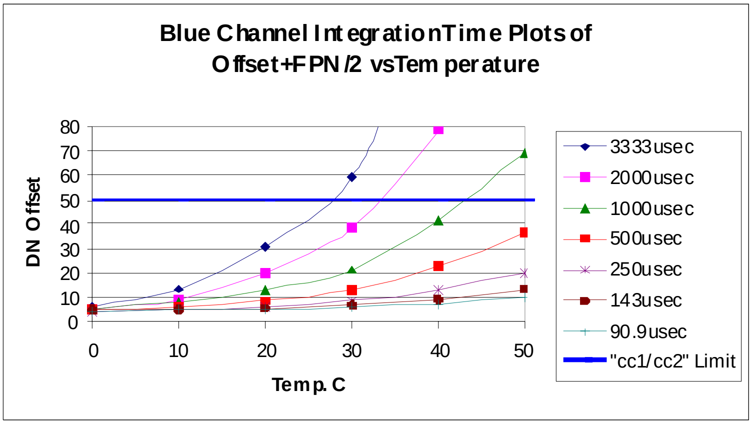
At high temperatures and low line rates, the increase in CCE by the IL-P3 sensor results in large dark offsets, caused by the amplification of temperature generated dark signal integrated over long periods. This effect has an impact on the ability of the Trillium camera to correctly calibrate itself. The plots below detail the offset characteristics and associated limits for successful calibration.

The first plot shows the limit for cc3 being able to calibrate the camera (without a dark reference) and meet the calibration accuracy specifications:




**Integration Time De-rating Plots for the cc3 Calibration Mode, Typical Gains Set to 2**

The second plot shows the limits for cc1/cc2 being able to calibrate the camera. The exposure time/temperature range for cc1/cc2 is greater than cc3. However, caution must be taken when calibrating at the lower line rates, as the effects of temperature drift will become greater. Plots for the blue channel only are shown, as the red/green channel offsets are lower due to their gain in the analog signal processing chain being only 60% of the blue channel.




**Integration Time De-Rating Plots for the "cc1/cc2" Calibration Mode, Typical Gains Set to 2**

**Note:** The de-rating curves are specified in integration time. Thus, low line rates can be used if the integration time is not exceeded.

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# Appendix F: Revision History

| Revision | Description |
|---|---|
| 00 | Manual release |
| 01 | Removed section 3.10 Increasing Sensitivity with Binning and removed the binning command from section C7. Binning Is not available in this camera. |
| 02 | Removed "Pending" from Appendix B: EMC Declaration of Conformity and updated declaration to new standards. |
| 03 | Removed all references to matched lenses. These are no longer available for this camera.<br>Fixed incorrect gain range listed in section 1.3 from -6 to 12dB to 1 to 15.98dB and in section 3.7 from 0 to 15.98 to 1 to 15.98.<br>Removed references to 0dB gain on pages 9, 69, and 70 and changed the value to 2 (the linear equivalent). |

# INDEX

## L



## M



## N



## O



## P



## R



## S



## T



## U



## V



## W