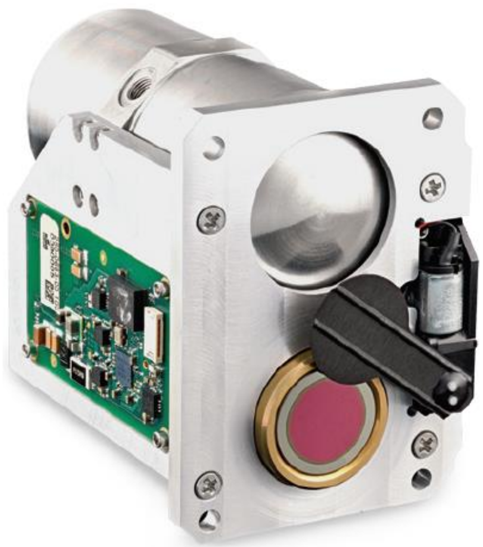

FLIR NEUTRINO LC®
THERMAL IMAGING CORE
ENGINEERING DATASHEET

Doc. # 102-2020-40, Release 320

Official Publication Date: December 30, 2021
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General Description

Neutrino® LC is a complete thermal imaging camera module designed to integrate easily into a Original Equipment Manufacturer (OEM) systems. The sensor array operates at a high operating temperature (HOT) for power and fast time to image, images mid wave infrared (MWIR) radiation, and outputs a thermal video stream. A highly configurable platform, Neutrino LC provides a host of user-selectable features and interfaces for a variety of applications.

Features

- VGA (640x512) sensor array
- Multiple hardware configurations
- Multiple f/# options: f/5.5 and f/4.0 with more options in future releases
- Multiple spectral transmission options: 3.4µm to 5µm standard, with more options in future releases
- Integral shutter assembly option
- Small size, weight, and power (SWaP); capability to trade feature set for power
- Linear cooler technology for low vibration, low audible noise, and standby mode option for faster cooldown
- Fast cooldown of < 4 minutes at room ambient temperature, with "fast" start-up mode option available with shutter
- User-configurable I/O with multiple channels for video and command/control, including USB2, digital parallel, and UART
- SDIO and I2C channels for peripheral support (e.g. memory card, external GPS, gyro, digital compass, etc.)
- State-of-the-art signal processing, including advanced noise filters for superior sensitivity, eZoom, and colorization
- Power-safe field upgrades
- Designed for industrial/military environment

Applications

- UAV systems
- EVS
- NDT/Medical/Science
- Security & surveillance systems
- Military dismount systems

Key Specifications

IMAGING	
Sensor Technology	HOT MWIR
Sensor Size	640 x 512 pixels, 15µm pitch
Spectral Band	3.4 to ≥ 5.1 µm standard
Effective frame rate	60Hz nominal, configurable
Thermal Sensitivity	< 30 mK[1]
NUC	(4) configurable NUCs
Time to Image	< 4 min, room temp
ELECTRICAL	
Input Voltage	+12 VDC, Cooler +3.3 VDC, Camera
Power Dissipation	< 4.5 W typical, SS/room temp
Video Channels	Parallel and USB CameraLink[2], NTSC/PAL[2]
Control channels	UART or USB
Peripheral channels	I2C, SDIO
PHYSICAL ATTRIBUTES	
Size	< 79(L) x 45.5(W) x 61(H) mm
Weight	< 380 grams
f/number	f/5.5, f/4.0
Cold Shield Height	19.71mm (f/5.5) 19.40mm (f/4.0)
ENVIRONMENTAL	
Operating Temp.	-40 °C to +71 °C
Storage Temp.	-57 °C to 80 °C

Note(s):

1. No filters, 50% well fill, $T_{Background}$ = 25 °C flood
2. These video standards use the parallel channel, available support on accessory board

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1 DOCUMENT

1.1 Revision History

VERSION	DATE	COMMENTS
Rev100	02/04/2019	Release 1.0
Rev110	03/15/2019	Release 1.0, various updates and edits
Rev200	07/31/2019	Release 1.1 software and features, various updates and edits
Rev210	01/28/2020	Various updates and edits
Rev300	05/20/2020	Release 1.2 software and features, various updates and edits
Rev310	09/14/2020	Release 1.2.1 updates to CMOS Color RGB/BGR modes, Section 7.9 and Section 8.2.1
Rev311	11/30/2021	Removed RoHS compliancy
Rev320	12/30/2021	Various updates and edits including shock specification, spectral response, and NEdT measurement parameters. Teledyne FLIR branding and format updates. Copy edit updates.

1.2 Contact Us

In multiple locations throughout this document, FLIR's website is referenced as a source of additional information. This website can be accessed via the following URL:
https://www.flir.com/applications/camera-cores-components

The website also contains a Support Page:
https://flir.custhelp.com/

1.3 Document Conventions

Throughout this document, modes and parameters which are user-configurable via the command and control interface (CCI) are shown in **bold font**. Status variables which can be read via the CCI (and/or via the telemetry line in some cases) but not directly altered are shown in *italic font*.

1.4 Scope

Neutrino LC is a highly configurable thermal imaging core comprised of the following major components:

- IDCA Assembly: The integrated Dewar/Cooler assembly (IDCA) includes a Stirling linear cooler and Dewar with an integrated high operating temperature (HOT) mid-wave infrared (MWIR), VGA (640x512/15 µm) focal plane array (FPA).
- Cooler Controller Electronics: The cooler controller electronics control the cooler operation to cooldown, then maintain Dewar temperature for optimum power dissipation and image quality. The cooler electronics provide all cooler-related electrical inputs on a single connector, as detailed in Section 4.
- Camera Electronics: The camera electronics include common signal-processing electronics, providing state-of-the-art noise filtering, image enhancement, operational logic, and camera functions, as described in Sections 0, 6, and 0. The camera electronics also provide all camera electrical I/O on a single connector (except for cooler power), as detailed in Section 4.
- Shutter assembly (optional): An integral shutter assembly provides best uniformity by allowing the camera to automatically perform a periodic correction (termed flat-field correction) as required.

2 KEY SPECIFICATIONS

Unless otherwise stated, all specifications apply to all Neutrino LC configurations.

TABLE 1: KEY SPECIFICATIONS

SPECIFICATION	DESCRIPTION
Overview	
Sensor technology	HOT MWIR
Pixel size	15 µm
Array format	640 x 512
Spectral range	3.4 to ≥ 5 µm standard
Well capacity	7×10^6 electrons
Effective frame rate	60 Hz baseline 30Hz with averager enabled Configurable or external sync driven 2Hz to 60Hz 60Hz/50Hz NTSC/PAL[1]
Thermal sensitivity	< 30 mK [2]
Operability	≥99.5%
Non-uniformity corrections (NUC)	(4) User-Programmable NUCs Automatic flat-field correction (FFC), shuttered config only
Electronic zoom	1x to 8x zoom (see Section 6.5)
Image orientation	Adjustable Revert (vertical flip) and/or Invert (horizontal flip)
Symbol overlay	Alpha blending for translucent overlay
Electrical	

Video output channel	Two options: (see Section 8.2)
	• USB
	• Parallel/CMOS
	  ○ CameraLink[3]
	  ○ BT.656 NTSC/PAL[3]

Video output format	Three runtime-selectable options (see Section 7.8): • Data before AGC (16b, output resolution = 640 x 512) • Data after AGC, before digital zoom (8b, output resolution = 640 x 512) • Data after colorization and zoom (various bit-width, output resolution = 640x512)
Input clock	None Required
Frame sync	Three options: (see Section 7.3) • Free running: Frame timing internally synchronized

SPECIFICATION	DESCRIPTION
	• Master mode: Frame timing internally synchronized, with fsync pulse provided externally • Slave mode: Frame timing externally synchronized
Command & Control Interface (CCI)	Two options: (see Section 8.1) • UART • USB
Command & Control API	See Neutrino LC Software Interface Description Document (IDD)
Peripheral interfaces	• I2C (Neutrino LC master, peripheral as slave device) • SDIO
Camera input supply voltage (nominal)	3.3V (See Section 12.1)
Cooler input supply voltage (nominal)	12.0V (See Section 12.1)
Power dissipation	< 4.5 W[4]
Mechanical	
Package dimensions	Shutter-less: 74mm (L) x 45.5mm (W) x 61mm (H) Integral Shutter: 78.5mm (L) x 45.5mm (W) x 61mm (H)
Weight	< 380g
Environmental	
Operating temperature range	-40 °C to +71 °C[5]
Storage temperature range	-57 °C to +80 °C[6]
Operational Altitude	40,000ft (~12km)
Humidity	Non-condensing between 5% to 95%
Shock	150g, 0.5msec half-sine pulse, (X-axis) 300g, 0.5msec half-sine pulse, (Y-axis) 600g, 0.5msec half-sine pulse, (Z-axis)
Vibration	5.8grms, 3-axis, 1hr each

Note(s)

1. *50Hz / 25Hz is available only with the parallel/CMOS channel configured for BT.656-like output and is only intended for interface to a display. See Section 7.11.*
2. *No filters, 50% well fill, $T_{Background}$ = 25 °C flood. NEdT is also a function of integration time and f/#.*
3. *These video standards use the parallel/CMOS channel, available support in software (See Section 7.11) and accessory boards*
4. *Initial, typical value for steady state, room temperature ambient*
5. *Assuming recommended heat sinking and air flow*
6. *Storage temperatures > 71 °C for extended periods of time may cause vacuum degradation which increases power consumption and decreases the overall lifetime of the product*

3 SYSTEM ARCHITECTURE

A simplified architectural diagram of the Neutrino LC thermal imaging core is shown in Figure 1.

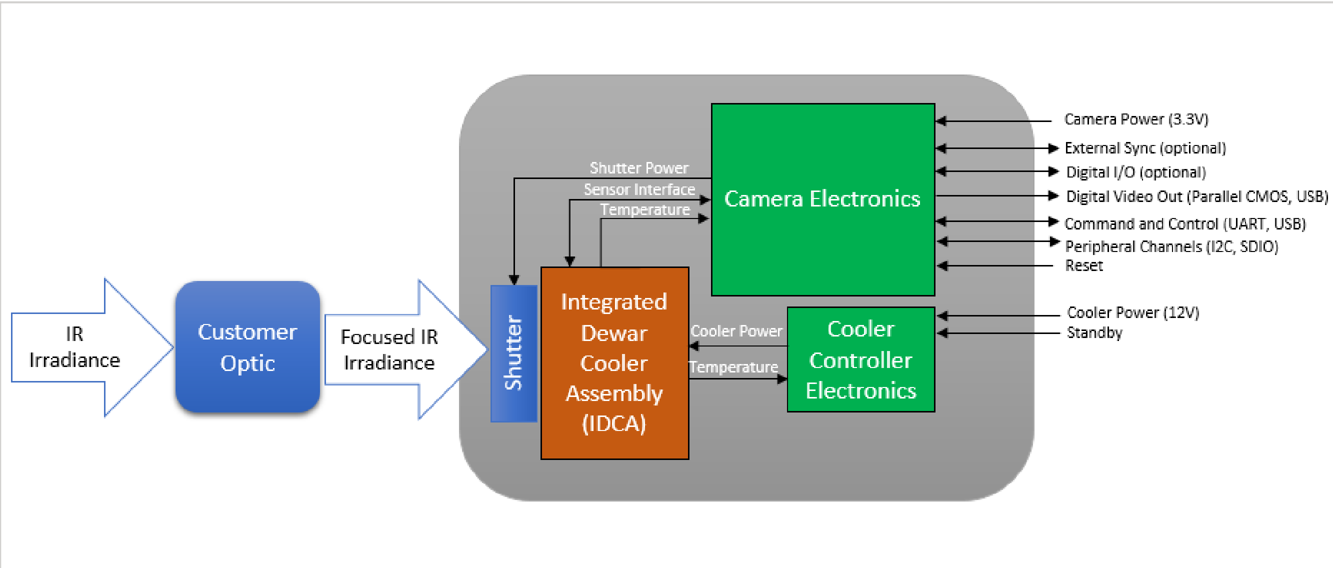


FIGURE 1: NEUTRINO LC SIMPLIFIED ARCHITECTURE

The customer provided optic assembly focuses infrared radiation from the scene through the Dewar assembly windows/filters and cold shield aperture onto the detector. The shutter assembly periodically blocks radiation from the scene, presenting a uniform thermal signal to the sensor array. This uniform input signal allows internal correction terms to be updated, improving image quality.

The camera electronics consists of a System on a Chip (SoC) which drives the cooled focal plane array (FPA) integrated in the Dewar assembly. The FPA is a two-dimensional 640x512 array of high operating temperature (HOT) MWIR photodetectors of 15-micron pitch. The detector array is hybridized to a readout integrated circuit (ROIC). Photons from the mid-wave IR band impinging on the focal plane are converted to an electrical current. The resulting signal is digitized and processed by the SoC, which provides signal conditioning and output formatting. The SoC is also responsible for all camera logic as well as the Command and Control Interface (CCI). The signal pipeline is fully defined in Section 0 while the output interfaces are defined in Section 8.

4 ELECTRICAL PINOUT

As shown in Figure 2, the electrical interface to the Neutrino LC camera electronics board is via a single 80-pin connector, Hirose DF40C-80DP-0.4V(51). The recommended mating connector is Hirose 80-pin board-to-board receptacle (socket) DF40HC-(4.0)-80DS-0.4V (51), for a mating stack height of 4.0 mm.

Also shown in Figure 2, the electrical interface to the Neutrino LC cooler electronics board is via a single 4-pin locking connector, Molex pico-lock 503763-0491. The recommended mating connector is Molex 4-pin pico-lock crimp housing 503764-0401, for a 1.50mm mated height.

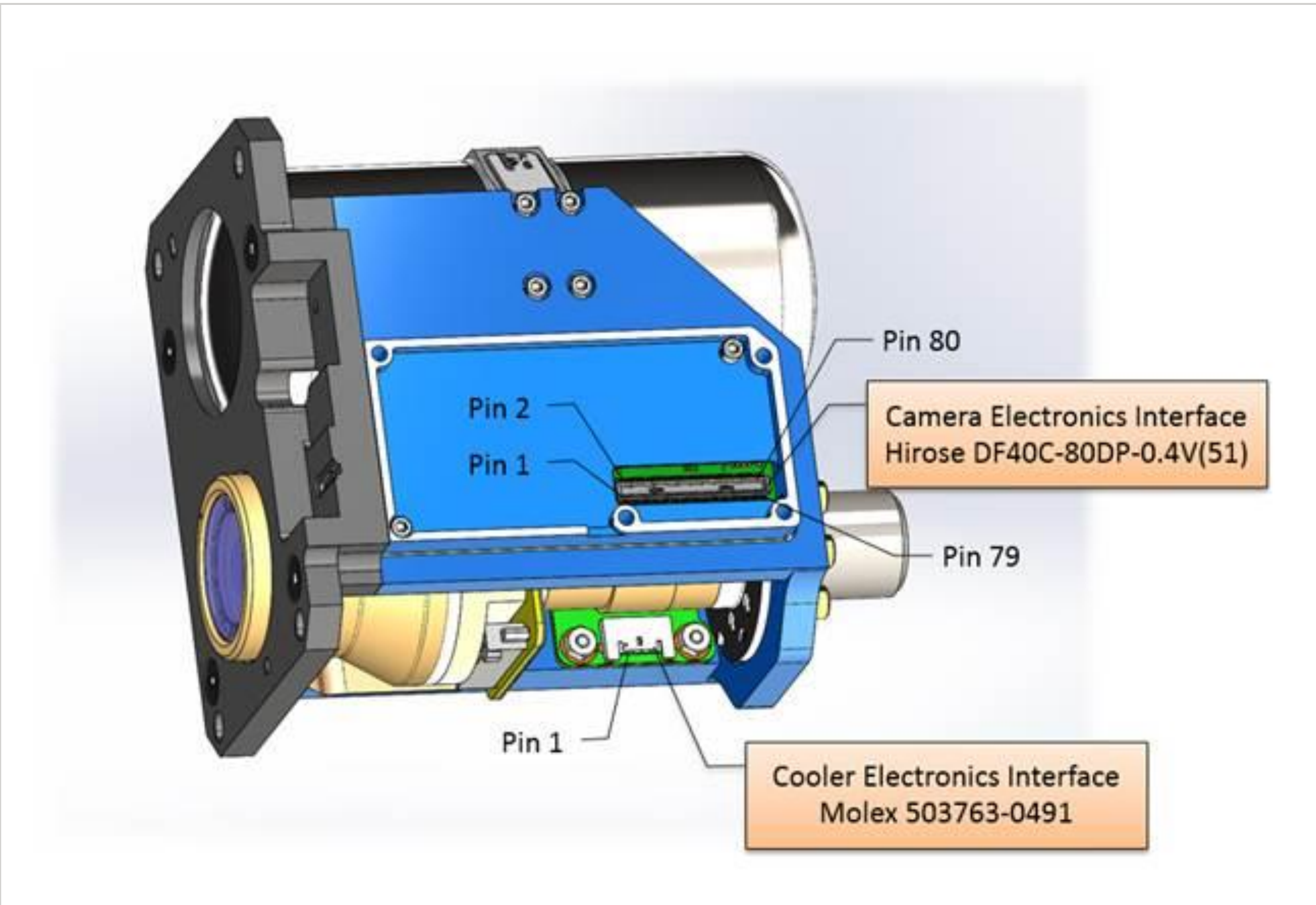


FIGURE 2: NEUTRINO LC CAMERA ELECTRONICS CONNECTOR PIN NUMBERING

4.1 Pin Assignments

Pin assignments and description for the camera electronics connector are shown in Table 2 and Table 3. Any channels or signals which will not be used should be left floating. Pin assignments and description for the cooler electronics connector are shown in Table 4.

TABLE 2: NEUTRINO LC CAMERA ELECTRONICS PIN ASSIGNMENTS AND PIN DESCRIPTION

PIN #	PIN NAME	SIGNAL TYPE	SIGNAL LEVEL	DESCRIPTION
1, 3, 5, 7, 10, 13, 19, 20, 29, 30, 39, 40, 49, 50, 59, 60, 69, 70, 79	DGND	Power	GND[1]	Digital Ground
2, 4, 6, 8	3V3	Power	3.3V	Input Power
11	USB_D_P	Diff Pair	USB spec compliant	USB2 data+
9	USB_D_N	Diff Pair	USB spec compliant	USB2 data-
15	USB_VBUS	Power	USB spec compliant	USB VBus
17	USB_ID	I/O	USB spec compliant	USB ID
14	USB_TX_P	Diff Pair	USB spec compliant	Reserved for USB3 transmit+
12	USB_TX_N	Diff Pair	USB spec compliant	Reserved for USB3 transmit-
18	USB_RX_P	Diff Pair	USB spec compliant	Reserved for USB3 receive+
16	USB_RX_N	Diff Pair	USB spec compliant	Reserved for USB3 receive-
21, 22 , 25, 27, 28, 31, 32, 33, 34, 35, 36, 37, 38, 41, 42, 43, 45, 46, 47, 48, 51, 52, 53, 54, 55, 56, 58, 61, 62, 63, 64, 65, 66, 67, 68, 73, 75, 77, 78	GPIO	I/O	1.8V	See Table 3
24	RESET	I/O	FLOAT (asserted low)[2]	See Section 7.1
72	EXT_SYNC	I/O	1.8V	Configurable: Disable, Master, Slave
23, 26, 44, 57, 71, 74, 76, 80	No Connect		N/A	

Note(s)

1. *System chassis is connected to camera DGND through a 1MΩ resistor.*
2. *When not asserted, the RESET pin should float. When asserted, all circuitry is removed from power. A 1msec pulse width is required. An internal, weak pull-up resistor exists on RESET pin.*

TABLE 3: ASSIGNMENT OF GPIO PINS

PIN #	SIGNAL NAME	SIGNAL DESCRIPTION
33	uart_app_sin	UART Input
43	uart_app_sout	UART Output
41	cmos_data_13	CMOS Bit 13
21	cmos_data_14	CMOS Bit 14
38	cmos_data_15	CMOS Bit 15
34	cmos_data_16	CMOS Bit 16
22	cmos_data_17	CMOS Bit 17
42	cmos_data_18	CMOS Bit 18
37	cmos_data_19	CMOS Bit 19
52	cmos_data_20	CMOS Bit 20
54	cmos_data_21	CMOS Bit 21
35	cmos_data_22	CMOS Bit 22
36	cmos_data_23	CMOS Bit 23
58	GPIO	Discrete I/O
51	cmos_data_2	CMOS Bit 2
56	cmos_data_3	CMOS Bit 3
27	cmos_data_4	CMOS Bit 4
28	cmos_data_5	CMOS Bit 5
32	cmos_data_6	CMOS Bit 6
31	cmos_data_7	CMOS Bit 7
25	cmos_data_8	CMOS Bit 8
46	cmos_data_9	CMOS Bit 9
45	cmos_data_10	CMOS Bit 10
48	cmos_data_11	CMOS Bit 11
47	cmos_data_12	CMOS Bit 12
55	cmos_pclk	CMOS pixel clk
53	cmos_vsync	CMOS vsync
73	cmos_hsync	CMOS hsync
78	cmos_data_valid	CMOS data valid
77	cmos_data_0	CMOS Bit 0
62	cmos_data_1	CMOS Bit 1
63	i2c_scl	I2C clk
67	i2c_sda	I2C data
75	sd_clk	SD clk

PIN #	SIGNAL NAME	SIGNAL DESCRIPTION
66	sd_cmd	SD cmd/resp
65	sd_data0	SD Data 0
68	sd_data1	SD Data 1
61	sd_data2	SD Data 2
64	sd_data3	SD Data 3

TABLE 4: NEUTRINO LC COOLER ELECTRONICS PIN ASSIGNMENTS AND PIN DESCRIPTION

PIN #	PIN NAME	SIGNAL TYPE	SIGNAL LEVEL	DESCRIPTION
1	DGND	I/O	DGND	DGND, Standby signal 1
2	STANDBY	I/O	3.3V (asserted low)2	Standby, asserted low (< 1V) Normal, 3.3V or No Connect
3	GND	Power	GND	GND, Input Power 1
4	12V	Power	12V	Input Power

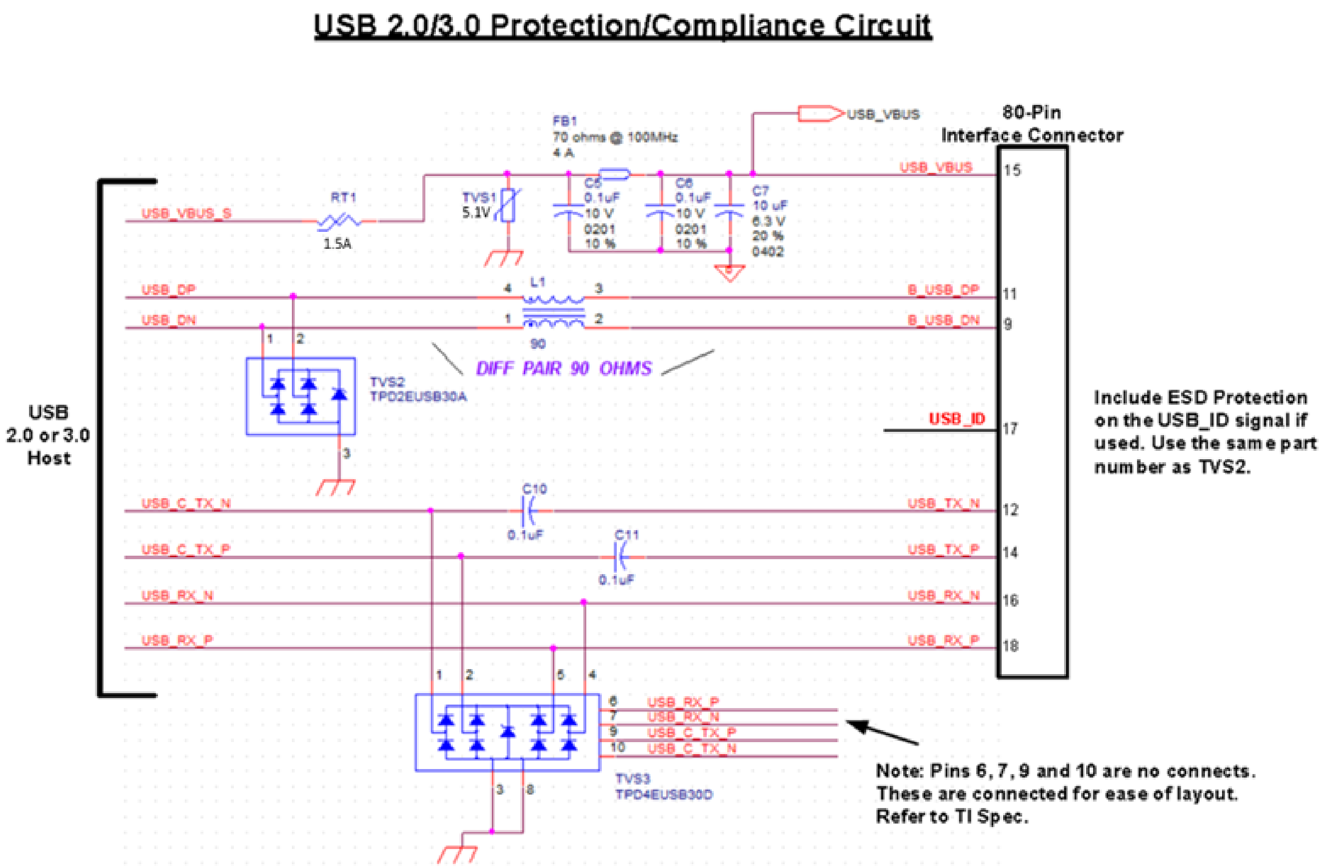
Note(s)

1. *It is not recommended to connect GND and DGND.*
2. *Internal 10kΩ pull-up resistor on STANDBY pin.*

4.2 External Circuitry

The Neutrino LC electrical interface should include the following considerations:

- TELEDYNE FLIR highly recommends implementing the protection circuit for the USB channel shown in Figure 3 on interfacing electronics if the USB channel is utilized.
- External pull-up resistors (4.7Kohm to 10Kohm) are recommended on all I2C signals if the channel is utilized.
- The optional GPIO UART port operates at a fixed 921600 baud, 8-bit data, no parity, and one stop bit.



Part Description	Vendor	Part Number	Ref Des
CAP CER 0.1uF 10V X5R 0201	Murata	GRM033R61A104KE15D	C5,C6,C10,C11
CAP - CER 10UF 6.3V 20% X5R 0402	TDK	C1005X5R0J106M050BC	C7
PTC Resettable Fuse 6V 1.5A, SMT 0805	Littelfuse Inc.	0805L150SL	RT1
DIODE ZENER 5.1V 100MW VMD2	Rohm Semi	VDZT2R5.1B	TVS1
TVS DIODE 3.6VWM 8VC SOT3	Texas Instruments	TPD2EUSB30ADRTR	TVS2
TVS DIODE 5.5VWM 8VC 10SON	Texas Instruments	TPD4EUSB30DQAR	TVS3
CHOKE COMMON MODE USB2.0 0805	Coilcraft	0805USB-901MLC	L1
FERRITE CHIP 120 OHM 3000MA 0603	Murata Electronics	BLM18SG700TN1D	FB1

FIGURE 3: RECOMMENDED USB PROTECTION CIRCUITRY, TO BE IMPLEMENTED ON INTERFACING ELECTRONICS

5 SIGNAL PIPELINE

A high-level block diagram of Neutrino LC's signal pipeline is depicted in Figure 4. The pipeline includes an optional frame averager, non-uniformity correction (NUC) and defect replacement, spatial and temporal filtering, automatic gain correction (AGC), electronic zoom, colorization and symbol overlay. These processing blocks are described in more detailed in the sections to follow. Note that video can be tapped at various locations within this pipeline. See Section 7.8 for a full description of the video output properties at each tap.

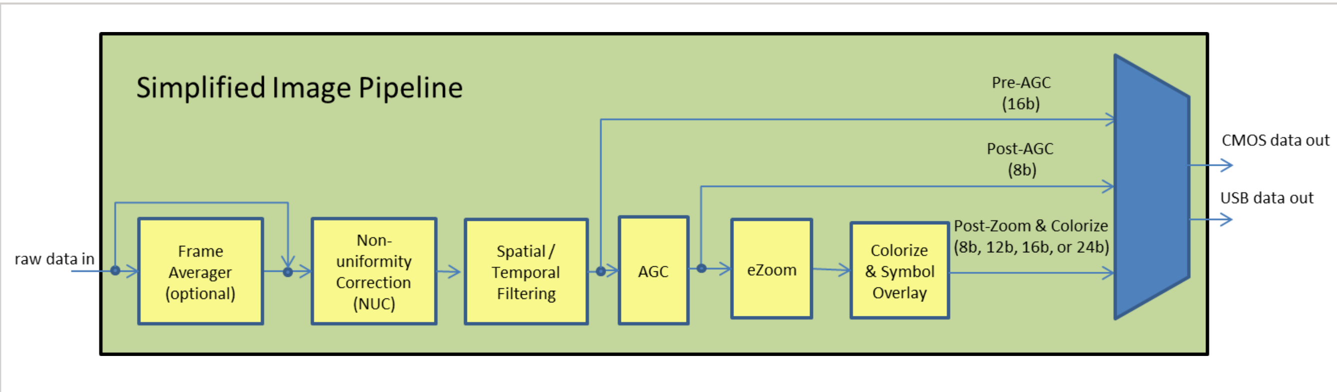


FIGURE 4: NEUTRINO LC SIGNAL PIPELINE

5.1 Frame Averager

At the beginning of the signal pipeline, Neutrino LC provides an optional frame-averager block (disabled by factory-default). When disabled, the nominal effective output frame rate is 60Hz; when enabled, it is 30Hz. The primary benefit of enabling the averager is power reduction. Depending upon configuration, camera electronics power savings approaching 100 mW can be realized. See Section 12.2. Neutrino LC utilizes a "smart averager" which minimizes blur during scene motion. Essentially whenever there is motion between the two input frames, the frame data received later in time is provided as output without averaging. A comparison between a simple averager and the smart averager is shown in Figure 5 below. Note the images shown below were not captured from Neutrino LC but are provided as a reference to demonstrate the algorithm effectiveness.

FIGURE 5: SMART AVERAGER PREVENTS BLUR IN MOVING SCENES

NOTE: By factory-default, the frame averager is disabled. The intended use case is that the averager is enabled and saved as a power-on default. The averager feature will not take effect until the next power cycle after saving as a power-on default, and it is not designed to be toggled during runtime.

5.2 NUC

The non-uniformity correction (NUC) block applies correction terms to ensure a uniform output from each pixel when the camera is imaging a uniform thermal scene such as a blackbody plate. Factory-calibrated NUC terms are applied to compensate for pixel offset variations, response variations, and defective pixels. It is expected that the integrator may re-calibrate these NUC terms with desired settings. These terms are enabled by factory default, and most users will have no reason to ever disable them except as noted below.

- Flat Field Correction (FFC): FFC is a per-pixel offset compensation term. Unlike all the other corrections applied by the NUC block, the FFC is not necessarily one-time calibrated but could instead be updated periodically in runtime against an integral shutter in the shuttered configuration. A user supplied external shutter or other uniform temperature reference could also be used. The FFC process is further described in Section 6.2. The integrator is expected to calibrate the FFC a minimum of once in the final system configuration using the FFC, one-point, or two-point calibration process. For best performance (i.e. lowest spatial non-uniformity), an FFC is recommended per power cycle, per runtime NUC table load/switch, and periodically after cooldown is achieved (recommendations in Section 6.2).
- Gain: a per-pixel correction term which compensates for pixel-to-pixel responsivity variation. This term compensates for variations stemming from the Dewar assembly and potentially variations stemming from the

customer's lens assembly. The integrator may desire to calibrate the gain in the final system configuration using the two-point calibration process.

- Bad Pixel Replacement (BPR): a correction process whereby pixels identified as defective are replaced by a value generated from nearest neighbors. There are both a factory defective pixel map and a user defective pixel map in which the user can add additional pixels to be replaced. The user defective pixel map may be added to manually, with a two-point calibration, and/or with a one-point calibration via CCI commands or through the GUI. The user defective pixel map can also be cleared, and the original "factory" defective pixel map can be restored.

Space for a total of four NUC tables is available in flash memory. Each NUC table includes a set of parameters and correction maps (e.g. FFC, Gain, Defective Pixel) which get applied to the pipeline as described above. A detailed description of NUC tables can be found in Section 6.9 and corresponding calibration methods can be found in Section 6.10.

5.3 Spatial / Temporal Filtering

The signal pipeline includes several sophisticated image filters designed to enhance signal-to-noise ratio (SNR) by reducing temporal noise and residual non-uniformity. The filtering suite includes TELEDYNE FLIR's algorithms optimized for reduction of spatial column noise (SCNR) and temporal noise (TF). Release 1.2 software introduced the spatial filter (DBMF) module, which is an algorithm intended to reduce spatial noise and egregious individual pixel temporal noise (commonly referred to as flickering pixels) by removing spatially non-uniform pixels on a per-frame basis. The spatial filter (DBMF) replaces the following filters existing in prior releases: the spatial pattern noise reduction (SPNR) filter requiring motion and dynamic defect replacement (DDR) in Release 1.1. Release 1.2 software also introduced a pixel binning module, which is an algorithm that averages 2x2 pixel kernels to decrease noise while simultaneously decreasing effective resolution; this algorithm is only intended for high sensitivity applications in which resolution is less important and is disabled by factory default. Like the NUC block, the filtering steps performed in this block are transparent to the user and require no external intervention or support.

A summary of the various filters with brief descriptions and factory default states is below. Most users will have no reason to ever disable any of the filters enabled by default and in general, temporal noise or uniformity will degrade as the result of doing so.

- Spatial Column Noise Reduction (SCNR): a filter intended to minimize column noise. The factory default is enabled.
- Temporal Filter (TF): a filter intended to minimize temporal noise. The factory default is enabled.
- Spatial Filter (DBMF): a filter intended to reduce spatial noise and remove temporally flickering pixels. The factory default is enabled.
- Pixel Binning (BIN): a filter intended to increase SNR but reduces effective resolution. The factory default is disabled.

5.4 AGC

Neutrino LC provides a highly configurable contrast-enhancement algorithm for converting 16-bit data to an 8-bit output suitable for display. The NUC block includes an integration time parameter than can be used to tailor the 16-bit output for application specific intrascene ranges. The Spatial / Temporal Filtering block does not provide any adjustable parameters. The AGC block includes many user-selectable parameters which allow the image enhancement to be tailored to specific applications, scene conditions, and subjective preferences. See Section 6.4 for a complete description of the algorithm and all associated parameters.

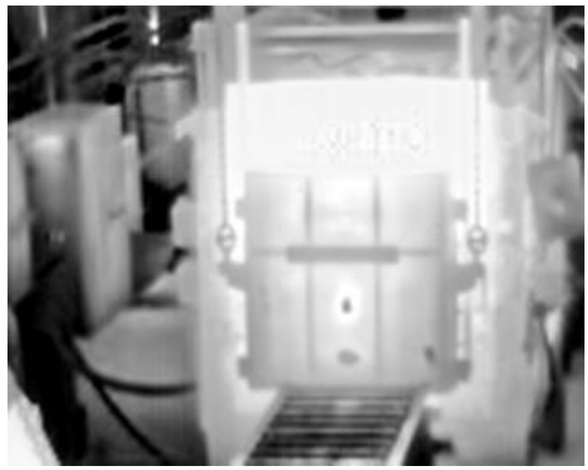
(a) Manual, Linear AGC example (b) Histogram Equalization AGC example

FIGURE 6: EXAMPLE IMAGERY WITH LINEAR AND HISTOGRAM EQUALIZATION AGC

5.5 eZoom

The electronic zoom block provides an optional interpolation of a subset of the field of view to the 640x512 resolution of the output stream. For example, it is possible to select the central 50% of the pixel area and stretch it to the full output resolution, resulting in a 2X zoom. See Section 6.5 for a more complete description of this feature and its associated parameters.

(a) 1X zoom (full FOV displayed)

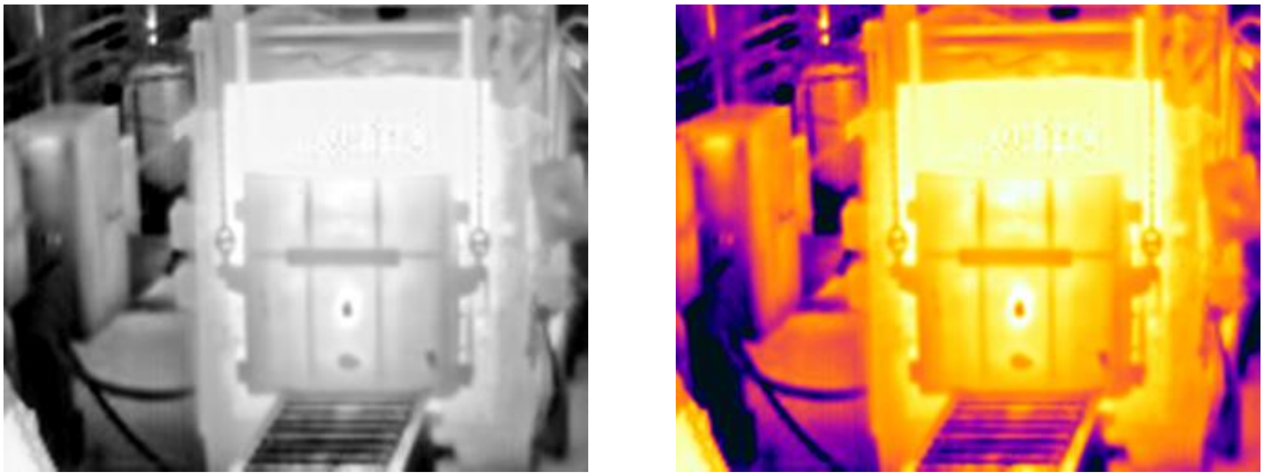


(b) 2X zoom (half FOV displayed)

FIGURE 7: EXAMPLE IMAGERY SHOWING EZOOM

5.6 Colorize

The colorize block takes the contrast-enhanced, post-eZoom thermal image as input and generates an output in which a color palette is applied. Neutrino LC provides a few built-in color palettes, as described in Section 6.6.



(a) Monochrome Image (b) Colorized Image

FIGURE 8: EXAMPLE IMAGERY SHOWING COLORIZATION

5.7 Symbol Overlay

The symbol-overlay block overlays symbol patterns over the infrared image. In addition to several automatic symbols described in Section 6.7, the symbol overlay block also allows display of user-specified symbols, as exemplified in Figure 9. A full description of Neutrino LC's custom-symbol capabilities is provided in Section 6.7.2.

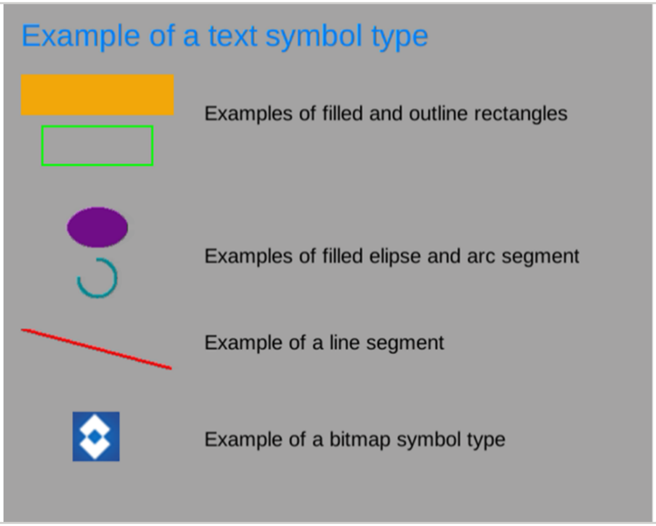


FIGURE 9: EXAMPLES OF SYMBOL TYPES

5.8 Latency

Latency of the signal pipeline is defined as the time difference between when the signal level of a given pixel is read from the sensor and when that signal is available as output from the camera. Referring to Figure 4, it is the amount of time for "raw data in" to be fully processed to "data out" at the selected video channel. The value varies depending upon where in the signal chain the output is tapped, as follows:

- Pre-AGC: ~18 msec
- Post-AGC: ~19 msec
- Post-zoom: ~37 msec (18 msec greater than the post-AGC tap)

For all three tap points, the output channel utilizes a multi-frame buffer as described in Section 7.10. This buffer introduces a frame of latency, which is the dominant latency source for the pre-AGC and post-AGC taps. For the post-zoom tap-point, the zoom operation itself also utilizes a multi-frame buffer, introducing a second frame of latency. The remaining fractions of a frame-time in the latency values provided above are the processing time required by the various blocks in the signal pipeline.

NOTE: The averager function combines two frames of the data from the sensor. The latency numbers shown above are applicable to the second of the two frames (the later frame) when the averager is enabled.

6 CAMERA FEATURES

Neutrino LC provides a variety of operating features, more completely defined in the sections which follow.

6.1 Power-On Defaults (User Selectable)

Neutrino LC provides a “save defaults” capability which allows all current mode and parameter settings to be stored as power-on defaults. Neutrino LC also provides the ability to restore the original factory default settings (which can then be re-saved as power-on defaults). See Table 8 in Section 8.1 for a list of affected modes and parameters. The table also shows the factory-default value for each setting.

6.2 Flat-Field Correction

Neutrino LC is factory and/or user calibrated to produce output imagery which is highly uniform when viewing a uniform-temperature scene. However, drift over long periods of time and cooldown cycles can degrade uniformity, resulting in imagery which appears with more spatial or pixel-to-pixel noise.

Neutrino LC is capable of automatically compensating for pixel to pixel variation with TELEDYNE FLIR’s Spatial Filter algorithm. It is beneficial to periodically perform a flat-field correction (FFC). FFC is a process whereby the NUC terms applied by the camera's signal processing engine are recalibrated to produce optimal image quality. The sensor is briefly exposed to a uniform thermal scene, and the camera updates the offset/FFC NUC term to ensure uniform output. The entire process takes approximately one second. A one-point calibration and an FFC accomplish the same purpose of replacing the offset/FFC term in the NUC portion of the signal pipeline; the terms can be utilized interchangeably, where the one-point calibration has the additional feature of updating the bad pixel term in the NUC.

As described in Section 7.6, Neutrino LC can be configured to perform FFC automatically (shuttered configuration) or only upon command via the CCI. Furthermore, the Neutrino LC shuttered configuration can be configured to use its internal shutter or to use an external scene as the uniform source. In the latter case, the camera must be viewing the uniform scene before FFC is commanded.

An FFC or one-point calibration update is recommended at a minimum per cooldown cycle and per NUC table switch. For the best spatial uniformity results, it is recommended that an FFC be performed once every 4 minutes for the first hour post cooldown and subsequently once every 20 minutes. The **FFC Period** and **FFC Start-up Period** parameters described below are programmed in accordance with this recommendation.

NOTE: If FFC is performed in "External" FFC mode while imaging a non-uniform scene, the scene will be "burned in" to the correction map, resulting in severe image artifacts.

There are user-selectable parameters associated with the FFC process which control when FFC events occur. Each is described below.

- **FFC Mode** (automatic, manual, or external) determines whether an FFC is performed automatically and whether or not it uses the internal shutter during an FFC event. See Section 7.6 for a detailed description of these modes. The factory-default is "external" for the shutterless configuration and "automatic" for the shuttered configuration.

  "Automatic" mode means that FFC events are triggered by:

  - Start-up
  - Expiration of internal timer with period specified by **FFC Period** (see below)
  - Temperature change beyond **FFC Temp Delta** (see below)
  - Change in **NUC Table** (see Section 5.2)
  - Explicit command
    - In "external" or "manual" modes, FFC events are triggered only by explicit user command, "manual" mode uses the integral shutter (shuttered configuration), while "external" mode requires an external, thermally uniform scene.

- **FFC Integration Period**: During each FFC event, the camera automatically integrates *n* frames of sensor data to generate the resulting correction term. **FFC Integration Period** specifies the value of *n*, either 2, 4, 8 or 16. Utilizing fewer frames decreases the FFC period (with diminishing returns due to overhead) whereas utilizing more frames reduces the effect of temporal noise on this spatial noise correction. Figure 10 quantifies the benefit. The factory-default value is 8 frames. Note that with averager enabled (i.e., 30Hz output rather than 60Hz output), a value of 8 frames represents twice as much time as with averager disabled. That is, for the same value of **FFC Integration Period**, the time required to complete FFC is approximately twice as long with averager enabled.

- **FFC Period:** When the camera is in automatic FFC mode, **FFC Period** defines the maximum elapsed time between automatic FFC events. When the camera is in manual or external FFC mode, this parameter defines the maximum elapsed time before the *FFC Desired* flag is enabled. **FFC Period** is specified in seconds (e.g., the factory-default value of 1200 represents a 1200 second, that is 20 minutes, maximum time between successive FFC events). A specified value of 0 is an exception which disables the time-based trigger. The factory-default value is recommended under most operating conditions.

- **FFC Temp Delta:** When the camera is in automatic FFC mode, **FFC Temp Delta** defines the maximum temperature change of the FPA between automatic FFC events. When the camera is in manual or external FFC mode, this parameter defines the temperature change which triggers the *FFC Desired* flag to be set. **FFC Temp Delta** is specified in tenths of a Celsius degree (e.g., the factory-default value of 10 represents a 1-degree temperature change between successive FFC events). A specified value of 0 is an exception which disables the temperature-based trigger. The factory-default value is recommended under most operating conditions.
- **FFC Start-up Period** specifies a period of time (in seconds) after power-up during which the camera triggers FFC in response to "time since previous FFC" intervals equal to one-fifth of the value of **FFC Period**. For example, if **FFC Period** is set to its factory-default value of 1200 seconds, which results in an FFC event every 20 minutes when at steady-state, then an FFC event occurs every 1/5 x 1200 seconds or 4 minutes between start-up until a time period equal to **FFC Start-up Period**. The value of **FFC Start-up Period** is user-selectable, but it is not recommended to change the factory-default value of 3600 seconds or one hour.

  Note: The behavior described above is valid for Release 1.1 software and later software releases. Release 1.0 behavior scaled FFC Temp Delta parameter by 1/3 instead.
- **FFC Warn Time**: Prior to any automatic FFC event, Neutrino LC enters an "FFC Imminent" state, which is signaled via the telemetry line and via an on-screen warning. (See Section 7.6 for more detail regarding the "FFC Imminent" state.) The time that the camera remains in "FFC Imminent" state is user-selectable via the **FFC Warn Time** parameter. The factory-default value is 2 seconds.

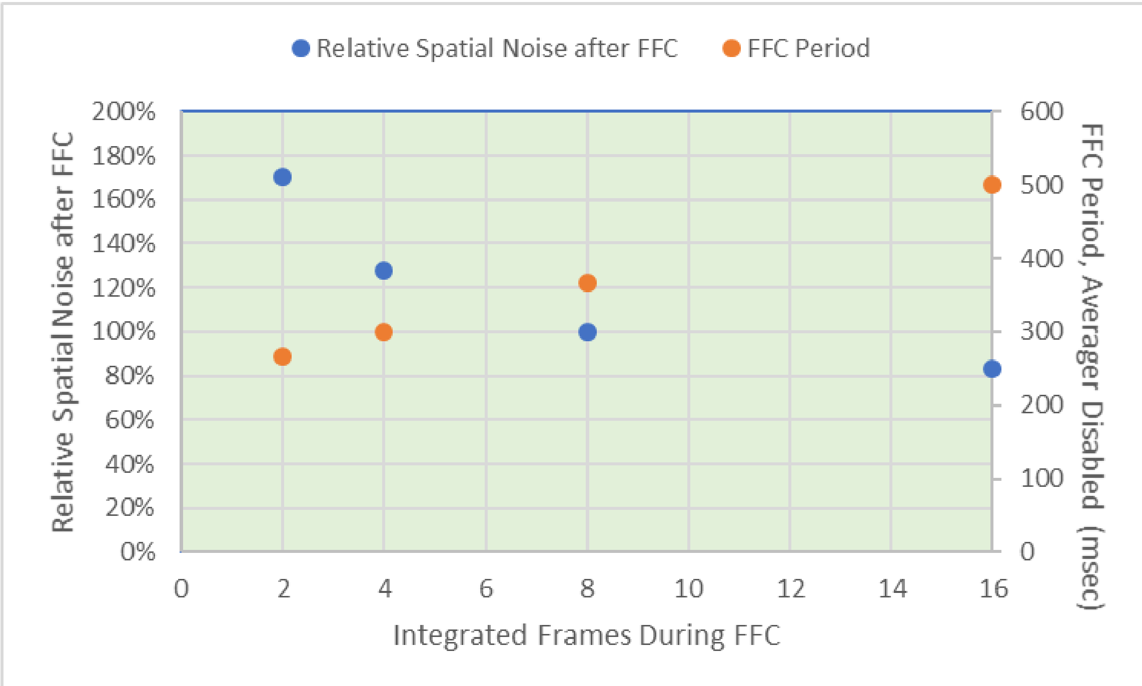


FIGURE 10: RELATIVE SPATIAL NOISE AFTER FFC VS. NUMBER OF INTEGRATED FRAMES (FACTORY-DEFAULT = 8)

In addition to the user-selectable parameters associated with the FFC process, Neutrino LC provides two status variables reported via the telemetry line (see Section 6.3):

- *FFC State*: provides information about the FFC event (i.e., has it been initiated since start-up, is it imminent, is it in progress, is it complete). Section 7.6 defines each of the FFC states.
- *FFC Desired***:** In manual and external FFC modes, the *FFC Desired* flag is used to signal the user to command FFC at the next possible opportunity. In automatic FFC mode, the flag is never set because the same conditions which cause it in manual and external FFC instead cause an automatic FFC. See Section 7.6 for detailed description of these conditions.

6.3 Telemetry

Neutrino LC provides the option to enable a single line of telemetry as either the first or last line in each frame. The telemetry line contains metadata describing the image stream and the camera. A complete list of the telemetry-line contents is provided in

Table 5.

NOTE: Telemetry is provided on the CMOS video channel only and is not currently an option for the USB video channel.

TABLE 5: TELEMETRY LINE ENCODING

WORD START (16B MODE)	BYTE START (8B MODE)	NUMBER OF BYTES	NAME	NOTES
0	0	2	Telemetry Revision	TBD
1	2	4	Camera serial number	
3	6	4	Sensor serial number	
5	10	20	Camera part number	ASCII encoded
15	30	14	Reserved	
22	44	12	Camera software revision	Bytes 44-47: SW major revision # Bytes 48-51: SW minor revision # Bytes 52-55: SW patch revision #
28	56	2	Frame rate	This is the actual data rate of the data channel in frames per second when in continuous mode. For some configurations, frames are duplicated to generate an effective frame rate which is less than the value shown in this field.
29	58	18	Reserved	
38	76	8	Status bits	Bits 0-1: FFC state 00 = never started 01 = imminent 10 = in progress 11 = complete Bits 2-4: Reserved Bit 5: FFC Desired Bit 6: Reserved Bit 7: Low-power state Bit 8: Overtemp state All other bits reserved.
42	84	4	Frame Counter	Rolling counter of output frames since start-up.
44	88	4	Frame Counter at last FFC	Value of the frame counter at the last FFC event
46	92	2	Reserved	

WORD START (16B MODE)	BYTE START (8B MODE)	NUMBER OF BYTES	NAME	NOTES
47	94	2	Camera temperature	In Kelvin x 10 (e.g., 3001 = 300.1K)
48	96	2	Camera temperature at last FFC	
49	98	12	Reserved	
55	110	4	Pipeline enable bits	Bit 0 = FFC offset enable/disable Bit 1 = Gain enable/disable Bit 3 = Averager enable/disable Bit 4 = Temporal Filter en/dis Bit 5 = SCNR enable/disable Bit 6 = SPNR enable/disable Bit 7 = BPR enable/disable Bit 15 = Revert enable/disable Bit 16 = Invert enable/disable Bit 19 = BIN enable/disable Bit 20 = DBMF enable/disable All other bits reserved
57	114	2	Number of frames to integrate at next FFC	
58	116	42	Reserved	
79	158	2	Current NUC Table	See note 2 of Table 7 in Section 7.6
80	160	2	Desired NUC Table	See note 2 of Table 7 in Section 7.6
81	162	4	Core Temp	In Celsius x 1000 (e.g., 30021 = 30.021C)
83	166	4	Overtemp event counter	
85	170	4	ROI Population Below Low-to High Threshold	
87	174	4	ROI Population Below High_to_Low Threshold	
89	178	6	Toggling pattern (intended as check of stuck CMOS signals)	Bytes 178-179: 0x5A5A Bytes 180-181: 0xA5A5 Bytes 182-183: 0x5A5A

WORD START (16B MODE)	BYTE START (8B MODE)	NUMBER OF BYTES	NAME	NOTES
92	184	4	Zoom factor	
94	188	4	Zoom X-center	Row number
96	192	4	Zoom Y-center	Column number
98	196	444	Reserved	
104	208	2	Integration Time	Units of microseconds
116	232	2	Start-up NUC Table	
117	234	4	Total Cooler Uptime	Units of minutes
119	238	2	Total Number of Cycles	
191	382	2	Image Valid	0 = False (Cooldown) 1 = True (Steady State)

6.4 AGC

Automatic gain correction (AGC) is the process whereby the 16-bit resolution of the signal pipeline is converted to an 8-bit signal suitable for a display system. Neutrino LC provides a sophisticated AGC algorithm which is highly customizable via a large number of parameters. It is a variant of classic histogram equalization (HEQ), which uses the cumulative histogram as the transfer function. (For a detailed explanation of histograms and AGC in general, refer to TELEDYNE FLIR's Camera Adjustments Application Note, available from the website linked in Section 1.2.) In classic HEQ, an image with 60% sky will devote 60% of the available 8-bit values (referred to as gray shades here forward) to the sky and leave only 40% for the remainder of the image. Neutrino LC's algorithm provides a number of parameters intended to allocate the gray shades more optimally according to user preferences. The AGC signal-processing block also incorporates TELEDYNE FLIR's Digital Detail Enhancement (DDE) algorithm, which is capable of accentuating details. A list of the AGC parameters is provided below, and a more detailed explanation of each one follows.

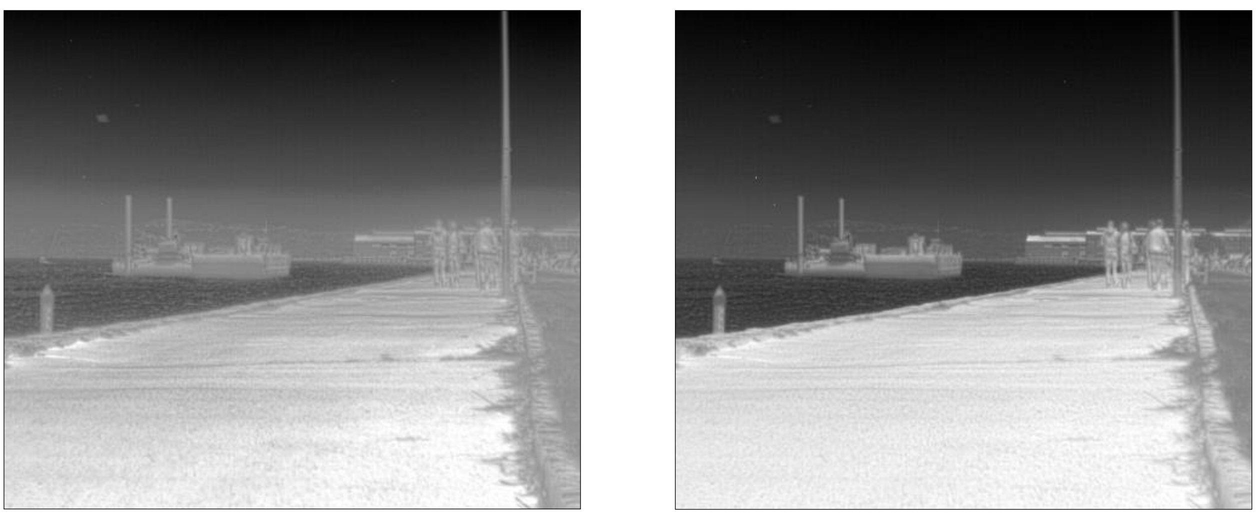
- AGC Mode
- Plateau Value (Percent Per Bin)
- Tail Rejection (Outlier Cut)
- Max Gain
- Linear Percent
- Adaptive Contrast Enhancement (ACE) (Gamma)
- Digital Detail Enhancement (DDE) (D2BR)
- Smoothing Factor (Sigma R)
- Region of Interest (ROI)
- Dampening Factor

6.4.1 AGC Mode

AGC Mode (Normal with Information-Based Equalization enabled, Normal with Information-Based Equalization disabled, Auto Bright, Auto Linear, or Manual) determines the transfer function used to convert 16bit to 8bit data.

6.4.1.1 Normal Mode

The Normal AGC mode is classic histogram equalization (HEQ). The information-based equalization enable/disable determines the weighting of pixels when the histogram is generated in Normal AGC mode. Many scenes are comprised of a small number of objects superimposed against a fairly uniform background (or perhaps two backgrounds such as sky and ground). In classic HEQ, the background dominates the histogram for such scenes and is therefore allocated a large percentage of the 8-bit gray shades, leaving few for the foreground details. In Information-Based Equalization Enabled mode, the scene data is segregated into details and background using a High-Pass (HP) and Low-Pass (LP) filter. Pixel values in the HP image are weighted more heavily during the histogram-generation process, resulting in detail being allocated more 8-bit gray shades and thus benefiting from higher contrast in the output image. When Information-Based Equalization is disabled, every pixel is weighted equally. The factory-default value of **AGC Mode** is "Normal" mode with "Information-Based Equalization" disabled. Figure 11 shows an example image for both modes. With Information-Based Equalization disabled, the sky and pavement are assigned more gray shades, whereas when enabled, the ship and people receive more emphasis. Note that not all of the images shown in this section of the datasheet were acquired using a Neutrino LC camera.



(a) Information-Based Equalization Disabled (b) Information-Based Equalization Enabled

FIGURE 11: EXAMPLE IMAGES SHOWING BOTH HEQ AGC MODES

6.4.1.2 Auto Bright Mode

Auto Bright mode is a linear transfer function with automatic updates to the brightness and user-selectable contrast. The brightness is automatically updated based on the frame mean and can be offset with the brightness bias parameter. The relevant parameters in Auto Bright mode are brightness bias, contrast, damping factor, region of interest, DDE, and smoothing factor.

6.4.1.3 Auto Linear Mode

Auto Linear mode is a linear transfer function with automatic updates to the brightness and contrast. The contrast is automatically updated based on the frame minimum and maximum pixel value and can be adjusted with a multiplicative contrast parameter. The brightness is automatically updated to ensure the mean of the 8-bit output histogram is centered upon the user selectable brightness parameter. The relevant parameters in Auto Linear mode are brightness, contrast, outlier cut, damping factor, region of interest, DDE, and smoothing factor.

6.4.1.4 Manual Mode

Manual mode is a linear transfer function with user selectable brightness and contrast. The relevant parameters in Manual mode are brightness bias, contrast, DDE, and smoothing factor.

6.4.2 Plateau Value

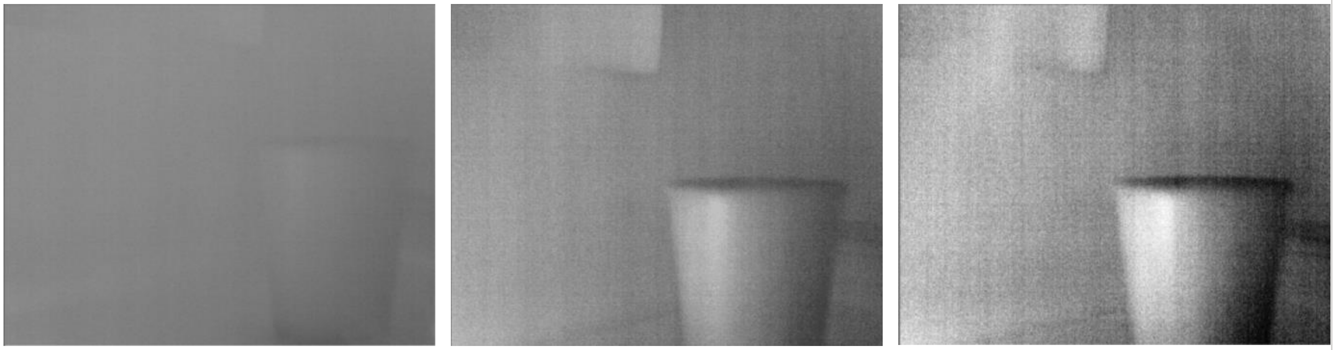
As mentioned above, one of the characteristics of classic HEQ is that it will devote gray shades proportionally to histogram population, meaning that large, mostly uniform portions of a scene will receive a large percentage of the gray shades. This characteristic can lead to those portions of the scene receiving excessive contrast (i.e., appearing noisy) while small objects are washed out due to getting a small allocation of gray shades. The **Plateau Value** parameter can reduce this effect by clipping the maximum value of any histogram bin. The factory-default value is 10%.

6.4.3 Tail Rejection

Tail Rejection determines what percentage of histogram outliers to ignore when generating the transfer function between 16b and 8b. For example, if the value is set to 2%, the mapping function ignores the bottom 2% of the histogram as well as the top 2%, optimizing the mapping function for the central 96%. Any pixels in the lower rejected tail are mapped to minimum gray value, and any in the upper rejected tail are mapped to maximum gray value. The factory-default value of **Tail Rejection** is 1%.

6.4.4 Max Gain

Max Gain determines the maximum slope of the transfer function between 16b and 8b. In scenes with very little thermal contrast (i.e., narrow histograms), an unconstrained transfer function can allocate essentially all 256 gray shades to a small number of 16b values. While this does enhance the displayed contrast, it also makes image noise more obvious. Limiting the maximum slope of the transfer function can result in images which are more pleasing to the eye in that they appear less grainy. Figure 12 shows an example image with 3 values of **Max Gain**, illustrating the pros and cons of low and high values. The factory-default value is 1.0, but perhaps more than any other AGC parameter, the optimal value varies with application and personal preference.

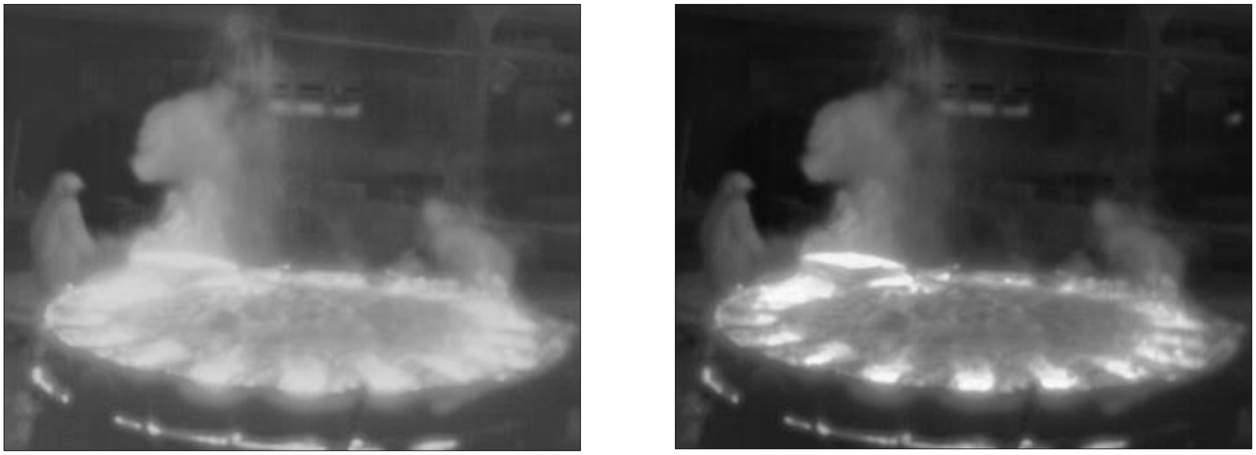


(a) Low value of **Max Gain** (b) Mid value of **Max Gain** (c) High value of **Max Gain**

FIGURE 12: EXAMPLE IMAGES SHOWING THREE DIFFERENT MAX GAIN VALUES

6.4.5 Linear Percent

One of the benefits of non-linear AGC algorithms is efficient mapping of gray shades. Consider a scene containing a single hot object against a cold background. The resulting histogram is bimodal, with a large unpopulated region separating the two modes. A linear mapping function causes one of those modes to be mapped to very dark shades and the other to very bright shades; all of the mid-level shades are wasted since the unpopulated bins between the two modes map to them. A non-linear transfer function solves the problem by essentially collapsing the two modes of the input histogram together, preventing any empty bins between them in the resulting output histogram. However, this too can be non-ideal in some scenes. Consider for example a scene with a person standing in front of a wall. Even if the person is significantly warmer than the wall, the contrast in the displayed image between the two objects might collapse to nearly zero as the result of a non-linear mapping. **Linear Percent** provides a compromise between true linear AGC and a non-linear AGC by defining the percentage of the histogram which will be allotted to linear mapping. As shown Figure 13, a higher value leads to more "separation" in gray shades between the person and the hot furnace in the image. The default value of **Linear Percent** is 20%, but like **Max Gain**, the optimal value varies with application and personal preference.



(a) **Linear Percent** = 0% (b) **Linear Percent** = 30%

FIGURE 13: EXAMPLE IMAGES SHOWING DIFFERENT VALUES OF LINEAR PERCENT

6.4.6 Adaptive Contrast Enhancement (ACE)

ACE provides contrast adjustment dependent on relative scene temperature. The scale of values ranges from 0.5-4.0. In white-hot polarity, an **ACE** value less than one darkens the image, increasing contrast in hotter scene content, while an **ACE** value greater than one will do the opposite. Figure 14 shows the of **ACE** effect on the transfer function, and Figure 15 shows an example image with 3 different values. The factory-default is 0.97.

NOTE: When toggling between white-hot and black-hot, it is suggested to toggle the **ACE** value between 1-X and 1+X. For example, if a value of 0.90 is utilized in white-hot mode, a value of 1.10 is suggested in black-hot mode.

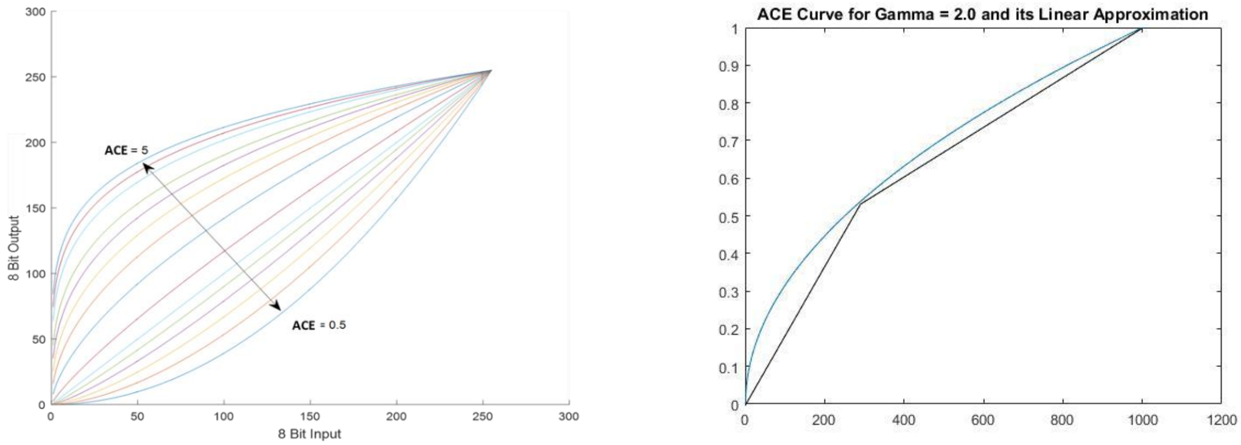


FIGURE 14: GRAPHICAL ILLUSTRATION OF ACE AND A CORRESPONDING EXAMPLE OF THE PIECE WISE APPROXIMATION OF THE ACE CURVE THAT IS IMPLEMENTED.

(a) **ACE** = 0.9 (b) **ACE** = 1.0 (c) **ACE** = 1.3

FIGURE 15: EXAMPLE IMAGES SHOWING DIFFERENT VALUES OF ACE

6.4.7 Digital Detail Enhancement (DDE)

The **DDE** parameter either attenuates (values less than unity) or amplifies (values greater than unity) the high pass (HP) content of the scene. Examples are shown in Figure 16. A **DDE** value of 0 in conjunction with a **Smoothing Factor** value of 0 bypasses the detail enhancement feature. The factory-default value is 1.

(a) **DDE** = 0.8 (b) **DDE** = 1.3

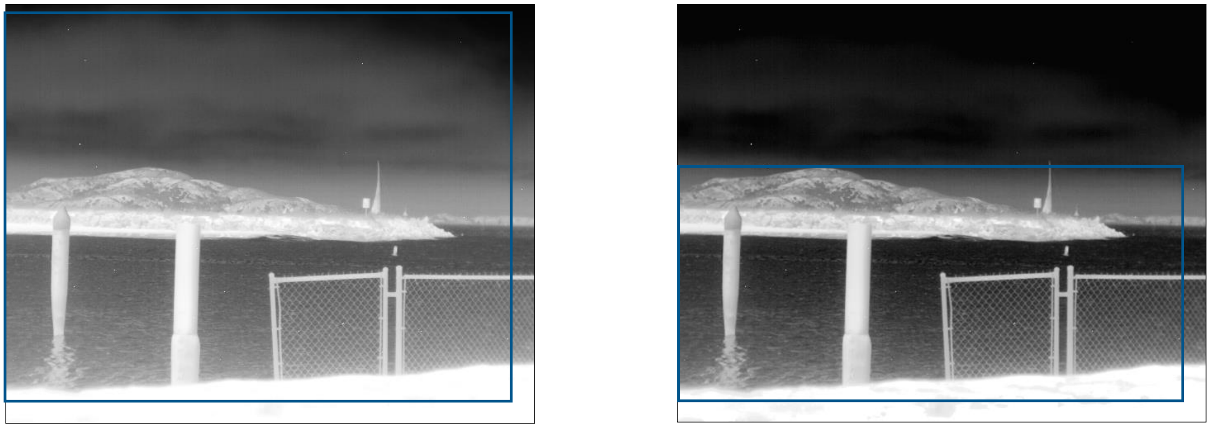
FIGURE 16: EXAMPLE IMAGES SHOWING DIFFERENT VALUES OF DDE

6.4.8 Smoothing Factor

The **Smoothing Factor** parameter defines which spatial frequencies are included in the HP image and which are in the LP image, both of which are relevant to the Information-Based-Equalization Enabled mode of operation and to the DDE algorithm. A higher value results in more frequencies being included in the HP portion of the image. A **DDE** value of 0 in conjunction with a **Smoothing Factor** value of 0 bypasses the detail enhancement feature. The factory-default value of **Smoothing Factor** is 1250.

6.4.9 Region of Interest (ROI)

In some scenarios, it may be desirable to optimize the AGC for some subset of the total field of view, such as the central portion of the scene. Or perhaps for a fixed-mount application, it may be beneficial to exclude some portion of the scene, as illustrated in Figure 17. The ROI provides this capability. It is comprised of four parameters (**Start Column**, **Start Row**, **End Column**, **End Row**), which define the corners of a rectangle. The default ROI is the full sensor array excluding a two-pixel border (**Start Column** = 1, **Start Row** = 1, **End Column** = 638, **End Row** = 510).



(a) ROI = Full Image

(b) Sky excluded from ROI

FIGURE 17: EXAMPLE IMAGE FOR 2 DIFFERENT ROI

6.4.10 Damping Factor

The AGC algorithm computes the optimum transfer function for each new frame of incoming data. However, it is not always beneficial to allow the applied transfer function to change rapidly. Consider when a mid-sized hot object enters an otherwise bland scene. The new object will be allocated brighter gray shades, resulting in the background migrating towards darker shades. If this transition happens suddenly from one frame to the next, it can be disconcerting to a viewer, appearing as an image flash. Neutrino LC provides a temporal filter which can mitigate against a sudden flash by limiting how quickly the AGC can react to a change in scene conditions. A lower value of the **Damping Factor** parameter allows the algorithm to react quicker. A value of 0% results in no filtering at all, and a value of 100% causes the AGC transfer function to stops updating altogether. The factory-default value is 85%.

6.4.11 Brightness Bias

The **Brightness Bias** parameter defines the brightness or the offset term in signed 16-bit space of the linear transfer function in Auto Bright and Manual AGC modes. In Auto Bright AGC mode is it an offset to the automatically adjusted brightness based on frame mean. Increasing values of brightness bias increase the brightness or shift the 8-bit histogram to higher values and decreasing values of brightness bias decrease the brightness or shift the 8-bit histogram to lower values. The factory-default value of **Brightness Bias** is 0.

6.4.12 Brightness

The **Brightness** parameter defines centered value of the 8-bit histogram in Auto Linear AGC mode. Increasing values of brightness increase the brightness or shift the 8-bit histogram to higher values and decreasing values of brightness decrease the brightness or shift the 8-bit histogram to lower values. The factory-default value of **Brightness** is 127.

6.4.13 Contrast

The **Contrast** parameter defines the contrast or gain term of the linear transfer function in Auto Bright, Auto Linear, and Manual AGC modes. In Auto Linear AGC mode is it a multiplier to the automatically adjusted contrast based on frame minimum and maximum. The parameter value is scaled by 64, such that a value of 64 is a contrast of unity, a value of 16 is a contrast of 0.25x, and a value of 128 is a contrast of 2x.

The factory-default value of **Contrast** is 64.

6.5 Ezoom

Neutrino LC provides a digital zoom capability in which a zoom window (either the full sensor-array data or some cropped subset) is interpolated to the 640x512 resolution of the post-zoom output stream. However, using the classical definition of digital zoom, sensor FOV divided by displayed FOV, the minimum zoom is 1X. That is the definition of zoom used herein. The zoom function provides 49 discrete zoom levels (0 – 48). The transfer function between zoom and specified **Zoom Level**, ZL, is as follows:

Zoom = 2 ^ (ZL/16)

This transfer function is depicted graphically in Figure 18. Note that the maximum zoom is $2^3 = 8$X.

By factory default, the cropped “zoom window” is concentric with the center of the array. However, it is possible to specify the center of the zoom window to be any valid row/column in the sensor array, a feature known as “pan and tilt” of the zoom window. This feature is illustrated in Figure 19 for a 2X zoom window (ZL=16). The left-hand pane of the figure shows the default location of the zoom window relative to the full sensor array, and the right-hand pane shows the zoom window panned and tilted to the upper left. The camera automatically range checks the specified center row and column of the zoom window and will disallow an invalid value (i.e., one which would cause the zoom window to extend outside the edge of the sensor array). For example, if **Zoom Level** is set to 16, the column used for center of the zoom window is automatically constrained to values between 160 and 480.

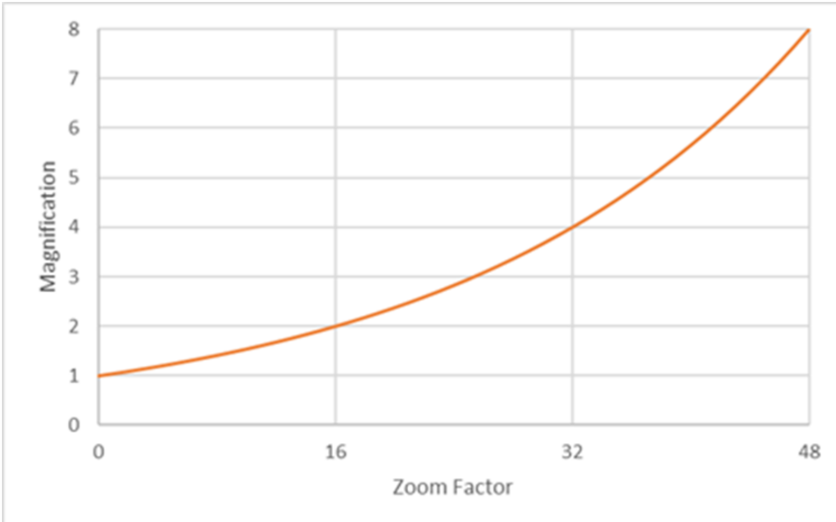


FIGURE 18: ZOOM (RELATIVE MAGNIFICATION) AS A FUNCTION OF SPECIFIED ZOOM LEVEL

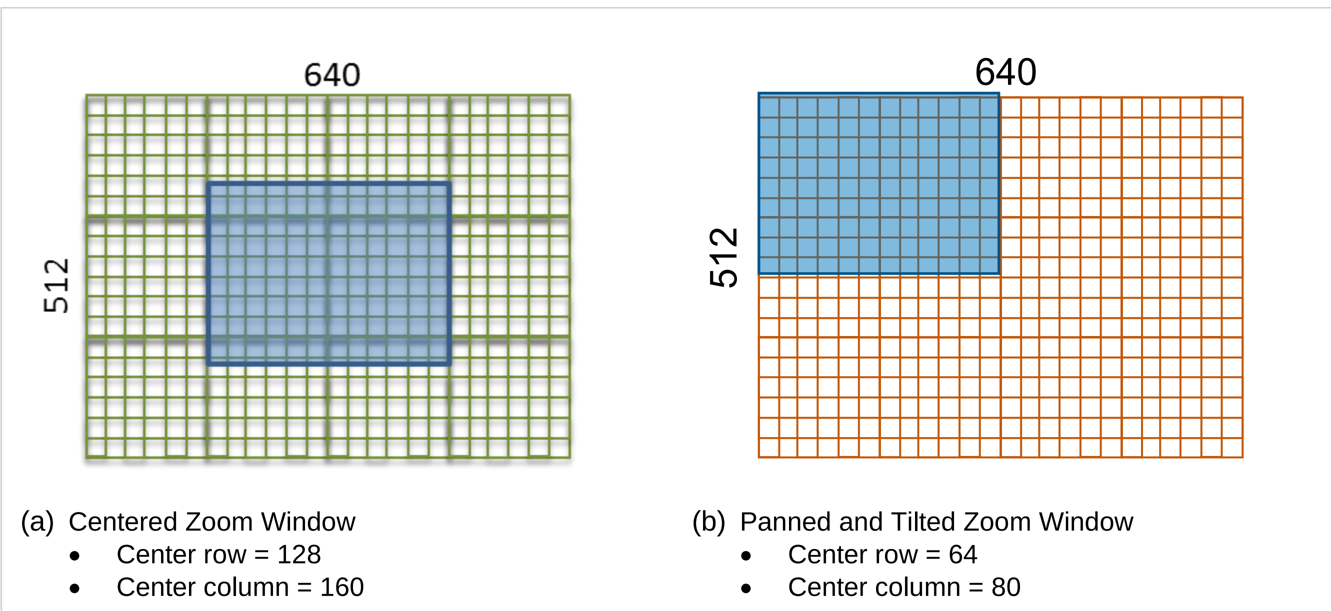


FIGURE 19: ILLUSTRATION OF “PAN AND TILT”,

In summary, the following parameters provide full control of the zoom function:

- **Zoom Level** is a variable between 0 and 48 which determines the applied zoom according the equation:

  Zoom = 2 ^ (ZL/16)

  The factory-default value of **Zoom Level** is 0.

- **Zoom Center Column** is the x-coordinate of the sensor array at which the zoom window is centered. For maximum zoom (width of zoom window = 80 columns), valid values range between 40 and 600. However, the valid range automatically shrinks as the zoom window grows to prevent it from spilling outside the sensor array. For example, for minimum zoom (width of zoom window = 640 columns), the only valid value for **Zoom Center Column** is 320. The factory-default value is 320.
- **Zoom Center Row** is the y-coordinate of the sensor array at which the zoom window is centered. For maximum zoom (height of zoom window = 64 rows), valid values range between 32 and 480. However, the valid range automatically shrinks as the zoom window grows to prevent it from spilling outside the sensor array. For example, for minimum zoom (height of zoom window = 512 rows), the only valid value for **Zoom Center Row** is 256. The factory-default value is 256.

NOTE: None of the zoom parameters **(Zoom Level, Zoom Center Column, or Zoom Center Row)** have any effect on the video signal if it is tapped prior to zoom. See Section 7.8.

6.6 Colorization

As shown in Figure 20, Neutrino LC provides a number of factory-installed palettes, also referred to as color look-up tables or LUTs. (In these illustrations of the palettes, the upper left corner represents the color associated with an 8-bit input value of 0, and the lower-right represents the color associated with a value of 255.) Figure 21 and Figure 22 show two sample images with each palette applied. In a later software release, Neutrino LC will additionally provide the option to replace the factory-installed palettes with custom palettes defined by the user. Changing the parameter Color Palette causes the applied palette to change. The factory-default value is “white hot”.

NOTE: The selected **Color Palette** has no effect on the video signal if it is tapped prior to colorization. See Section 7.8.

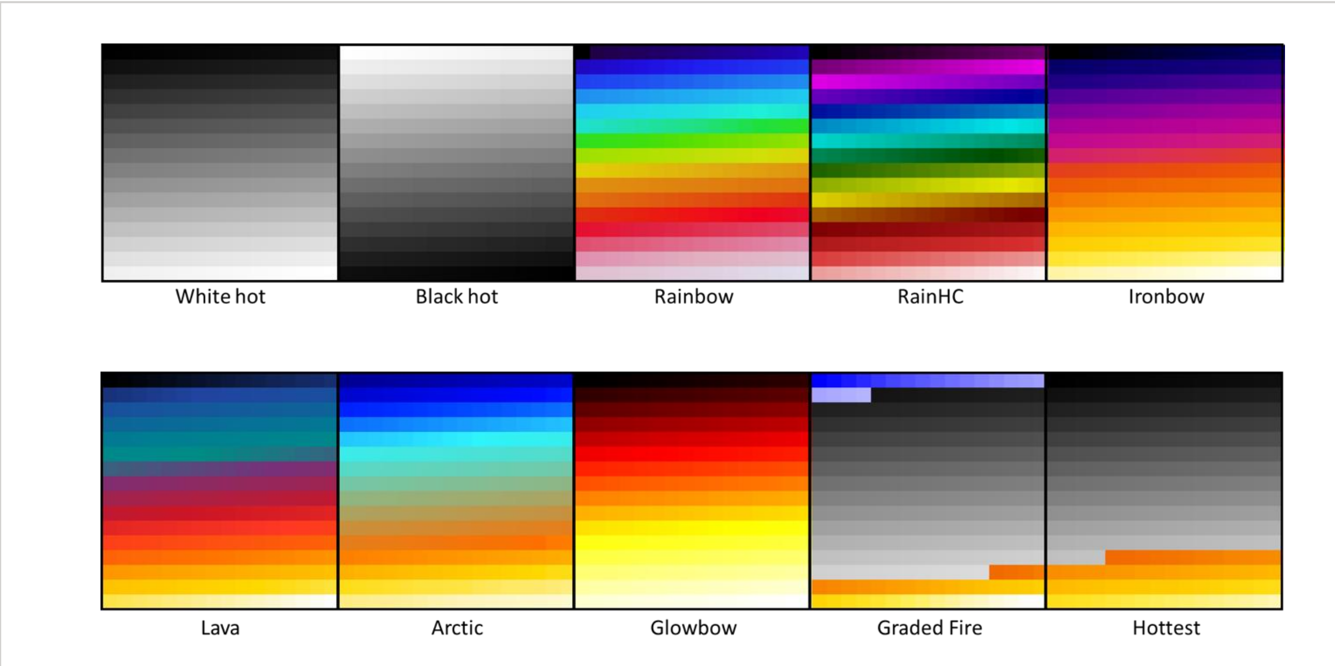


FIGURE 20: FACTORY-LOADED COLOR PALETTES

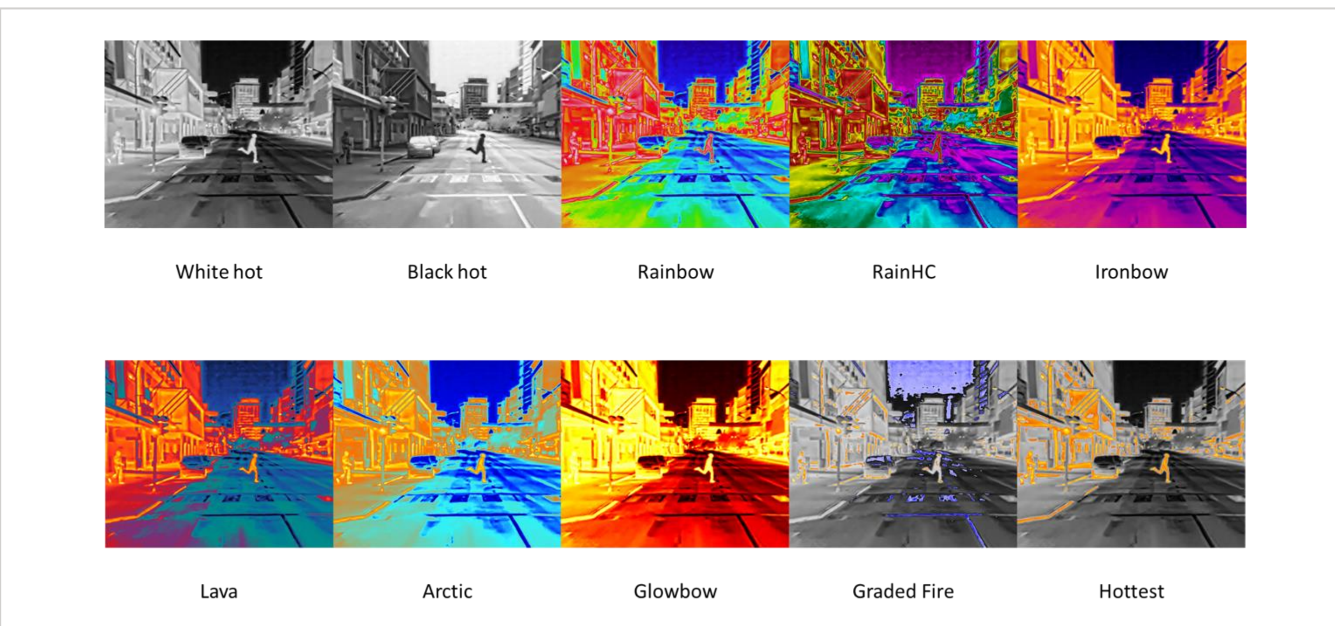


FIGURE 21: SAMPLE IMAGE1 WITH COLOR PALETTES

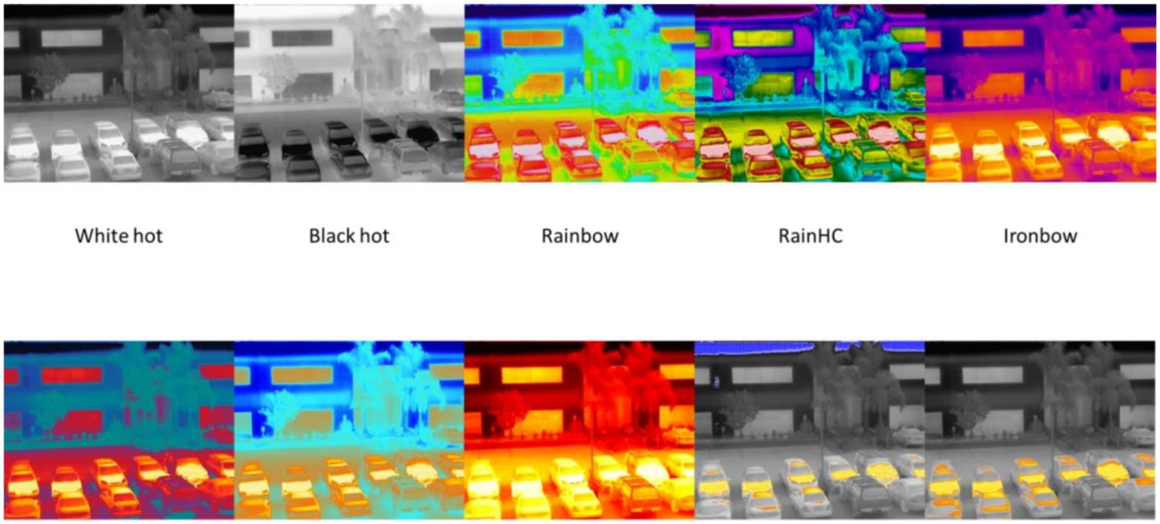


FIGURE 22: SAMPLE IMAGE2 WITH COLOR PALETTES

6.7 Symbol Overlay

6.7.1 Automatic Symbols

The baseline Neutrino LC configuration provides 3 symbol overlays which are automatically enabled or disabled in response to various system states and conditions, as described below. An override is provided for each (for example, it is possible to override automatic display of the overtemp symbol while leaving all other symbols unaffected). Additionally, it is possible to globally disable the display of *all* symbol overlays, which includes the automatic symbols described in this section as well as any custom symbols described in the next section.

- FFC In Progress: By factory default, the symbol shown in **Error! Reference source not found.** is displayed whenever the FFC State = "FFC Imminent" or "FFC in Progress". (See Section 7.6 for full description of the FFC states.)
- FFC Desired: By factory default, the symbol shown in **Error! Reference source not found.** is displayed whenever the "FFC Desired" flag is set. (See Section 6.11.3 and Section 7.6.)
- Overtemp State: The overtemp mode is disabled by factory default, but if the user chooses to enable this feature, by factory default the symbol shown in **Error! Reference source not found.** is displayed whenever the camera is in the overtemp state. (See Section 7.4 for full description of this state.)

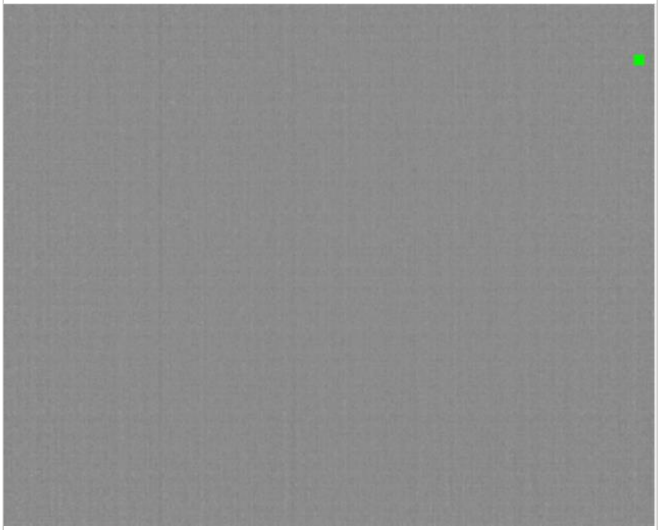


FIGURE 23: “FFC IMMINENT / IN PROGRESS” SYMBOL (FACTORY-DEFAULT)

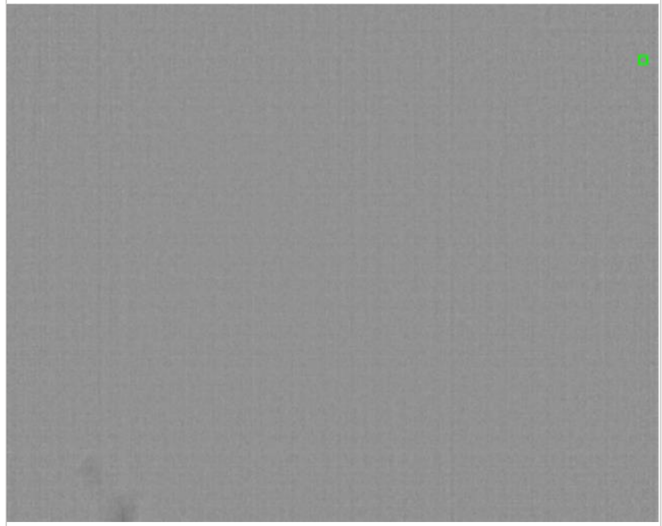


FIGURE 24: “FFC DESIRED” SYMBOL (FACTORY-DEFAULT)

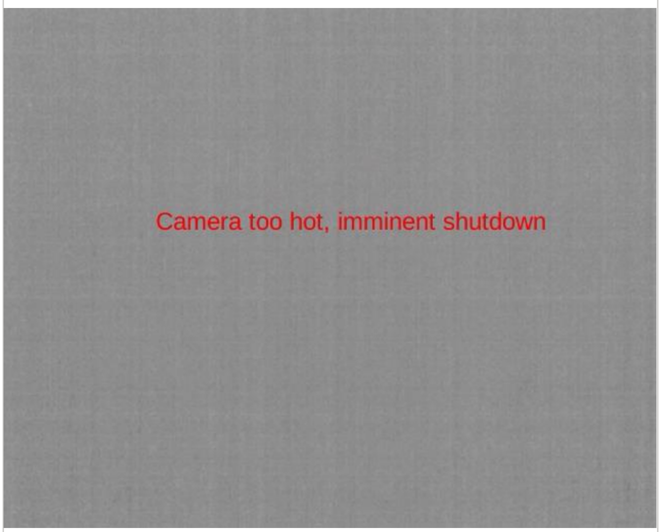


FIGURE 25: “OVERTEMP” SYMBOL (FACTORY-DEFAULT)

The factory-default attributes of all 5 automatic symbols are shown in Table 6 below. (See Section 6.7.2 for descriptions of the various attributes.) However, it is possible to customize the automatic symbols by changing any of the attributes (other than ID#).

TABLE 6: FACTORY-DEFAULT ATTRIBUTES OF THE AUTOMATIC SYMBOLS

	FFC IMMINENT	FFC DESIRED	OVERTEMP
ID#	10	11	14
Element Type	Filled Rectangle	Outlined Rectangle	Text
X Position	620	620	150
Y Position	50	50	200
Width	10	10	400
Height	10	10	25
Color	0000FF00	0000FF00	00FF0000
Z-position	0	0	0
Start Angle			
End Angle			
Font			1
Size			24
Alignment			TOP LEFT
ASCII Text			Camera too hot, imminent shutdown

6.7.2 Customized Symbols

The Neutrino LC provides the option to specify custom symbol overlays. The camera supports several built-in symbol types, including rectangles, elliptical arcs, text, and lines, as exemplified in Figure 26. In addition to built-in symbols types, the camera also allows bitmaps to be uploaded to the camera for display. Width of the bitmap must be an integer multiple of 8.

NOTE: The Neutrino LC Graphical User Interface (GUI) is capable of opening PNG, BMP, and JPEG files and converting them into the correct bitmap format.

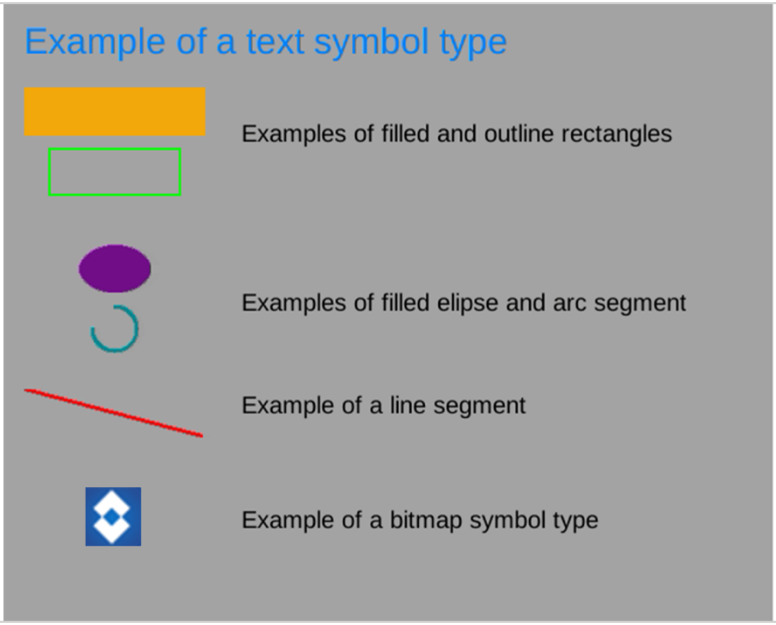


FIGURE 26: EXAMPLES OF SYMBOL TYPES

Each symbol type has a variety of user-specified attributes, as listed below.

Symbol attributes common to every symbol type:

- Symbol ID# (0 to 254): a handle for addressing the symbol when changing its attributes. Note that ID numbers 10 to 14 are pre-allocated for automatic symbols such as the FFC imminent icon. (See Section 6.7.) Changing the attributes of any of these symbol IDs will alter the appearance of the associated built-in symbol. See Table 6 for the ID# and other attributes of each automatic symbol.
- Symbol enable: 0 = not currently drawn, 1 = currently drawn
- X and Y coordinates, where x=0, y=0 is the upper left of the image and x=639, y=511 is the lower right. The upper-left corner of the symbol is placed at the specified coordinates. Note the symbol map/canvas is always 640x512 since symbol overlay occurs at the post-colorization tap in the pipeline, and that tap has 640x512 size regardless of sensor resolution. (See Section 7.8) It is not permissible to specify a location such that a portion of a symbol is outside the 640x512 canvas. (Attempting to do so will result in an error.)
- Transparency, where a value of 0 represents an opaque symbol and a value of 127 represents a completely transparent symbol. (Transparency values of 127-255 are invalid and have undefined behavior.) Setting a transparency value greater than 0 allows a symbol to be shown without completing hiding the infrared imagery (or other symbols) behind it, as illustrated in Figure 27.
- Z-position, indicating a background (z=0) or foreground plane (z=1-255), used to determine precedence in the event of overlapping symbols. For example, a symbol with 0% transparency on the n^{th} plane will completely hide a symbol located on the n-1 plane, as illustrated in Figure 27. (If two overlapping symbols both have the same z-position, the behavior is undefined.)

- Group number, from 1 to 19. It is possible to place multiple symbol ID#s into a common group. Doing so allows the entire group to be enabled/disabled and/or moved simultaneously. Moving a group causes the X/Y location of each symbol within the group to be updated automatically.

Other attributes for built-in symbol types

- Color, specified as an RGBA index. This is a required attribute for all symbol types except bitmaps.
- Height / Width, specified in number of rows (1 to 512) / number of columns (1 to 640). This is a required attribute for filled rectangles, outline rectangles, elliptical arc segments, filled ellipses, and text symbol types. For text symbols, the height and width refer to the bounding box for the text. If actual text width exceeds specified width, wrapping will be applied (potentially exceeding specified height).
- Start radius / end radius, from 0 to 360. This attribute applies to the arc segment symbol type only. It specifies the starting angle and ending angle, where angle = 0 is to the right and angle = 180 is to the left. The arc between the starting angle and ending angle is drawn clockwise. For example, the arc segment shown in Figure 26 has starting radius = 270 and ending radius = 180.
- Start point / end point, each specified as an x/y coordinate. This attribute applies to line segment symbol type only.
- Font type. 1 = built in font (Chrome Croscore Arimo font, used under authority of the Apache License, Version 2.0), 2 = user uploaded font file. This attribute applies to text symbol type only. All of the text shown in Figure 26 was generated with the built-in font.
- Font size. This attribute applies to text symbol type only and controls the nominal height of each character of text, in rows. For example, a font size of 32 results in a character height which consumes ~1/8th of the total image height.
- Justification. This attribute applies to text symbol type only, and the valid options are
  - LEFT_TOP
  - CENTER_TOP
  - RIGHT_TOP
  - LEFT_MIDDLE
  - CENTER_MIDDLE
  - RIGHT_MIDDLE
  - LEFT_BOTTOM
  - CENTER_BOTTOM
  - RIGHT_BOTTOM
- Text, in UTF-8 characters. The text string is a fixed-width, null-terminated buffer containing exactly 128 bytes. This attribute applies to text symbol type only.

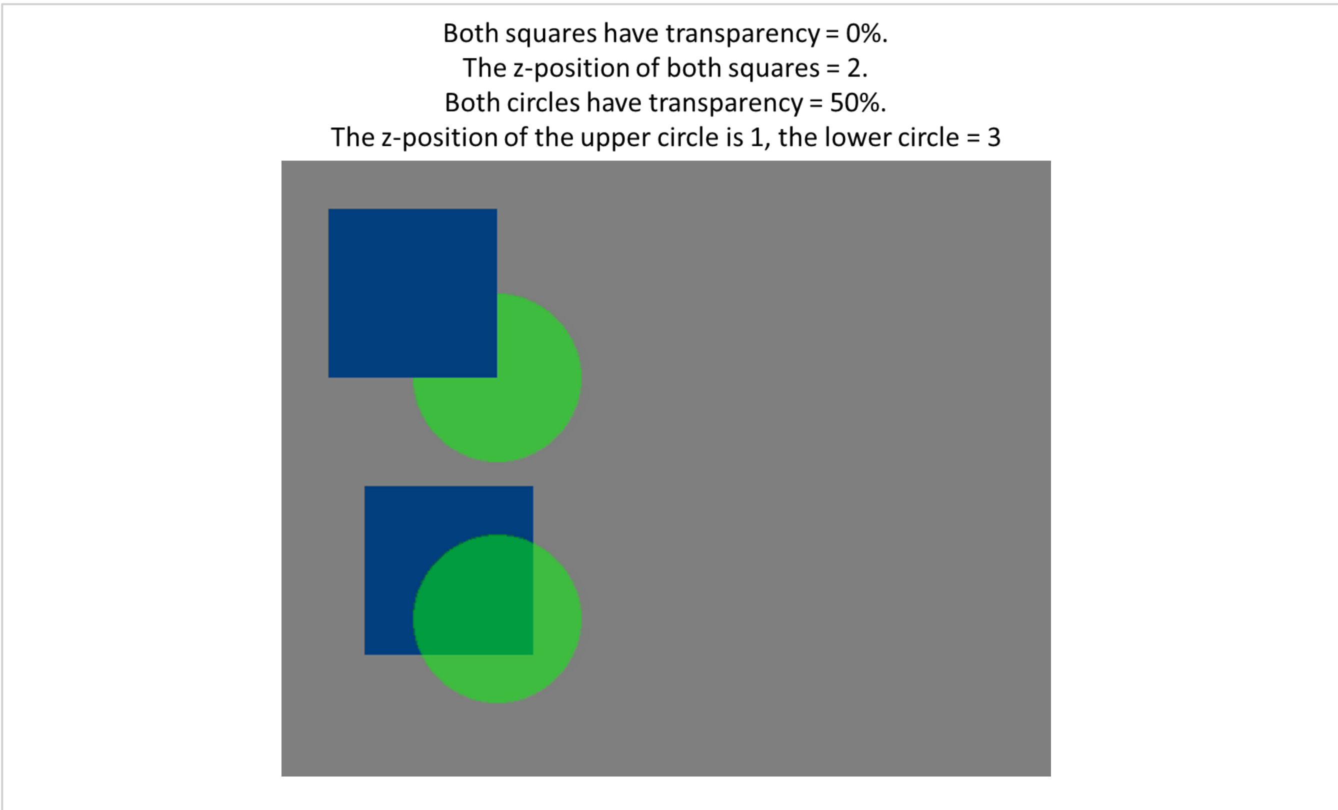
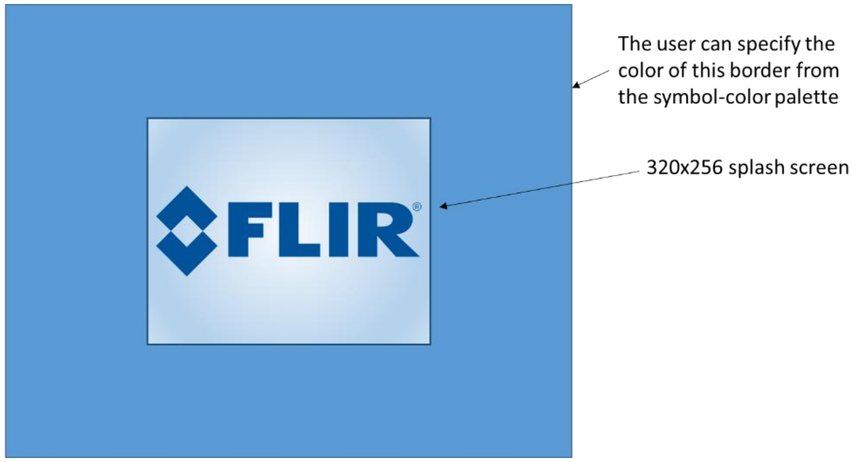


FIGURE 27: EXAMPLES OF OVERLAPPING SYMBOLS, ILLUSTRATING TRANSPARENCY AND Z-LOCATION

6.8 Start-up Splash Screen

Neutrino LC provides the option of outputting one or two user-specified splash screens at start-up, such as a company logo and camera configuration data. The splash screen(s) remains in the camera output until the cooldown state is reached. The splash screens are displayed consecutively, Splash Screen 1 first, possibly followed by Splash Screen 2 if one has been uploaded to the camera. The lengths of time that each splash screen is displayed, Splash1 Duration and Splash2 Duration, are variable in millisecond increments from 0 to 120,000 msec. If the sum of Splash1 Duration and Splash2 Duration is less than the time required for the camera to transition out of “booting” and/or “cooldown” state to a fully-operational state (see Section 7.1 for a description of start-up states), display of the initial splash screen is repeated, then the final splash screen is repeated, and so on until the cooldown and imaging state is reached. By factory-default, a uniform black splash screen is displayed for the minimum booting time, and there is no second splash screen.

Splash screens can be uploaded to the camera in .PNG format in either 320x256 or 640x512 resolution. If a 320x256 splash screen is provided, it will be centered within a 640x512 color border, as exemplified in Figure 28. The border color, Splash1 Background Color and/or Splash2 Background Color, is user-selectable.



(a) Example 320x256 splash screen, centered within a color border

(b) Example 640x512 splash screen (output with no border)

FIGURE 28: EXAMPLE SPLASH-SCREENS, 320X256 AND 640X512 RESOLUTION

NOTE: Splash screens are only properly displayed on video channels configured for post-colorization output. The post-colorization output tap has 640x512 size (See Section 7.8).

6.9 NUC Tables

The non-uniformity correction discussed in Section 5.2 includes the FFC, Gain, and Bad Pixel Replacement modules. There are four separate tables of non-uniformity correction terms referred to herein as “NUC tables”; that is there are four programmable tables comprised of individual FFC, Gain, and Defective Pixel maps along with read out parameters and bad pixel identification parameters.

6.9.1 NUC Table Parameters

The following camera settings are included in each of the four separate NUC tables and must be set prior to calibrating the per-pixel correction terms in the respective NUC table:

- **Integration Time**: The integration time is user-programmable with a range from 152µs up to 16.6ms for nominal 60Hz operation. The integration time is stored per-NUC table and should be set to the desired value prior to calibration of the per-pixel correction terms described above as it alters the readout properties.
- **Image Orientation:** The image orientation mode is user-programmable with the following options: normal (default), invert only (horizontally flipped), revert only (vertically flipped), or invert/revert. The image orientation mode is stored per-NUC table and should be set to the desired value prior to calibration of the per-pixel correction terms described above as it alters the readout properties.
- **Pixel Low/High Limit:** User-programmable thresholds for automatically identifying defective pixels based on a 16-bit count output against a user-provided “cold” scene during a one-point or two-point calibration process. If the pixel output is less than the **Pixel Low Limit** or greater than the **Pixel High Limit**, the pixel is marked as defective in DRAM and can be subsequently stored in the user defective pixel map.
- **Response Low/High Limit:** User-programmable thresholds for automatically identifying defective pixels based on response percentage of user-provided “cold” and “hot” scenes during a two-point calibration process. If the pixel response is less than the **Response Low Limit** or greater than the **Response High Limit**, the pixel is marked as defective in DRAM and can be subsequently stored in the user defective pixel map.

6.9.2 NUC Table Maps

The following per-pixel correction terms are included in each of the four separate NUC tables and are ideally calibrated with the user’s desired cameras settings and optics. Calibration of each of the correction terms residing in the NUC tables is discussed in Section 6.10.

- FFC: flat-field correction (FFC) is a per-pixel offset compensation term. The customer is expected to calibrate the FFC a minimum of once in the final system (e.g. post optic integration with desired readout settings) using the FFC function or one-point calibration process. There is an FFC correction capable of being stored per-NUC table.
- Gain: a per-pixel correction term which compensates for pixel-to-pixel responsivity variation. The customer is expected to calibrate the gain a minimum of once in the final system (e.g. post optic integration with desired

readout settings) using the two-point calibration process. There is a gain correction capable of being stored per-NUC table.

- User Defect Map: In addition to the factory calibrated defective-pixel map to define which pixels are replaced in the BPR module, the user has the option of adding pixels to it. There is a user defined defective pixel map per-NUC table. The user defective-pixel maps can be written to individually (per NUC table). There is also a command to write the current user defective-pixel map to all NUC tables. The user also has the option to restore the factory-calibrated map in the event that non-defective pixels are inadvertently added during operation in the user defect map.

6.9.3 NUC Table Selection

The NUC table to be loaded by default upon start-up without user intervention on each power cycle is defined by a user-selectable parameter called Start-up NUC. The factory default is set to table 0, and the range of potential NUC tables for the Start-Up NUC parameter span the 0 to 3 available tables.

In addition to the user-selectable parameters associated with the NUC Table control feature, Neutrino LC provides a status variable reported via the telemetry line (see Section 6.3) or by status request on the CCI (see Section 8.1):

- Current NUC Table: The Current NUC Table variable will have a value of 0, 1, 2, or 3 depending on which has been selected.

6.9.4 NUC Table Defaults

The NUC tables are calibrated with default parameters at the factory. The NUC table parameter and maps may be altered by the user as discussed in Section 6.10. The factory default parameters are specific to the optical configuration and are programmed as follows:

CONFIGURATION	NUC TABLE	INTEGRATION TIME (MS)	IMAGE ORIENTATION	PIXEL LOW/HIGH LIMIT	RESPONSE LOW/HIGH LIMIT
f/5.5	0	15.0	normal	8000/56000	0.7/1.30
f/5.5	1	12.0	normal	8000/56000	0.7/1.30
f/5.5	2	6.0	normal	1000/50000	0.7/1.30
f/5.5	3	3.0	normal	1000/50000	0.7/1.30
f/4.0	0	8.0	normal	8000/56000	0.7/1.30
f/4.0	1	6.0	normal	8000/56000	0.7/1.30
f/4.0	2	3.0	normal	1000/50000	0.7/1.30
f/4.0	3	2.0	normal	1000/50000	0.7/1.30

6.10 NUC Calibration

This section discusses the calibration processes required for the signal pipeline non-uniformity corrections discussed in Section 5.2. Neutrino LC includes the ability to calibrate and store four separate sets of non-uniformity corrections with variable readout settings as discussed in Section 6.9.

For the most consistent results, it is recommended that the two-point NUC calibration occurs more than one-hour post cooldown. A two-point calibration is recommended as a one-time update (i.e. in the factory) while a one-point calibration or FFC update is recommended at a minimum per cooldown cycle for the best spatial uniformity results (i.e. by the end-user).

6.10.1 One-Point Calibration

A one-point calibration and an FFC accomplish the same purpose of replacing the offset/FFC term in the NUC portion of the signal pipeline; the terms can be utilized interchangeably. The calibration process requires exposing the camera in its final state (e.g., with integrated optic and desired read out settings) to a uniform blackbody (e.g., a shutter for Manual/Auto **FFC Modes** or a uniform blackbody source for External **FFC Mode**). The FFC term is updated for the current NUC table in DRAM only, and the user must explicitly store the current NUC table to flash for power-cycle persistence. The Neutrino LC Graphical User Interface (GUI) provides various places to execute an FFC or perform a one-point calibration, along with ability to store the calibration to flash.

Using the CCI for the calibration state machine with **NUC Type** set to “One-Point” instead of commanding an FFC includes the additional feature of automatically identifying defective pixels based on the **Pixel Low/High Limits** parameters. The defective pixels identified are added to the user defective pixel map for the current NUC table in DRAM only, and the user must explicitly store the current NUC user defective pixel map to flash for power-cycle persistence.

A one-point calibration is automatically completed as part of the two-point calibration process against the “cold” uniform scene provided by the user. The perform FFC and one-point calibration commands initiated by the user update the FFC term in DRAM only for the current NUC table loaded. To store the current FFC to flash memory, the user must write the current NUC table to flash.

6.10.2 Two-Point Calibration

A two-point calibration replaces the FFC and Gain terms in the NUC portion of the signal pipeline. The NUC calibration terms account for pixel to pixel offset and response variations and aperture roll-off, and minor sources of out-of-field irradiance. The FFC and Gain terms are updated for the current NUC table in DRAM only, and the user must explicitly store the current NUC table to flash for power-cycle persistence. The two-point calibration process also includes the additional feature of automatically identifying defective pixels based on the **Pixel Low/High Limits** and **Response Low/High** parameters. The defective pixels identified are added to the user defective pixel map for the current NUC table in DRAM only, and the user must explicitly store the current NUC user defective pixel map to flash for power-cycle persistence.

The calibration process requires exposing the camera to two different blackbody temperatures. The Neutrino LC App provides a Graphical User Interface (GUI) which sequences all the steps required to complete the two-point calibration process and includes ability to store the NUC calibration and resulting user defective pixel map to flash for power-cycle persistence.

The high-level procedure below describes the steps to calibrate a single NUC Table. Note that four NUC tables are capable of being calibrated and stored in memory for various intra-scene ranges and/or performance. For versions of software prior to Release 1.2, altering the image orientation required special steps to manually invert and/or revert the factory calibrated defective pixels, but Release 1.2 software handles bad pixel replacement in all image orientations automatically without special requirements for calibration.

1. Change the **FFC Mode** to "External"
2. Load the desired NUC Table for calibration
3. Change the **NUC Type** to "Two-Point"
4. Setup the desired NUC table configuration settings:
    a) **Integration Time**
    b) **Frame Rate**
    c) **Image Orientation**
    d) **Pixel Low/High Limits**
    e) **Response Low/High Limits**
5. Initiate the NUC state machine with a start command.
6. Place the "hot" scene uniform black body source such that it subtends the full field of view (FOV). Initiate a transition to the next NUC state with a next command.

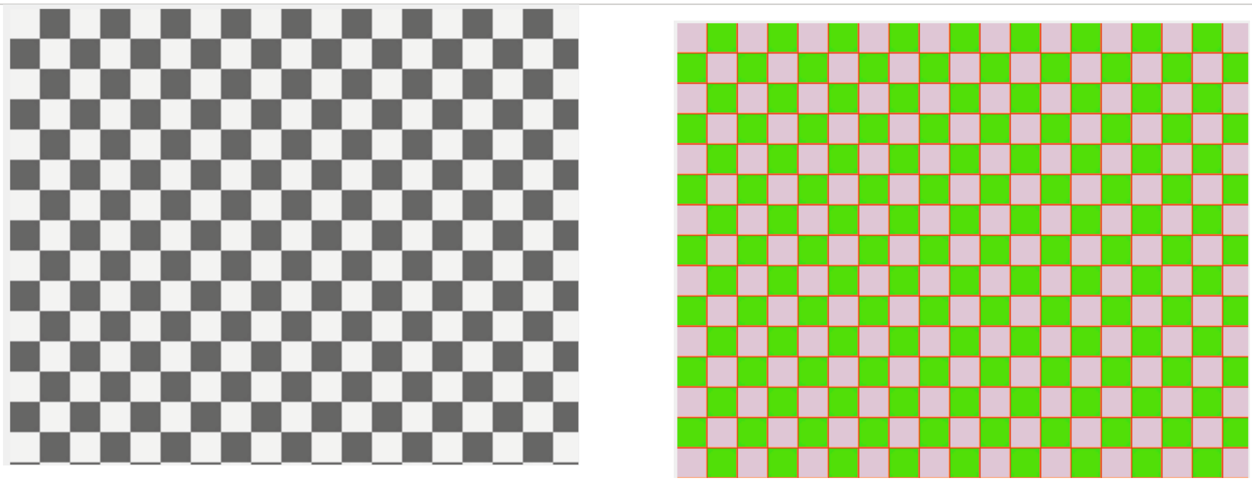
    Note: The "hot" and "cold" black body temperatures should be selected such that there is sufficient difference for gain to be accurately calculated but without causing saturation or clipping at either temperature. For example, at approximately 75% and 25% respectively of full well, i.e. black body temperatures that cause the mean output to be approximately 48,000 and 18,000 16-bit counts respectively.
7. Place the "cold" scene uniform black body source such that it subtends the full field of view (FOV). Initiate a transition to the next NUC state with a next command.
8. Review the imagery and defective pixel statistics with the resulting FFC, gain, and user defective pixel maps. A good NUC will provide a uniform image for a black body at temperatures in between the "hot" and "cold" BB temperatures. If the image quality is as desired, store the current NUC Table to flash, then store the user defective pixel map to flash.

6.11 Diagnostic Features

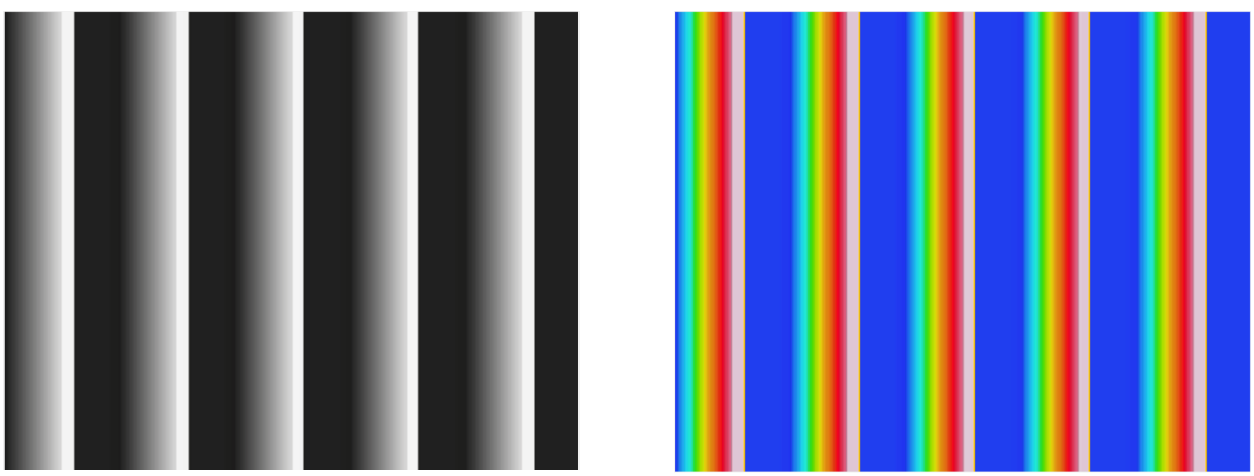
Neutrino LC provides a few diagnostic features, more completely defined in the sections that follow.

6.11.1 Test Patterns

Neutrino LC provides capability to display several preset test patterns, two of which are illustrated in



(a) Checkerboard test pattern

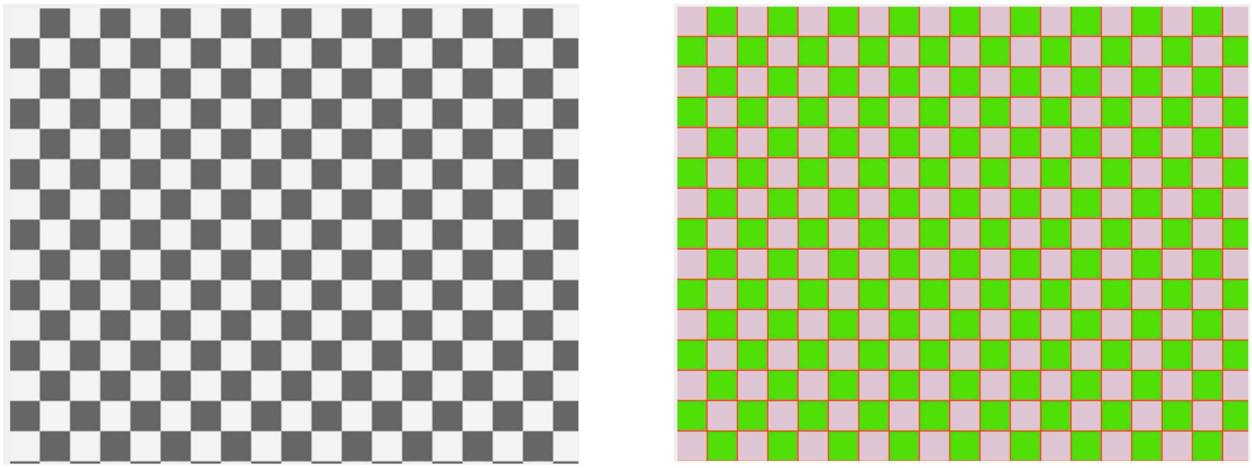


(b) Vertical-shade test pattern

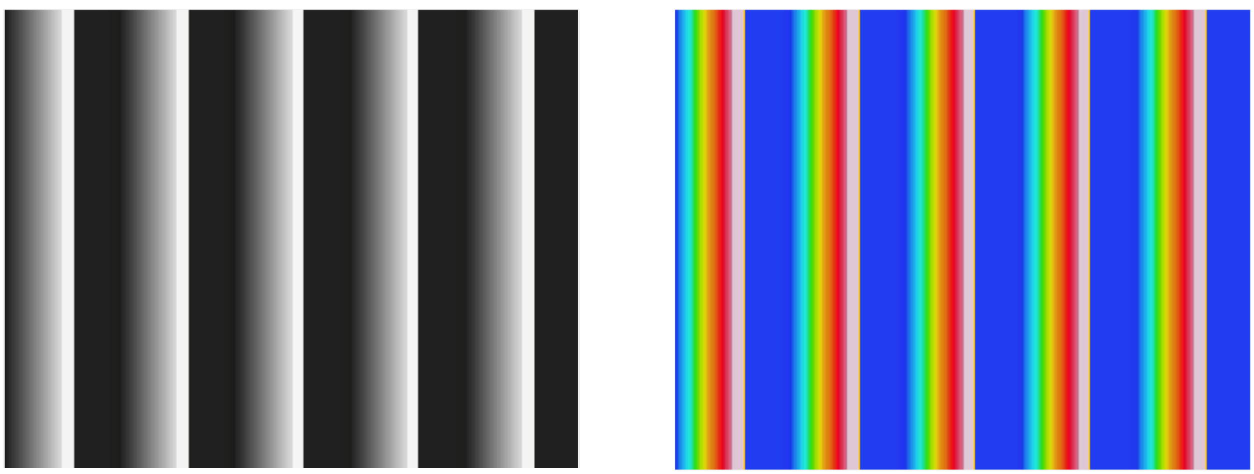
Figure 29. The capability to define a custom incrementing test pattern is included, where the user provides the start, end, and increment pixel values (in 14-bit format).

There are two separate test patterns. Each test pattern can be configured individually by the user by providing an index argument of 0 or 1. The test ramps can then be displayed by calling their index to allow a toggling capability.

The test patterns are intended primarily to adjust display properties and/or for diagnostic purposes (for example, to verify the camera is providing a valid output).



(c) Checkerboard test pattern



(d) Vertical-shade test pattern

FIGURE 29: TWO TEST PATTERNS (SHOWN IN BOTH WHITE-HOT AND RAINBOW PALETTES)

6.11.2 Camera Temperature

Neutrino LC provides capability to report its temperature via the Camera Temperature status variable. This temperature represents that of the Dewar package (which includes the FPA) and is the value used to determine the proper cooler controller state, the image readiness state, and whether to trigger FFC (see Section 6.2).

Neutrino LC also provides capability to report the temperature of its internal signal-processing engine via the Core Temperature status variable. This temperature is the value used by the overtemp logic described in Section 7.2.

6.11.3 Status Indicators

Neutrino LC provides a number of status indicators, reported via the telemetry line (see Section 6.3), via the CCI, and in some cases as optional symbol overlays on the video signal. These indicators are listed below. See the referenced sections for context and/or more detailed information.

NOTE: The text below describes the factory-default location and appearance of each symbol overlay, but it is possible to change any attribute of these status-indicating symbols. For example, rather than a solid green rectangle appearing in the upper right of the video signal during FFC, it is possible to configure Neutrino LC to display text or any other symbol (including an uploaded bitmap file) at any location. It is also possible to disable any or all of the status-indicating symbols such that they do not appear.

- *FFC State*: The *FFC State* variable provides information about the FFC event (i.e., has it been initiated since start-up, is it imminent, is it in progress, is it complete). Section 7.6 defines each of the FFC states. By factory default, a small solid green square will appear in the upper right of the post-colorization video signal when FFC state = "FFC imminent" or "FFC In Progress". (See **Error! Reference source not found.** in Section 6.7.)
- *FFC Desired*: When operating in manual or external FFC mode, the *FFC Desired* flag is used to signal the user to command FFC at the next possible opportunity. In automatic FFC mode, the flag is never set because an automatic FFC takes place instead. See Section 7.6 for detailed description of the conditions which cause the flag to be set. By factory default, a small unfilled square (green border) will appear in the upper right of the post-colorization video signal whenever the *FFC Desired* flag is set. (See **Error! Reference source not found.** in Section 6.7.)
- *Current NUC Table*: The *Current NUC Table* variable indicates the current NUC table in which the camera is operating. As described in Section 5.2, a value of 0, 1, 2, or 3 are valid status responses and depend on the **Start-up NUC** and user commanded NUC table. There is no symbol overlay symbol to indicate this status directly.
- *Overtemp*: The *Overtemp* flag indicates the camera has exceeded its maximum operating temperature and desires to enter the Low-Power state. See Section 7.2 for more information regarding the Overtemp feature and Low-Power state. By factory default, a text warning will appear in the center of the display whenever the *Overtemp* flag is set, but the camera will not move to the Low-Power state (See **Error! Reference source not found.** in Section 6.7.)
- *Low-Power State*: The *Low-Power* flag indicates the camera is in Low-Power state, typically the result of an overtemp event. See Section 7.2 for more information regarding the Overtemp feature and Low-Power state. There is no symbol overlay associated with Low-Power State because the video signal is disabled when in this state. The telemetry line will enable the Low-Power flag one frame before Neutrino LC enters the Low-Power state.
- *Image Valid State*: The *Image Valid* flag indicates the cooler has reached steady state and the camera is providing live imagery instead of a splash screen (as it does in the cooldown state). See Section 7.1 for more information regarding the start-up states.

6.12 Upgradeability / Backward Compatibility

Neutrino LC can be updated with new software releases via the CCI. The upgrade is easily accomplished using the Neutrino LC Graphical User Interface (GUI). A more detailed Software Upgrade Application Note provides step-by-step directions for those users who wish to update software from their own host platform rather than via the GUI. This App Note will be available at a future date from the website linked in Section 1.2.

Neutrino LC provides fault-tolerant software upgradeability, meaning that if power to the camera is disrupted during an upgrade event, the core is capable of rebooting with the functionality required to repeat the upgrade process. All future releases of software will be backwards compatible with all production versions. In other words, upgrading a production camera with an authorized software release will not result in a loss of function or performance.

Neutrino LC software releases to date include:

- Release 1.0, software v2.0.17820
- Release 1.1, software v2.1.20626
- Release 1.2, software v2.1.24181
- Release 1.2.1, software v2.1.24752

7 OPERATING STATES AND MODES

Neutrino LC provides several operating states and modes, more completely defined in the sections which follow. In general, modes of operation are user-selectable (i.e., the camera operates this way or that way depending upon user selections) whereas states are camera behaviors or operating conditions which take place automatically.

7.1 Start-Up States

7.1.1 Camera Start-Up States

Neutrino LC provides four camera start-up states. In most cases, the transitions between states are the result of explicit action from the user, indicated by **bold text** in Figure 30. The transition from “booting” to “fully booted” is automatic, requiring no user intervention. The four states and the transitions between them are described in more detail below.

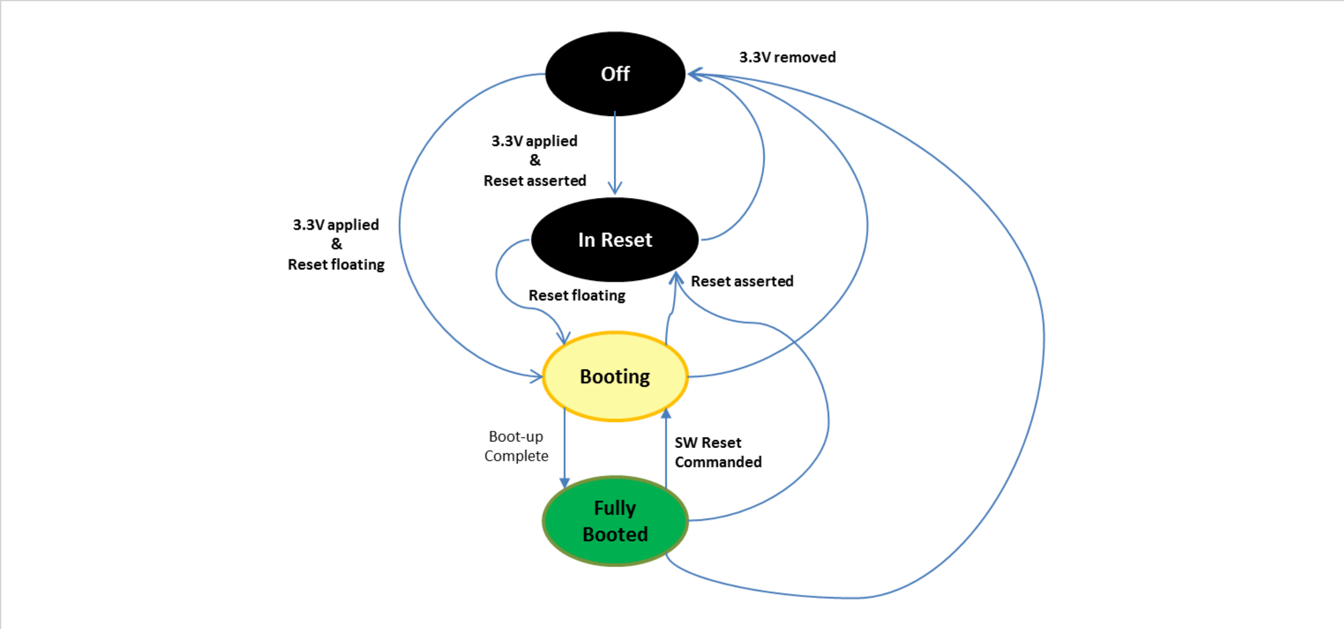


FIGURE 30: CAMERA START-UP STATES

- **Off**: When no voltage is applied, the camera electronics are in the “Off” state. In the off state, no camera functions are available, and the camera consumes no power.
- **In Reset**: When voltage is applied but the reset pin asserted, the camera electronics are in the “In Reset” state. In the “In Reset” state, no camera functions are available, and the camera electronics consume no power. Note that the Reset pin is asserted low.
- **Booting**: In the “Booting” state, the camera electronics are loading the program and initializing for full operation. Note that the reset pin must be floating to exit from the “Booting” state to the “Fully Booted” state.
- **Fully Booted (Cooler Steady State):** In the “Fully Booted” state where the Cooler is in Steady State operation, the camera electronics are fully functional, capable of responding to commands via the CCI, and producing optimal imagery. Typical start-up time to the fully booted state (assuming the system has already passed the Cooldown state and is operating in Steady State, see Cooler Start-Up States) is between 3 and 5 seconds, depending upon settings and operating conditions.
- **Fully Booted (Cooler Cooldown State):** In the “Fully Booted” state where the Cooler is in the Cooldown state, the camera electronics can respond to commands via the CCI, but a splash screen rather than valid imagery is displayed on the 8-bit output channels. Valid imagery is enabled after the desired setpoint has been achieved and the Cooler is operating in Steady State (see Cooler Start-Up States). Typical start-up time to the fully booted state with splash screen display and camera communication is between 3 and 5 seconds and typical start-up time to the fully booted state with valid imagery is between 3 and 6 minutes, depending upon settings and operating conditions.

The transition between Cooler Cooldown and Steady State (discussed further in the following section) occurs once the setpoint temperature has been reached. Immediately prior to the cooler reaching setpoint, the camera's splash screen display is removed from the 8-bit output channels, and the focal plane array is enabled to display valid imagery. To determine which state the camera electronics are currently in, query the current **FPA Temperature** until the desired setpoint (as defined by the **Normal Startup Temp** parameter) has been reached or surpassed. Software Release 1.2 added a new **Image Valid** parameter to query via CCI or telemetry to determine if cooldown has been reached and the camera is in the imaging state.

The following relevant parameters can be accessed via CCI and telemetry:

PARAMETER	SDK FUNCTION	TELEMETRY PIXEL (0-BASE)	FORMAT
Image Valid	bosonGetImageValid()	191	0 = Splash Screen (Cooldown) 1 = Image Valid (Steady State)
Current FPA Temperature	bosonlookupFPATempDegKx10()	47	Kelvin x 10
Setpoint at which the FPA is enabled	coolerGetNormalStartupTemp()	114	Kelvin x 10

NOTE: It is recommended to have the RESET pin floating in general, and it must be floating when the camera is in the "Booting" state, not tied to 3.3V or ground.

NOTE: It is important not to power the camera electronics without powering the cooler electronics in advance or simultaneously. Powering the camera electronics without powering the cooler electronics for long periods of time can cause the FPA to slowly heat within the vacuum-sealed Dewar and cause permanent degradation to the resulting imagery.

7.1.2 Cooler Start-Up States

Neutrino LC provides various cooler start-up states. In some cases, the transitions between states are the result of explicit action from the user, indicated by **bold text** in Figure 31. The transition from "booting" to "fully booted" and the various cooler states after the "On" state is achieved are automatic, requiring no user intervention. The states and the transitions between them are described in more detail below.

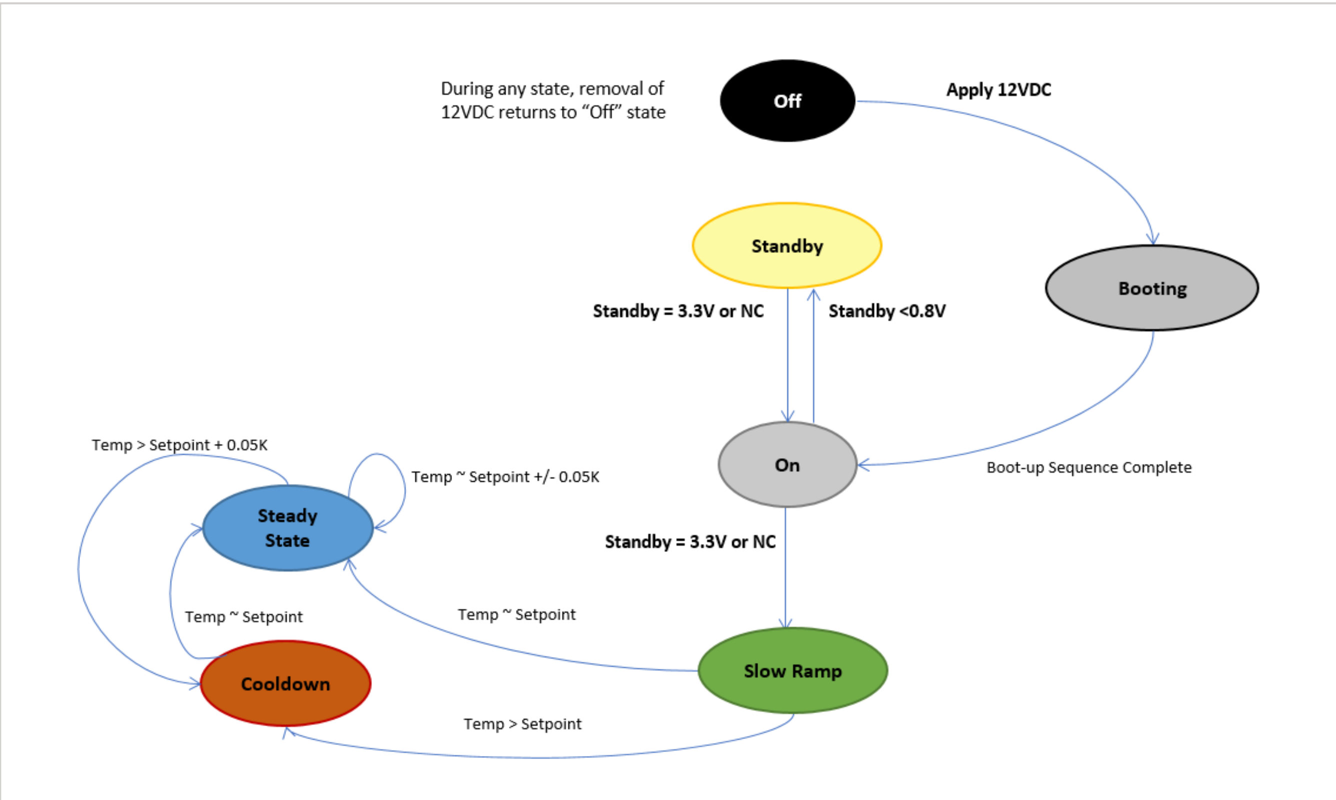


FIGURE 31: COOLER START-UP STATES

- **Off**: When no voltage is applied, the cooler electronics are in the "Off" state. In the "Off" state, no cooling is available, and the cooler consumes no power.
- **Booting**: In the "Booting" state, the cooler electronics are loading the program and initializing for full operation. The motor drive voltage has not yet been enabled.
- **On:** In the "On" state, the cooler electronics are fully functional and determining which state to transition to next based on up-time, Dewar and setpoint temperatures, and standby signal state.
- **Standby**: When the standby pin is asserted to a low-level state (<0.8V applied), the "Standby" state is entered and maintained until the standby pin transitions to a high-level state (3.3V nominal) or floating/no connection state. In the "Standby" state, a decreased motor drive voltage is applied to allow some level of cooling with minimal power consumption for a faster cooldown cycle when this state is transitioned back in to the "On" state.

- **Slow Ramp:** The "Slow Ramp" state lasts for approximately 20 seconds and simple allows for a gradual transitionary period of motor drive voltage such that the drive input to the cooler is a ramp rather than a step function.
- **Cooldown:** In the "Cooldown" state, the cooler is being driven with the maximum drive voltage possible in order to cool the Dewar down to the setpoint temperature. This is the period of highest power consumption. The cooldown time is approximately 4 minutes at room temperature ambient before the setpoint is reached and the "Steady State" is reached and between 3 and 6 minutes across the full operating temperature range.
- **Steady State:** In "Steady State", the Dewar has been cooled down, the motor drive voltage and resulting power dissipation throttles back from the "Cooldown" state, and the motor drive voltage continues to be applied at a steady magnitude in to maintain the setpoint. The feedback loop in the cooler controller electronics allows the Dewar temperature to remain stable within <0.1K (typically < ±0.05K) with a relatively constant power dissipation (and motor drive voltage) assuming the external conditions remain constant.

7.2 Averager Modes

Neutrino LC provides two averager modes affecting the video output signal:

- **Averager disabled (factory default)**
- **Averager enabled**

The mode is enabled by using the **Averager Enable** command, saving the power-on defaults, and power cycling the camera. As described in Section 5.1, the primary benefit of enabling the averager is power reduction for those applications which do not require a high frame rate.

NOTE: By factory-default, the frame averager is disabled. Intended use case is that the averager is enabled once at start-up and optionally saved as a power-on default. Toggling the averager off and on more than once per power cycle is not recommended and may result in video instability.

7.3 Synchronization Modes

Neutrino LC has an external synchronization I/O signal which can be used as an input to control the camera frame rate or as an output to synchronize an external device. The following section describes the related modes and operational features relative to the External Sync feature.

Neutrino LC provides three external synchronization modes:

- **Disabled (factory default):** The camera synchronization occurs internally in free-run mode. The external sync I/O signal is neither an input nor an output.

- **Master:** The camera continues to be synchronized internally, and the external sync I/O signal serves as an output. The Neutrino LC is the master and an external device is the slave. The master output pulse is nominally 1.8V with a pulse width of 777ns.
- **Slave**: The camera must be synchronized from an external device, and the external sync I/O signal serves as the input. An external device is the master and Neutrino LC is the slave. The slave input is nominally 1.8V. Sync pulses with frequencies greater than 60Hz will result in skipped frame syncs, effectively providing a frame rate less than the input frequency.

The readout data is from the previous integration cycle. The end of integration latches the new image data into the next readout cycle. The following readout modes are available:

- **Integrate While Read (factory default):** the integration time starts during the readout cycle. The order of operations in time follows this schema: start of readout -> start of integration -> end of readout -> end of integration.
- **Integrate Then Read:** the integration time starts and ends before the readout cycle.

The following readout priority modes are available:

- **Readout Priority (factory default):** the synchronization pulse occurs triggering the start of readout, and finally the start of integration process begins.
- **Integration Priority:** the synchronization pulse occurs triggering the start of the integration process, and finally the start of the readout begins.

An example of the Master external sync mode with the default readout modes is shown in Figure 32.

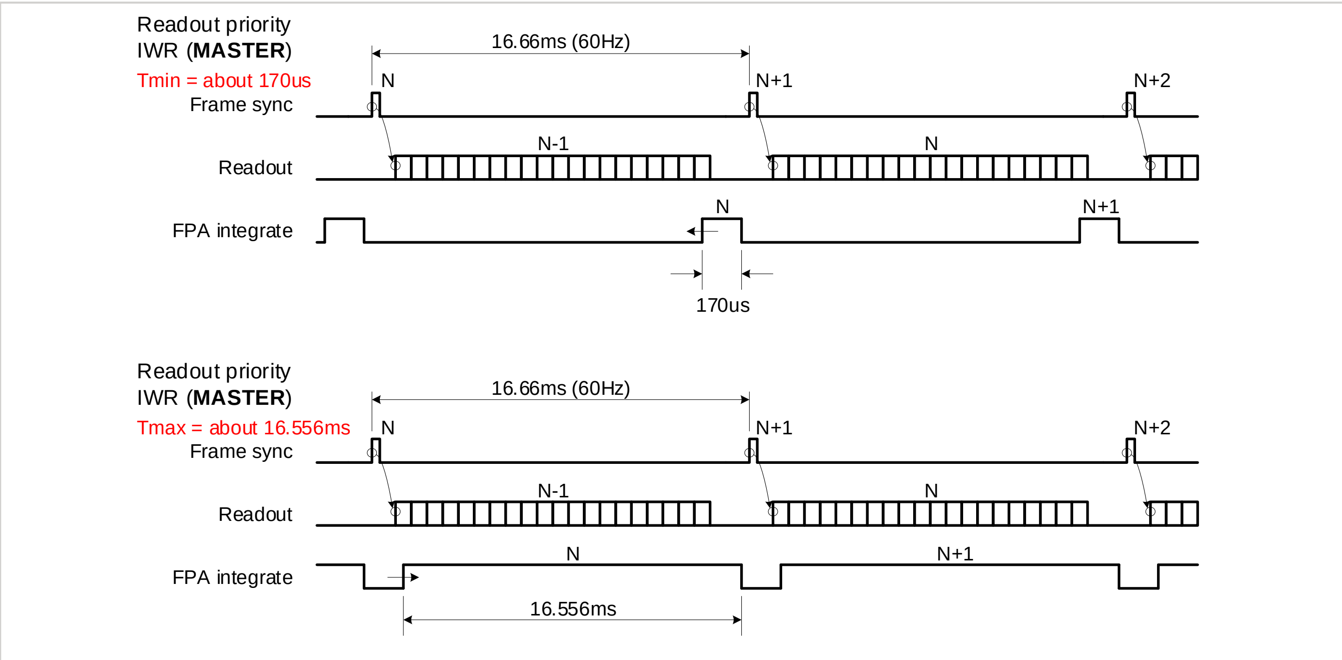


FIGURE 32: MASTER MODE WITH DEFAULT PARAMETERS (IWR, READOUT PRIORITY)

7.4 Overtemp Modes and States

Neutrino LC provides two overtemp shutdown modes:

- **Enabled:** The camera automatically transitions to a low-power state when internal core temperature exceeds the maximum safe value. The camera is capable of responding to commands in the low-power state, but the FPA is disabled to reduce power on the cooler electronics and the image pipeline is deliberately disabled to reduce power dissipation and thereby reduce core temperature and overall system temperature. As illustrated in Figure 33, the transition between the normal imaging state and the low-power state is via a temporary "overtemp" state, as described below.
- **Disabled (factory default):** The camera transitions to the overtemp state but not to the low-power state in response to core temperature exceeding the maximum safe value. This mode is provided strictly for mission-critical applications in which it is essential to extend mission life as much as possible, even at risk of permanent damage. Because of the high risk of damage resulting from extended operation in the overtemp state, operation in the "Overtemp Shutdown Disabled" mode voids the camera warranty.

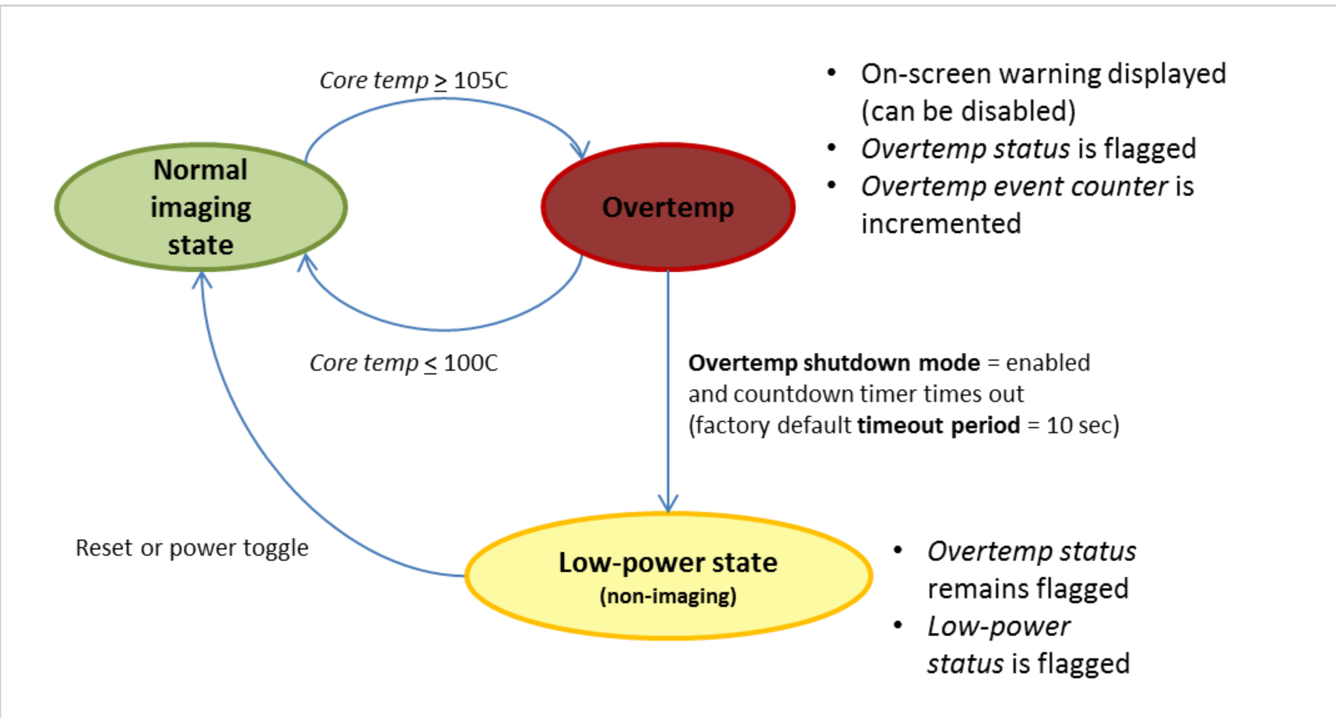


FIGURE 33: OVERTEMP AND LOW-POWER STATES

- **Normal Imaging State to Overtemp State**: When the camera's internal core temperature exceeds its maximum safe value, 105 °C, the camera automatically transitions to the overtemp state. In this state, an *overtemp status flag* is set (Bit 8 of the status bits provided in columns 38 – 41 of the telemetry line, see Section 6.3), an *overtemp event counter* is incremented (columns 83 and 84 of the telemetry line), and the on-screen warning shown in **Error! Reference source not found.** is provided on the post-colorize / symbol overlay video tap. It is possible to disable the display of the on-screen warning. See Section 6.7. A countdown timer starts when the camera first enters the overtemp state. The factory-default **timeout period** of the countdown timer is 10 seconds.

- **Overtemp State to Normal-Imaging State**: If core temperature falls into a safe operating range (≤ 100 °C) while the camera is still in overtemp state, a transition back to normal-imaging state takes place. The *overtemp status fl*ag is cleared, the on-screen warning is removed, and the countdown timer is stopped and restored to its starting value.
- **Overtemp State to Low-Power State**: Unless **overtemp shutdown mode** has been set to "disabled" (as described above), the camera automatically transitions from overtemp to the low-power state when the overtemp countdown timer times out. In low-power state, the camera continues to respond to commands sent over the CCI, but the image-processing pipeline is disabled, causing no further output frames to be provided at the video channels. The fact that the camera is in the low-power state can be ascertained via a *low-power status flag* readable via the CCI. The same status is also provided in the telemetry line (Bit 7 of the status bits provided in columns 38 – 41 of the telemetry line) on the very last frame before the camera transitions from overtemp state to low-power state. It is also worth noting that the camera's *core temperature* value can be read via the CCI while in the low-power state.
- **Low-Power State to Normal Imaging State**. The only exit from the low-power state is by toggling camera power or by reset (by asserting the reset signal or via a reset command). Note that if the camera's core temperature is still above maximum safe value after reset, the entire process will start over again. That is, the camera will immediately transition back into the overtemp state.

The factory default value of the **timeout period** of the overtemp countdown timer is 10 sec, but it can be varied between 0 and 20 seconds. A value of 0 is treated as an exception. Instead of causing the camera to immediately transition from overtemp to non-imaging state (i.e., a zero-second stay in the overtemp state), a value of 0 causes the camera to *never* transition to the low-power state. That is, a value of 0 is effectively treated like infinity and is therefore an alternative means of preventing the automatic transition to low-power state.

NOTE: See Section 6.11.2 for the distinction between *Camera Temperature* and *Core Temperature*. The latter is the relevant variable for triggering the overtemp and low-power states.

NOTE: See Section 9.1 for recommended heatsinking practices to avoid an overtemp condition.

7.5 Telemetry Modes

Neutrino LC provides three telemetry modes affecting the CMOS output signal:

- **Telemetry enable** is either true or false. Factory-default value is true.
- **Telemetry location** determines whether the telemetry line is provided on the first row (as a header) or on the last row (as a footer) of each video frame. Factory-default value is header.
- **Telemetry encoding** determines how the telemetry line is provided on the CMOS pins:
  - **16b mode**: In this mode, the factory-default, each telemetry datum is provided as a 16b word on cmos_data[0-15].
  - **8b mode**: In this mode, each telemetry datum is provided as two consecutive bytes (big-endian order) on cmos_data[0-7]. Consequently, twice as many clock periods are required to transmit the data, so each datum takes up twice as many "pixels" compared to 16b mode.
  - **8b-swapped mode ("Y"mode)**: This mode is identical to 8b mode except bytes are provided in little-endian order (least-significant byte provided first).

See Section 6.3 for a complete description of the telemetry line.

NOTE: In the current product release, telemetry mode only affects the CMOS output as telemetry is not an option for the USB video channel. It is anticipated that telemetry will be optional on the USB channel in a later field-upgradeable software release.

7.6 FFC Modes and States

Neutrino LC provides three different FFC modes:

- **Automatic (factory default, shuttered configuration):** The camera periodically performs automatic FFC with an integral shutter in response to a number of conditions, as described in more detail in
- Table 7. (See Section 6.2 for a more general description of the FFC feature.)
- **Manual:** The camera *never* performs FFC except upon receipt of the "Do FFC" command (as described in
- Table 7). The camera performs FFC against the integral shutter. The camera sets an *FFC Desired* flag under specific conditions described in
- Table 7.
- **External (factory default, shutter-less configuration):** The camera *never* performs FFC except upon receipt of the "Do FFC" command. Moreover, it does not utilize the internal shutter for FFC but instead must be imaging a uniform external source before FFC is commanded. (The uniform source must be held in place until the FFC State changes from *FFC In Progress to FFC Complete*, as described below.) The camera sets an *FFC Desired* flag under several conditions described in

- Table 7.

TABLE 7: CAMERA BEHAVIOR IN EACH FFC MODE IN RESPONSE TO VARIOUS OPERATING CONDITIONS

CONDITION	BEHAVIOR IN AUTO FFC MODE	BEHAVIOR IN MANUAL FFC MODE	BEHAVIOR IN EXTERNAL FFC MODE
Start-up	Automatic FFC takes place once applicable cooldown threshold met. If a valid offset map is stored to the Startup NUC Table, it is loaded in the short time between splash removal and first auto FFC.	If a valid offset map is stored to the Startup NUC Table, it is loaded. *FFC Desired* flag is set.	If a valid offset map is stored to the Startup NUC Table, it is loaded. *FFC Desired* flag is set.
Commanded FFC (Do FFC)	FFC takes place	FFC takes place; *FFC Desired* is cleared	
Frame Counter – Frame Counter at Last FFC ≥ FFC Period (see note 1)	Automatic FFC takes place	*FFC Desired* is set	
|*Camera Temp* – Camera *Temp at Last FFC*| ≥ FFC Delta Temp (see note 1 and note 2)	Automatic FFC takes place	*FFC Desired* is set	
Table Switch Commanded	FFC takes place	If a valid offset map is stored is stored for the desired NUC Table, it is loaded. *FFC Desired* flag is set.	If a valid offset map is stored is stored for the desired NUC Table, it is loaded. *FFC Desired* flag is set.

Note(s)

1. *Frame Counter, Frame Counter at Last FFC, Camera Temp, Camera Temp at Last FFC are all status variables which are provided via the telemetry line (see Section 6.3) or via command on the CCI. FFC Period and FFC Delta Temp are both user-selectable parameters which can be specified via the CCI, as further described in Section 6.2.*
2. *Software Release 1.0 behavior: From start-up until a time specified by FFC Start-up Period, the condition is instead |Camera Temp – Camera Temp at Last FFC| ≥ FFC Delta Temp / 3, as described in Section 6.2.*
3. *Software Release 1.1 and later behavior: From start-up until a time specified by FFC Start-up Period, the condition is instead |Frame Counter – Frame Counter at Last FFC| ≥ FFC Period / 5, as described in Section 6.2.*

While the FFC mode defines when and how Neutrino LC performs FFC, the FFC state pertains to the FFC event itself. There are four FFC states, as illustrated in Figure 34.

- *FFC not initiated* (power-on default): In this state, Neutrino LC has applied no new FFC terms since power-on except for the NVFFC (stored NUC table FFC from a previous power-cycle). In automatic FFC mode, this state is never seen because Neutrino LC always performs automatic FFC at start-up.
- *FFC imminent*: The camera only enters this state when it is operating in automatic FFC mode. The camera enters "FFC imminent" state at a user-specified period prior to initiating an automatic FFC (factory default = 2 sec). The intent of this status is to warn the user that an FFC is about to occur.
- *FFC in progress*: Neutrino LC enters this state when FFC is commanded from the CCI or when an automatic FFC event is initiated. During each FFC event, the shutter is closed (integral shutter configuration, if in automatic or manual FFC mode), frames of sensor data are collected to generate the correction map, the shutter is opened, and the new FFC map is applied.
- Neutrino LC's video output is "frozen" throughout the "FFC in progress" state. That is, the last valid frame prior to entering "FFC in progress" is repeated throughout the event. The telemetry line is not frozen, only the thermal image.
- *FFC complete*: Neutrino LC automatically enters this state whenever a commanded or automatic FFC is completed.

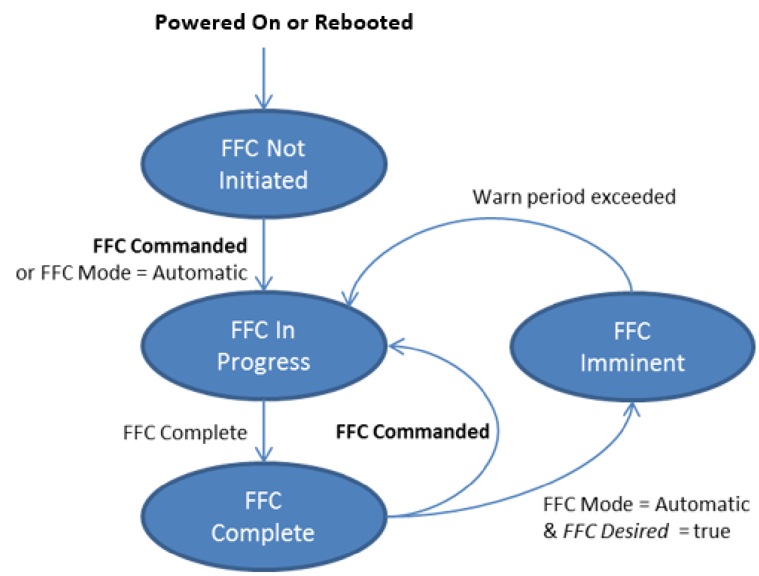


FIGURE 34: FFC STATES

7.7 AGC Modes

As described in Section 6.4, Neutrino LC provides the following AGC modes:

- **Normal (factory default):** Histogram Equalization with
- **Information-Based Equalization Mode Enabled:** the AGC transfer function is based on the amount of information in the scene. That is, portions of the scene which contain variations (e.g., foliage) are weighted more heavily than portions which only vary gradually (e.g., sky).
- **Information-Based Equalization Mode Disabled (factory default)**: the AGC transfer function weights all pixels equally.
- **Auto Bright**: Linear AGC with brightness automatically adjusted based on frame mean.
- **Auto Linear**: Linear AGC with both contrast and brightness adjusted based on min and max pixel values.
- **Manual**: Linear AGC with contrast and brightness specified by the user.

7.8 CMOS Video-Tap Modes

As described in Section 0 and shown again in Figure 35, there are multiple locations in the signal pipeline where video can be tapped for output on the CMOS channel. Neutrino LC provides the following CMOS video-tap modes:

- **Pre-AGC (16-bit) (factory default)**: The output is linearly proportional to incident irradiance; output resolution is the same as FPA resolution (e.g., 640x512). Data is provided on CMOS_Data[0:15]. Note that AGC settings, zoom settings, and color-encoding settings have no effect on the output signal at this tap point.
- **Post-AGC / Pre-Zoom (8-bit)**: The output is contrast enhanced via the AGC algorithm; output resolution is the same as FPA resolution. Data is provided on CMOS_Data[0:7]. Note that zoom settings and color-encoding settings have no effect on the output signal at this tap point.
- **Post-Zoom, Post-Colorize (various bit-width options depending upon color-encoding mode, see Section 7.9)**: The output is stretched to 640x512 resolution regardless of array format, and the displayed field of view is a function of the user-specified zoom parameters. The output is transformed to color space using the specified color palette (see Section 6.6) and specified color encoding mode (see Section 7.9).

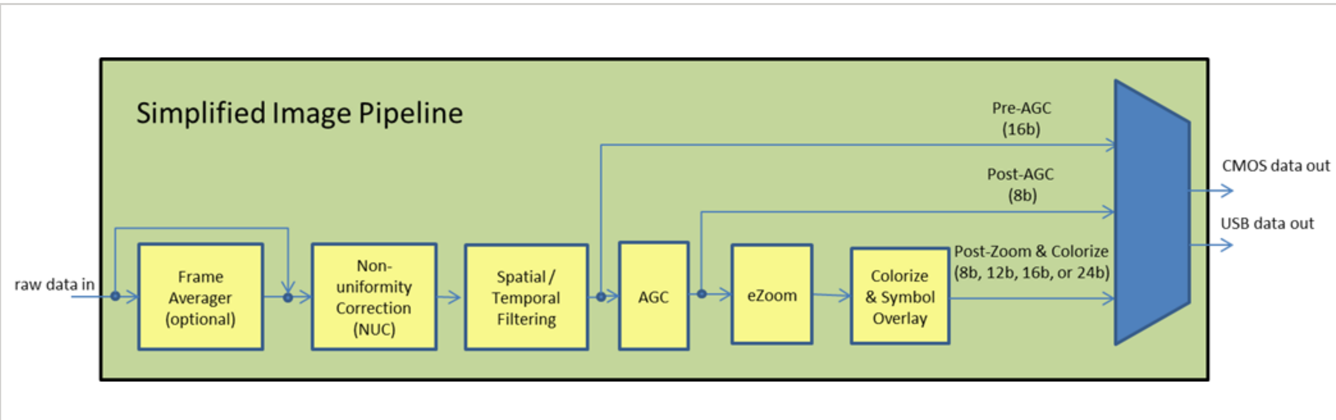


FIGURE 35: NEUTRINO LC SIGNAL PIPELINE

7.9 CMOS Color-Encoding Modes

Neutrino LC provides the following color-encoding modes which affect formatting of the output video signal when the post-colorize tap is selected:

- **YCbCr 4:2:2 (16-bit per pixel) (factory-default)**: The signal consists of a luminance channel (8 bits per clock on CMOS_Data[0:7]), a blue chrominance channel (8 bits on each even clock cycle on CMOS_Data[8-15]), and a red chrominance channel (8 bits on each odd clock cycle on CMOS_Data[8-15]).
- **YCrCb 4:2:2 (16-bit per pixel)**: The signal is identical to YCbCr except the red and blue chrominance channels are swapped. That is, the red chrominance channel is provided on the even clock cycle and the blue chrominance channel on the odd clock cycle.
- **RGB 5:6:5 (16-bit per pixel)**: The signal consists of a red channel (5 bits per clock on CMOS_Data[1,4,7,10,13] is the 5 MSBs[7:3] of red), a green channel (6 bits per clock on CMOS_Data[0,3,6,9,12,15] is the 6 MSBs[7:2] of green), and a blue channel (5 bits per clock on CMOS_Data[2,5,8,11,14] is the 5 MSBs[7:3] of blue).

- **BGR 5:6:5 (16-bit per pixel):** The signal is identical to RGB 5:6:5 except the blue and red channels are swapped. That is, the blue channel is provided on CMOS_Data[1,4,7,10,13] and the red channel on CMOS_Data[2,5,8,11,14].

> **NOTE:** Only YCbCr 4:2:2, YCrCb 4:2:2, RGB 5:6:5, and BGR 5:6:5 are validated in the current software release. RGB and BGR modes were updated from 8:8:8 to 5:6:5 and validated in Release 1.2.1 software. All remaining options shown below are capable of being selected but are not currently validated. TELEDYNE FLIR does not recommend relying on any of these without thoroughly testing in the end application.

- **YCbCr 4:2:2 muxed (16-bit per pixel, 2 clocks per pixel):** The luminance and chrominance channels are time-multiplexed on CMOS_Data[0:7]. Specifically, the luminance is provided on clock cycles *n* and *n*+2, the blue chrominance channel on clock cycle *n*+1, and the red chrominance channel on clock cycle *n*+3, for *n* = 0, 4, 8…. The CMOS pixel clock rate is doubled when in this mode.
- **YCrCb 4:2:2 muxed (16-bit per pixel, 2 clocks per pixel):** The signal is identical to YCbCr 4:2:2 muxed except the order of the red and blue chrominance channels are swapped. That is, the red chrominance channel is provided on clock cycles *n*+1 and the blue chrominance channel on cycles *n*+3. The CMOS pixel clock rate is doubled when in this mode.

For reference, the color encoding of each mode is depicted graphically in Figure 36. Note the CMOS color-encoding mode has no effect on the video signal unless CMOS video-tap mode is "post colorize".

Color Mode	Clk	CMOS_Data																							
		23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
YCbCr 4:2:2	0	Unused								Cb[7:0]								Y0[7:0]							
	1	Unused								Cr[7:0]								Y1[7:0]							
YCrCb 4:2:2	0	Unused								Cr[7:0]								Y0[7:0]							
	1	Unused								Cb[7:0]								Y1[7:0]							
RGB 5:6:5	0 1	Unused								G 2	B 3	R 3	G 3	B 4	R 4	G 4	B 5	R 5	G 5	B 6	R 6	G 6	B 7	R 7	G 7
BGR 5:6:5	0 1	Unused								G 2	R 3	B 3	G 3	R 4	B 4	G 4	R 5	B 5	G 5	R 6	B 6	G 6	R 7	B 7	G 7
YCbCr 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							
	3	unused																Cr[7:0]							
YCrCb 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							

	3	unused	Cr[7:0]

FIGURE 36: VARIOUS COLOR-ENCODING MODES

Note(s)

1. Modes which are highlighted in gray are implemented but have not been validated in the current product release. Use is discouraged until a later field-upgradeable software release in which all modes are fully validated.

7.10 CMOS Output Modes

The final stage in the Neutrino LC signal pipeline is a multi-frame buffer. The CMOS output channel reads the front buffer while the signal pipeline writes a background buffer. Neutrino LC provides two CMOS output modes which affect the behavior of the CMOS channel in relation to the multi-frame buffer:

- **Continuous (factory-default):** In this mode, the CMOS channel provides data at a regular cadence (i.e., exact same clocks per frame period without exception). If the background buffer is still being written when the front buffer has been fully read out, the front buffer is read out again, resulting in a duplicated frame. This mode of operation is preferred for interfacing to a display system which requires data at a regular interval. The output frame rate in continuous mode is either 60Hz (averager disabled, see Section 5.1) or 30Hz (averager enabled) regardless of the frame rate setting.
- **One-shot:** In this mode, the CMOS channel inserts idle time between successive frames in those instances where there is not a back buffer ready for readout when the front buffer has been completely read. Consequently, the number of clocks per frame period is not a constant but can instead vary slightly. In this mode of operation, every frame is unique. That is, the output frame rate is equal to the frame rate setting. This mode of operation is preferred for interfacing to a frame grabber which can tolerate slight frame-rate jitter. With the a user specified frame rate settings of 52Hz, the output frame rate is 52Hz with averager disabled 26Hz with averager enabled.

NOTE: The CMOS Output mode has no effect on the USB video channel. The USB video channel always operates in one-shot mode.

7.11 Analog Modes

Neutrino LC provides the option of outputting a BT.656-like signal using the pins normally used to provide the CMOS video channel. This capability is utilized by the TELEDYNE FLIR USB / Analog VPC Accessory (see Section 15.2) to obtain analog video output. There are three “analog modes”:

- **Analog Disabled (factory default)**: The CMOS channel is configured to output video according to the timing and logic described in Section 8.2.1.

- **NTSC:** The CMOS channel is configured for BT.656 output at 60Hz frame rate, outputting 525 lines per frame (525/60).
- **PAL:** The CMOS channel is configured for BT.656 output at 50Hz frame rate, outputting 625 lines per frame (626/50).

When the CMOS channel is configured for BT.656 output, cmos_vsync, cmos_hsync, and cmos_data_valid are unused, as are cmos_data[8-23]. That is, only cmos_pclk and cmos_data[0-7] are utilized, with the most-significant bit provided on cmos_data7, and the least significant bit provided on cmos_data0. Clock rate remains 27 MHz when the channel is configured for BT.656 output.

There are several noteworthy caveats regarding the BT.656 output signal:

- The output is single ended, not differential.
- Digital line alignment does not follow the BT.656 standard exactly. Specifically, in a strictly compliant implementation, each video line begins with an EAV code, then blanking, then SAV code, then Video Data. In Neutrino LC, digital alignment is achieved by observing only EAV/SAV pairs when only the "H' bit is changing, making it a non-standard implementation. TELEDYNE FLIR has not seen any resulting problems from this.
- No scaling of BT.656 output (vertical or horizontal) is supported.
- TELEDYNE FLIR has observed some image pulsing on older CRT monitors. LCD monitors are recommended for optimal analog display.
- BT.656 limits output to values within the range 16 to 235. Because the BT.656 channel and the USB channel both receive data from a common output buffer, the USB video signal will also be limited to values within the range 16 to 235 when Analog mode is set to NTSC or PAL.

When Neutrino LC is mated with the TELEDYNE FLIR USB / Analog VPC Accessory, it automatically detects a video encoder on the accessory. It will not normally allow the NTSC or PAL modes to be selected unless this video encoder is detected. It is possible (and necessary) to override this automatic detection feature for applications which intend to utilize the BT.656 output without installing the TELEDYNE FLIR USB / Analog VPC Accessory. This override is accomplished via command over the CCI.

NOTE: When analog mode is set to NTSC or PAL, Neutrino LC automatically sets the CMOS Video-Tap Mode to Post Colorization (see Section 7.8), the CMOS Color-Encoding Mode to YCbCr 4:2:2.(see Section 7.9), and the CMOS Output Mode to Continuous (see Section 7.10). These are required settings and changing any of them will prevent the BT.656 channel from functioning properly.

NOTE: When averager mode is set to enabled, the BT.656 output channel continues to provide data at either 60Hz (NTSC mode) or 50Hz (PAL mode) by duplicating every frame at the output.

7.12 Image Orientation Modes

Neutrino LC provides the option of inverting and/or reverting the read out and therefore output imagery on all video outputs. This mode is not intended to be run-time selectable, and therefore the non-uniformity corrections should be calibrated with the image orientation mode in the intended run-time state. There are four "image orientation modes":

- **Normal (factory default)**: The read out starts (pixel (0,0)) in the upper, left corner of the FPA where the normal mechanical orientation of the camera package relative to the normal FPA orientation is defined in Figure 41.
- **Invert:** The read out is flipped about the horizontal axis.
- **Revert:** The read out is flipped about the vertical axis.
- **Invert/Revert:** The read out is flipped about both the horizontal and vertical axes.

8 INTERFACE DESCRIPTIONS

This section describes the primary electrical interfaces to the camera:

8.1 Command and Control Interface

Neutrino LC provides two options for a command and control interface (CCI):

- UART (for asynchronous serial interfaces such as RS232), 921600/8-N-1 (921.6kBaud, 8 data bits, no parity bit, 1 stop bit)
- USB, 8-N-1

Each interface is described in a separate document, the Neutrino LC Software Interface Description Document (IDD), TELEDYNE FLIR document #102-2020-42. For both CCI channels, the Neutrino LC core is a "slave" device which never transmits a message without first receiving one and always transmits a reply to a received message. In general, all commands issued through the CCI take the form of a "get" (reading data), a "set" (writing data), or a "run" command (executing a function). shows a partial list of modes, parameters, and operations which are controllable through the CCI. A graphical user interface (GUI) which provides full command and control is available for download on TELEDYNE FLIR's website. see Section 1.2.

TABLE 8: PARTIAL LIST OF MODES, PARAMETERS, AND OPERATIONS CONTROLLABLE THROUGH THE CCI

MODE, PARAMETER, OR OPERATION	FACTORY DEFAULT	SECTION IN THIS DOCUMENT	TELEMETRY LINE LOCATION
Mode Controls			

MODE, PARAMETER, OR OPERATION	FACTORY DEFAULT	SECTION IN THIS DOCUMENT	TELEMETRY LINE LOCATION
Overtemp Mode	Disabled	7.4	n/a
Averager Mode	Disabled	7.2	28
Telemetry Mode	Enabled	7.5	n/a
FFC Mode	Automatic (shuttered) External (shutter-less)	7.6	n/a
AGC Mode	Information-Based Equalization enabled	7.7	n/a
CMOS Video-Tap Mode	Pre-AGC	7.8	n/a
CMOS Color-Encoding Mode	Continuous	7.9	n/a
CMOS Output Mode	Continuous	7.10	n/a
Parameter Controls			
Telemetry Location	Header	7.5	n/a
Telemetry Encoding	16b	7.5	n/a
FFC Period	1200 (20 minutes)	6.2	n/a
FFC Delta Temp	10 (1.0 deg Celsius)	6.2	n/a
FFC Integration Period	16 (16 frames)	6.2	57
FFC Warn Period	20 (2 seconds)	6.2	n/a
FFC Start-Up Period	3600 (60 minutes)	6.2	n/a
AGC Mode	Normal	6.4	124
Information Based Mode (Entropy)	Disabled	6.4	n/a
Plateau Value (Percent Per Bin)	10%	6.4.2	n/a
Tail Rejection (Outlier Cut)	1%	6.4.3	n/a
Max Gain	1.0	6.4.4	n/a
Linear Percent	20%	6.4.5	n/a
ACE (Gamma)	0.97	6.4.6	n/a
DDE (D2BR)	1.0	0	n/a
Smoothing Factor (Sigma R)	1250	6.4.8	n/a
AGC ROI Start Row	1	6.4.9	n/a

MODE, PARAMETER, OR OPERATION	FACTORY DEFAULT	SECTION IN THIS DOCUMENT	TELEMETRY LINE LOCATION
AGC ROI Start Col	1	6.4.9	n/a
AGC ROI End Row	510	6.4.9	n/a
AGC ROI End Col	638	6.4.9	n/a
Dampening Factor	85%	6.4.10	n/a
Brightness Bias	0	6.4.11	n/a
Brightness	127	6.4.12	n/a
Contrast	64	6.4.13	n/a
Zoom Factor	0	6.5	n/a
Zoom-Center Column	320	6.5	n/a
Zoom-Center Row	256	6.5	n/a
Color Palette	White Hot	6.6	n/a
Specify Symbol Attributes	n/a	6.7.2	n/a
Splash 1 Duration / Splash 2 Duration	0 (min time) / 5000 ms	6.8	n/a
Splash 1 Background Color / Splash 2 Background Color	n/a	6.8	n/a
Operations			
Load NUC Table	n/a	6.9	n/a
Get Current NUC Table	n/a	6.9	79
SW Reset	n/a	7.1	n/a
Set Defaults	n/a	6.1	n/a
Restore Factory Defaults	n/a	6.1	n/a
Perform FFC	n/a	6.2	n/a
Get Part Number	n/a		5-14
Get Serial Number	n/a		1-2
Read SW Revision	n/a		21-26
Upload Symbol Bitmap	n/a	6.7.2	n/a
Upload Splash Screen	n/a	6.8	n/a
Erase Splash Screen	n/a	6.8	n/a

8.2 Video Interfaces

Neutrino LC provides two separate channels for output video:

- CMOS
- USB

NOTE: It is possible to provide simultaneous output on both channels. For example, CMOS can be configured to provide 16-bit data prior to AGC while USB provides the post-colorization video tap.

8.2.1 CMOS

Neutrino LC provides the option of a digital data protocol resembling that of a typical CMOS camera. Specifically:

1. The CMOS video channel is comprised of a pixel clock, up to 24 parallel bits of data, a vertical sync, a horizontal sync, and a data-valid signal. The channel utilizes 1.8V logic levels. See Section 4.1 for pin assignments. The vertical sync and horizontal sync are asserted low. The data-valid and all data lines are asserted high.
2. Each frame period consists of three distinct sections, as illustrated in Figure 37:
    a. The vertical sync period, during which the vertical sync, *cmos_vsync*, is asserted. The width of the vertical sync pulse, *vsw*, varies depending upon whether telemetry is enabled, as depicted in Table 9.
    b. A period during which successive rows of data are provided. The total number of rows during each frame, *nr*, varies depending upon settings, as shown in Table 9.
    c. A variable blank period between the end of the last row period and the next vertical sync. This variable blank period is only present in "one shot" CMOS output mode. (see Section 7.10). In "continuous" CMOS output mode, this period is always 0 clocks. The difference in frame timing between the two modes is defined in Table 10.
3. Each row period consists of four distinct sections, as depicted in Figure 38:
    a. The horizontal sync period, during which the horizontal sync, *cmos_hsync*, is asserted. The width of the horizontal sync pulse, *hsw*, is always 7 clocks, as depicted in Table 9.
    b. A variable blanking period between the horizontal sync and the start of valid data referred to as the front porch. The width of the front porch, *fp*, is not guaranteed.
    c. The period during which valid data is provided on *cmos_data[0:23]* and during which *cmos_data_valid* is asserted. The number of pixels (i.e., number of clocks) in the data valid period, *ppr*, varies depending upon the CMOS tap point, as shown in Table 9.
    d. A variable blanking period between the end of valid data and the end of the row period, referred to as the back porch. Like the front porch, the width of the back porch, *bp*, is not guaranteed. Given that *fp* and *bp* can vary, it is imperative that receiving electronics monitor *cmos_data_valid* to ascertain the start of valid pixel data on a row.
4. All signals in the CMOS channel are latched on the rising edge of the pixel clock, *cmos_pclk*, as illustrated in Figure 39. As shown in Table 10, the period of the pixel clock is user selectable with 27.000 MHz (factory default) intended for averager mode disabled and 13.500 MHz intended for averager mode enabled, see Section 7.2 for averager feature details.
5. The output frame rate is also dependent upon whether the averager is enabled (30.0Hz) or disabled (60.0Hz), as well as the CMOS output mode.
    a. In one shot mode, the frame rate is defaulted to 60.0Hz but can be altered to any frequency between 1.0Hz and 60.0Hz. The averager will cause the selected frame rate to be halved. For example, if the frame rate has been selected as 26.0Hz, the output frame rate will be 26.0Hz in averager disabled mode and 13.0Hz in averager enabled mode.
    b. In continuous mode, output frame rate is always 30.0Hz or 60.0Hz, but frames are duplicated to produce an *effective* frame rate of the selected frame rate between 1.0Hz and 60.0Hz. For example, if the averager is enabled, and the frame rate is set to 7.5Hz each unique frame is followed by 3 duplicates, for an effective frame rate of 30.0Hz/4 (7.5Hz) and an output frame rate of 30.0Hz. Similarly, if the averager is disabled, each unique frame is followed by 6 duplicates, for an effective frame rate of 60.0Hz/7 (8.6Hz) and an output frame rate of 60.0Hz.

6. As described in Section 7.8 and Section 7.9, the number of valid data bits piped out the CMOS channel is either 8, 16, or 24, depending upon the CMOS video-tap mode and possibly on the colorization mode (if and only if video-tap mode = post-colorization). The CMOS channel encoding for each tap-mode / color-encoding mode is repeated in

Mode	Clk	CMOS_Data																							
		23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Pre-AGC		unused								Data[15:0]															
Post-AGC / Pre-Color		unused																Data[7:0]							
YCbCr 4:2:2	0	unused								Cb[7:0]								Y0[7:0]							
	1	unused								Cr[7:0]								Y1[7:0]							
YCrCb 4:2:2	0	unused								Cr[7:0]								Y0[7:0]							
	1	unused								Cb[7:0]								Y1[7:0]							
RGB 5:6:5	0 1	unused								G 2	B 3	R 3	G 3	B 4	R 4	G 4	B 5	R 5	G 5	B 6	R 6	G 6	B 7	R 7	G 7
BGR 5:6:5	0 1	unused								G 2	R 3	B 3	G 3	R 4	B 4	G 4	R 5	B 5	G 5	R 6	B 6	G 6	R 7	B 7	G 7
YCbCr 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							
	3	unused																Cr[7:0]							
YCrCb 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							
	3	unused																Cr[7:0]							
RGB 8:8:8 muxed	0	unused												G[3:0]				R[7:0]							
	1	unused												B[7:0]								G[7:4]			
BGR 8:8:8 muxed	0	unused												G[3:0]				B[7:0]							
	1	unused												R[7:0]								G[7:4]			

7. Figure 40 below.

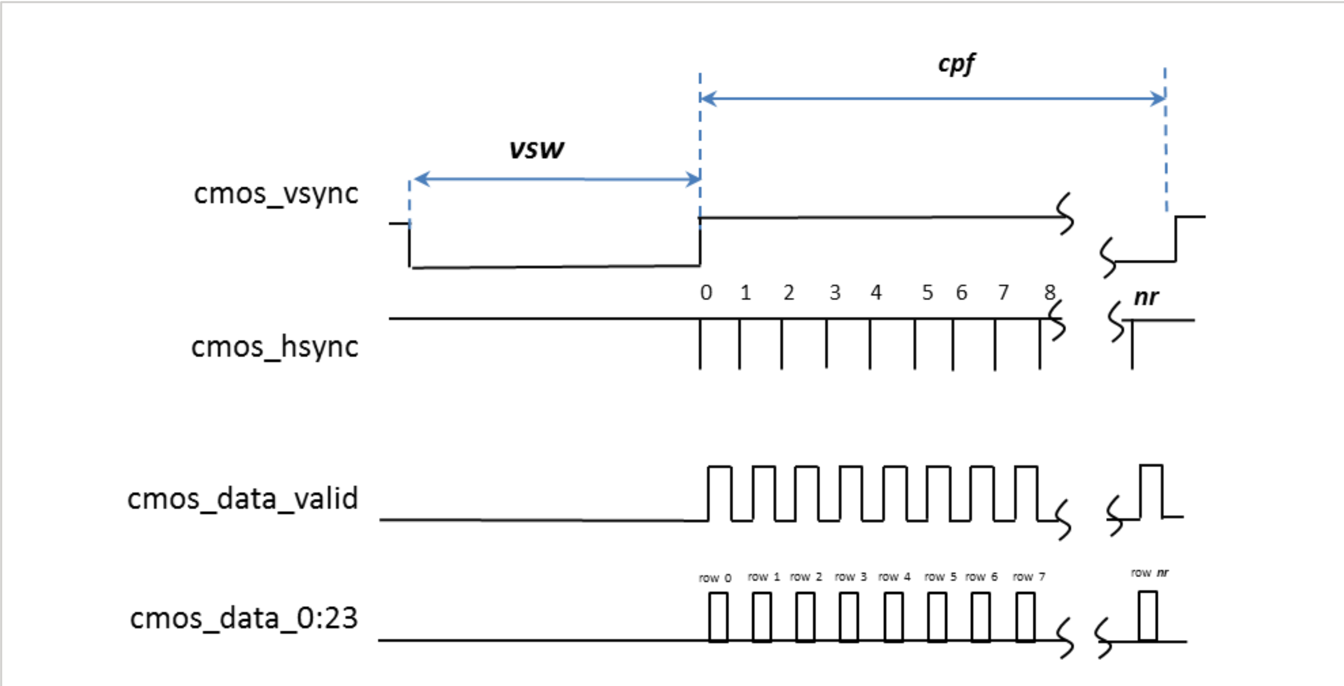


FIGURE 37: FRAME TIMING OF THE CMOS OUTPUT CHANNEL

See Table 9 for the values of *vsw* and *nr.* See Table 10 for the value of *cpf*,

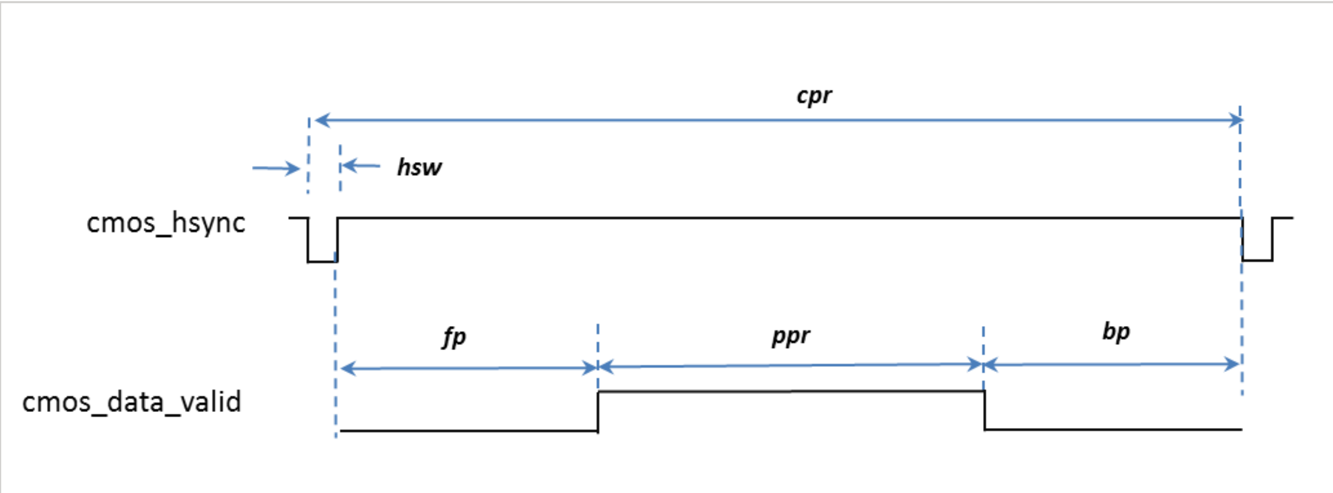


FIGURE 38: LINE TIMING OF THE CMOS OUTPUT CHANNEL

See Table 9 for the values of *hsw*, *cpr*, and *ppr*. *fp* and *bp* are configuration dependent.

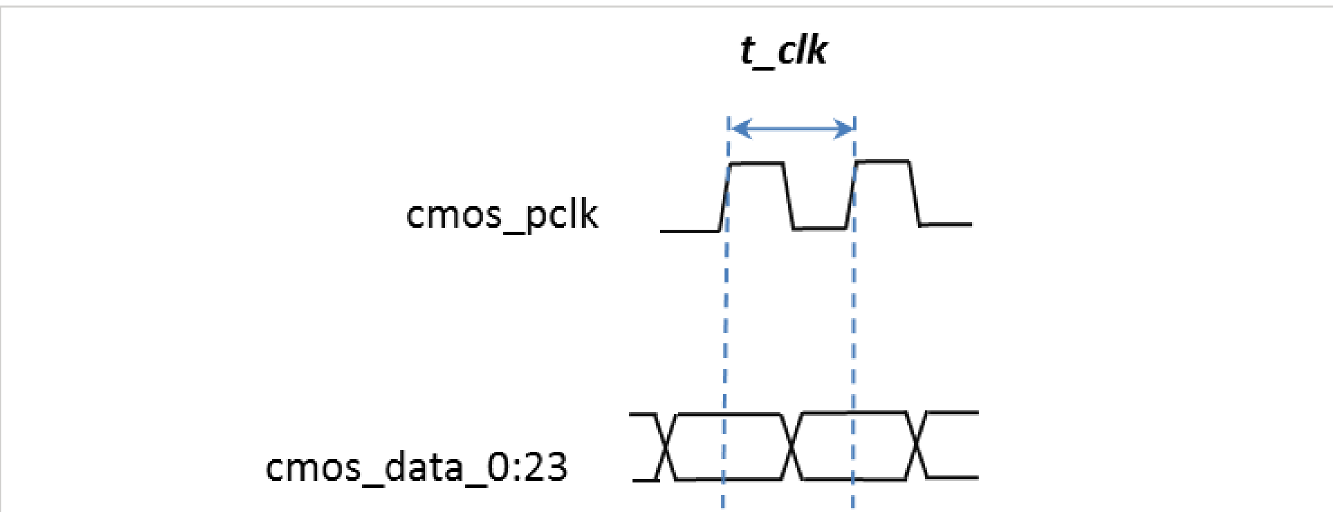


FIGURE 39: PHASE OF PIXEL CLOCK RELATIVE TO CMOS DATA

See Table 9 for the value of *t_clk.*

TABLE 9: TIMING OF THE CMOS CHANNEL AS A FUNCTION OF CAMERA SETTINGS, VALUES COMMON TO CONTINUOUS AND ONE-SHOT MODES

CMOS TAP POINT	**ALL CMOS TAP MODES**	
Telemetry	Disabled	Enabled
Vertical sync width, *vsw* (in row periods)	88	87
Vertical sync width, *vsw* (in clock periods)	66,000[1]	65,250[1]
Valid rows per frame, *nr*	512	513
Row periods per frame (*vsw* + *nr*)	600	
Horz sync width, *hsw* (in clocks)	8	
Pixels per row, *ppr*	640	
Clocks per row period, *cpr* (*hsw* + *fp* + *pp r*+ *bp*)	750	

Note(s)

1. *Numbers are exact in Continuous mode. In One-Shot mode, the vertical sync width may be longer than shown due to idle time.*

TABLE 10: TIMING OF THE CMOS CHANNEL AS A FUNCTION OF CAMERA SETTINGS, VALUES WHICH DIFFER BETWEEN CONTINUOUS AND ONE-SHOT MODES

a) Continuous mode settings

CMOS TAP POINT	**ALL CMOS TAP MODES**	
Averager	Disabled	Enabled
Clocks per frame, cpf (*cpr* x (*vsw* + *nr*))	450,000	
Clock rate, (1/*t_clk*) (in MHz)	27.000	13.5
Frame rate = 1/(*cpf* x *t_clk*)	60.000	30.000

b) One-shot mode settings

CMOS TAP POINT	**ALL CMOS TAP MODES**	
Averager	Disabled	Enabled
Clocks per frame, cpf (cpr x (vsw + nr)) See note 1	Varies,> 450,000	
Clock rate, (1/t_clk)(in MHz)	27.000	13.5
Frame rate = 1/(cpf x t_clk)	< 60.000	<30.000

Note(s)

1. *Additional clock periods of blanking are inserted as necessary at the end of the last row of valid data. The next vertical sync appears as soon as the next frame is ready.*
2. *Clock rate is user selectable with a factory default of 27.0MHz. If averager mode is enabled, the clock rate should be configured to 13.5MHz.*

Mode	Clk	CMOS_Data																							
		23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Pre-AGC		unused								Data[15:0]															
Post-AGC / Pre-Color		unused																Data[7:0]							
YCbCr 4:2:2	0	unused								Cb[7:0]								Y0[7:0]							
	1	unused								Cr[7:0]								Y1[7:0]							
YCrCb 4:2:2	0	unused								Cr[7:0]								Y0[7:0]							
	1	unused								Cb[7:0]								Y1[7:0]							
RGB 5:6:5	0 1	unused								G 2	B 3	R 3	G 3	B 4	R 4	G 4	B 5	R 5	G 5	B 6	R 6	G 6	B 7	R 7	G 7
BGR 5:6:5	0 1	unused								G 2	R 3	B 3	G 3	R 4	B 4	G 4	R 5	B 5	G 5	R 6	B 6	G 6	R 7	B 7	G 7
YCbCr 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							
	3	unused																Cr[7:0]							
YCrCb 4:2:2 muxed	0	unused																Y0[7:0]							
	1	unused																Cb[7:0]							
	2	unused																Y1[7:0]							
	3	unused																Cr[7:0]							
RGB 8:8:8 muxed	0	unused												G[3:0]				R[7:0]							
	1	unused												B[7:0]								G[7:4]			
BGR 8:8:8 muxed	0	unused												G[3:0]				B[7:0]							
	1	unused												R[7:0]								G[7:4]			

FIGURE 40: ENCODING OF THE CMOS OUTPUT CHANNEL FOR EACH VIDEO-TAP MODE / COLOR-ENCODING MODE

Note(s)

1. *Modes which are highlighted in gray are implemented but have not been validated in the current product release. Use is discouraged until a later field-upgradeable software release in which all modes are fully validated.*
2. *RGB 5:6:5 and BGR 5:6:5 modes were corrected and validated in software Release 1.2.1.*

NOTE: The CMOS color-encoding mode has no effect on the video signal unless CMOS video-tap mode is “post colorize”.

8.2.2 USB

Neutrino LC can provide digital data as a USB Video Class (UVC) compliant device. Two output options are provided. Note the options are *not* selected via the CCI but rather by the video capture or viewing software selected by the user. The options are:

- **Pre-AGC (16-bit)**: The output is linearly proportional to the flux incident on each pixel in the array; output resolution is 640x512. Note that AGC settings, zoom settings, and color-encoding settings have no effect on the output signal at this tap point. This option is identified with a UVC video format 4CC code of "Y16 " (16-bit uncompressed greyscale image)
- **Post-Colorize, YCbCrb**: The output is transformed to YCbCr color space using the specified color palette (see Section 6.6). Resolution is 640x512. Three options are provided, identified via the UVC video format 4CC code:
  - I420: 8-bit Y plane followed by 8-bit 2x2 subsampled U and V planes
  - NV12: 8-bit Y plane followed by an interleaved U/V plane with 2x2 subsampling
  - NV21: same as NV12 except reverse order of U and V planes

9 MECHANICAL CONSIDERATIONS

9.1 Mounting

The standard Neutrino LC includes a 4-hole mounting pattern. Reference the Neutrino LC Mechanical IDD, 425XXXXXXXX-XXXXX, for details.

9.2 Thermal Considerations

Adequate heatsinking and air flow must be provided to prevent the Neutrino LC core from overheating, particularly when operated in ambient temperatures approaching the maximum upper temperature range of the device (71 °C). The Dewar package and cooler housing temperatures should be maintained at temperatures below 85 °C at all times. The camera and cooler electronics (partially enclosed) should be maintained at a local ambient temperature below 85 °C at all times to prevent components on these boards consuming power from reaching their respective maximum ratings.

A small 5VDC fan directed at the Dewar with airflow specifications of 3 CFM has been shown to significantly impact thermal and therefore power performance.

Figure 41 depicts the recommended heatsinking interface for Neutrino LC.

FIGURE 41: RECOMMENDED INTERFACE FOR HEATSINKING NEUTRINO LC

9.3 Interface Board Mounting

Interface printed circuit board assemblies (PCBA), including the available accessory boards in Section 0, should reside on the frame surface or lip as shown in Figure 42 to ensure proper mating height of the 4mm stacking height connectors. The retaining screw locations and dimensions along with the connector definitions are included in the diagram for additional clarity.

Reference the Neutrino LC Mechanical IDD, 425-640XXX-XXXXX, for further details.

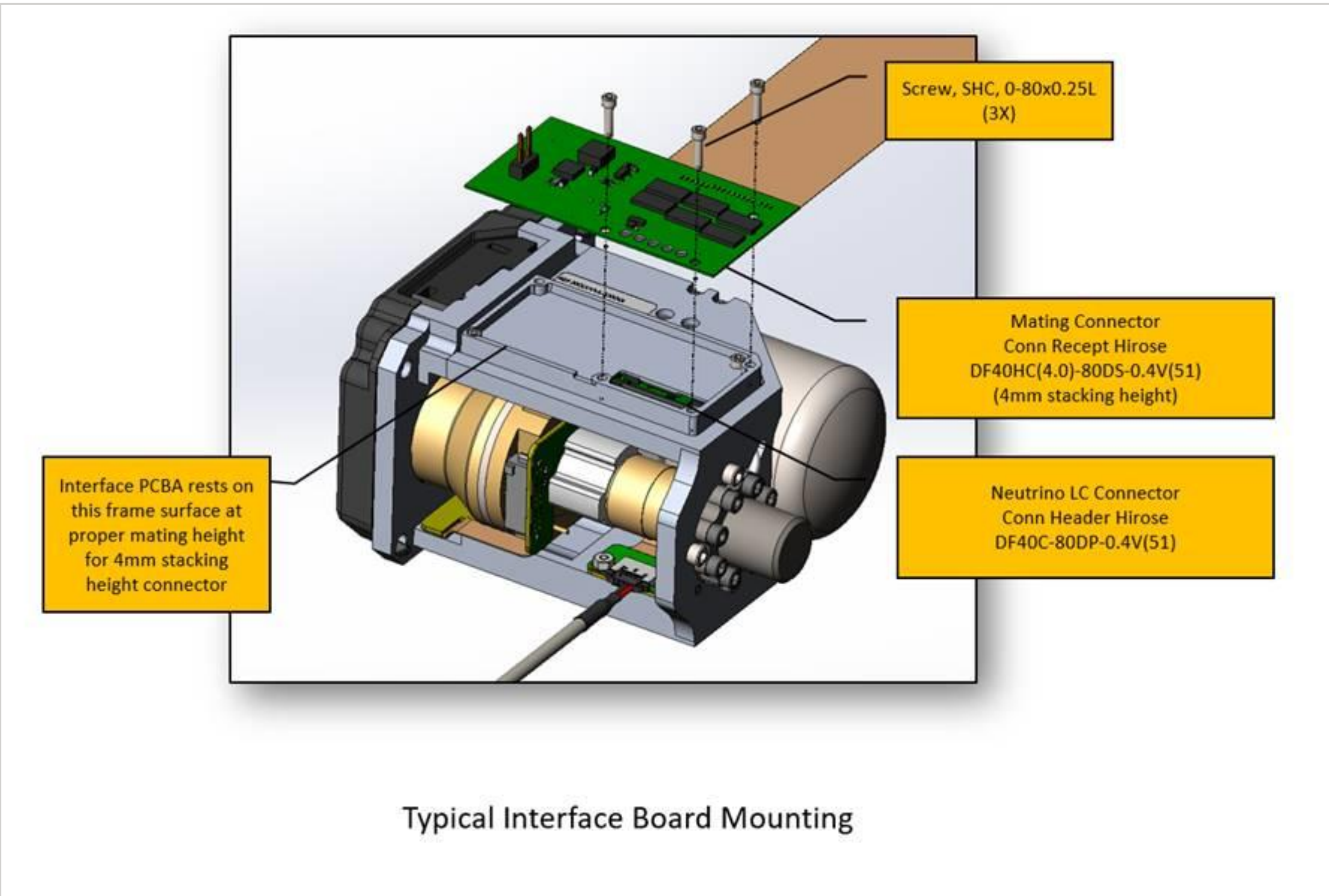


FIGURE 42: TYPICAL INTERFACE BOARD MOUNTING

NOTE: Boson accessory boards are compatible with Neutrino LC, but the fasteners are different between the two products. Neutrino LC accepts 0-80 fasteners and using the incorrect fasteners (e.g. Boson M 1.6) can result in damage to the frame.

10 OPTICAL CONSIDERATIONS

As shown Table 11 in the customer optics must be compatible with the optical and mechanical aspects of the Neutrino LC design. Reference the Neutrino LC Mechanical IDDs, 425XXXXXXXX-XXXXX for tolerances, mechanical interface suggestions, and additional details.

TABLE 11: OPTICAL SPECIFICATIONS

SPECIFICATION	F/5.5 CONFIGURATION	F/4.0 CONFIGURATION
f / #	5.5	4.0
Cold Shield Aperture to FPA Height	19.71mm	19.40mm
Cold filter	0.51mm, Sapphire	0.51mm, Sapphire
Window	1.02mm, Silicon	1.02mm, Silicon
Mechanical BWD for optic compatibility	>25.45mm (shutter) > 22.37mm (shutterless)	>25.45mm (shutter) > 22.37mm (shutterless)

11 IMAGE CHARACTERISTICS

11.1 Time to Image (Cooldown)

Neutrino LC does not image, and instead outputs a splash screen, until it reaches the desired setpoint or cooldown state. Table 12 below describes typical cooldown times for Neutrino LC as a function of ambient temperature.

TABLE 12: TIME TO IMAGE

CATEGORY	CRITERIA	TYPICAL
Time to Cooldown	Room Temperature Ambient (23 °C)	< 4 minutes
	High Temperature Ambient (71 °C)	< 6 minutes

11.2 Sensitivity

Table 13 shows sensitivity as a function of configuration as there is a strong dependence on f/#, integration time, and spectral response. The specified NEdT requirements are the absolute thresholds for acceptance of random temporal noise (σ_{tvh}) when operating without an optic, all signal processing disabled, and with the averager disabled. The specified NEdT metric is collected with the integration time chosen to achieve mid-well output imaging against a 25 °C black body flood source and normalized by the mean response calculated using 20 °C and 30 °C black body flood sources.

The absolute specification of “raw” NEdT using the method above is 30mK, and the nominal value is 25mK. The nominal NEdT value with signal processing enabled (default configuration) is 15 mK, and the NEdT values with averager enabled are approximately 20% lower.

For faster f/#’s, the integration time is decreased to achieve mid-well against the same background level (25 °C black body flood source), therefore the specifications for f/5.5 and f/4.0 are the same (increased signal is countered by the decrease in integration time).

TABLE 13: TEMPORAL NEDT

CONFIGURATION	APPROXIMATE INTEGRATION TIME	SPECIFICATION
f/5.5 standard (no signal processing)	15ms	< 30 mK
f/5.5 standard (with signal processing)		15 mK (typical)
f/4.0 standard (no signal processing)	8ms	< 30 mK
f/4.0 standard (with signal processing)		15 mK (typical)

11.3 Spectral Response

A typical relative photon spectral response curve is shown in Figure 43 for the standard Neutrino LC configuration. Note the response at ~4.25µm is due to atmospheric CO_2 absorption rather than system related response.

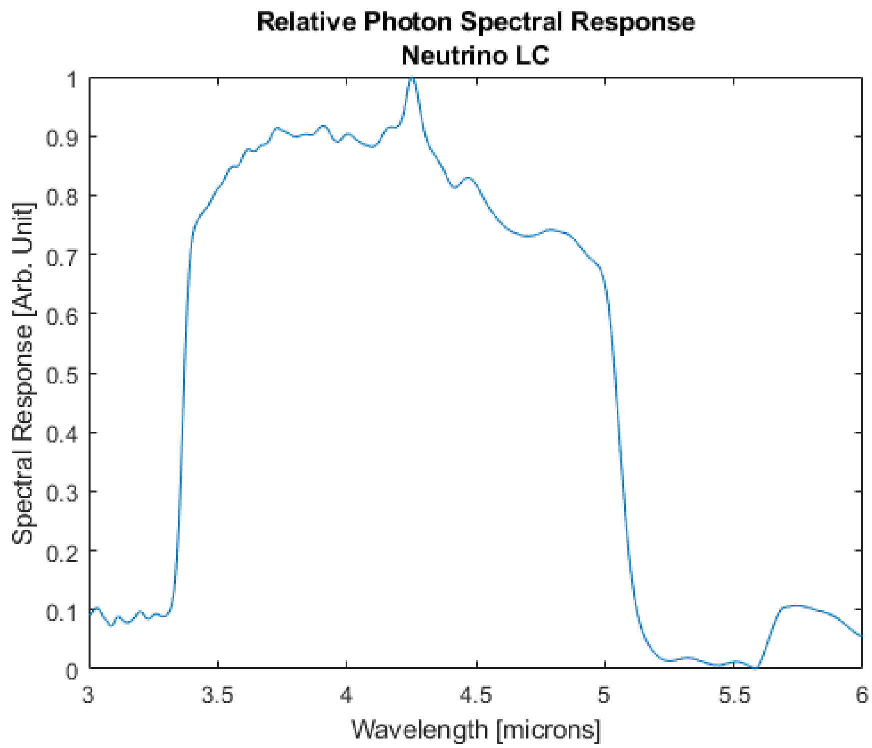


FIGURE 43: TYPICAL RELATIVE PHOTON SPECTRAL RESPONSE FOR STANDARD NEUTRINO LC

11.4 Intrascene Temperature

Intrascene temperature refers to the span of scene temperatures which map to the camera's 16-bit output range (i.e., the temperatures which can be imaged without railing the output). The intrascene temperature is highly depending upon configuration (f/#, spectral filters), customer optics (e.g. transmission), and the integration time. Integration time is variable per NUC table to allow the customer to achieve four different intrascene ranges in run-time by simply commanding a NUC table switch via CCI.

11.5 Operability

Operability refers to requirements pertaining to the number and location/grouping of non-operable pixels. Table 14 defines the operability requirements. By factory-default, all defective pixels are replaced in the output-video stream by data from adjacent non-defective pixels. A single pixel border is not considered in the operability specification; the one-pixel border is replaced by the mean of the most recent flat field correction in the video pipeline.

TABLE 14: GENERAL OPERABILITY REQUIREMENTS

OPERABILITY SPECIFICATION	TOTAL DEFECTS
Total Defects (Central 638 x 510)	<0.5%

11.5.1 Defect Definitions

A pixel may be marked defective based on multiple criteria at the factory. The criteria apply to a system without an optic.

1. The pixel will be marked defective if the output is out of range. Specifically, if the aperture corrected output is less than 8,000 or greater than 52,000 16-bit ADC counts against a 30 °C uniform black body source with integration time set for a mean output at mid-well.
2. The pixel will be marked defective if the responsivity of the pixel, calibrated using approximately 25% and 75% well-fill uniform black body source, is < 80% or > 120% of the mean of the pixels.
3. The pixel's temporal NEdT > 100mK against a 30 °C uniform black body source with integration time set for a mean output at mid-well.
4. The pixel is flickering. Where flickering is defined as instantaneous output deviating by more than 10x the RMS noise in any one frame over a period of five minutes.

The user may mark additional pixels defective or inoperable in the field to be replaced in addition to the factory defective pixels. The above criteria (1) for pixels out of range and/or (2) with anomalous responsivities are user-programmable to automatically occur with a two-point calibration. The user has the flexibility to accept the new (if any) bad pixels and store them to flash memory or not.

12 ELECTRICAL SPECIFICATIONS

12.1 DC and Logic Level Specifications

TABLE 15: DC AND LOGIC LEVELS

PARAMETER	DESCRIPTION	MIN	TYP	MAX	RIPPLE, P-P MAX	UNITS
3V3	Camera voltage	3.14[1]	3.30	3.46	0.060	Volts
USB_VBUS	USB Power	4.40	5.00	5.25	--	Volts
I_3V3	Primary supply current for camera electronics	--	[2]	TBD[3]	N/A	mA
I_VBUS	Supply current for USB	--	--	0.130	N/A	mA
GPIO EXT_SYNC	High-level input voltage GPIO EXT_SYNC	1.17	1.8	2.1	TBD	Volts
GPIO EXT_SYNC	Low-level input voltage GPIO EXT_SYNC	-0.3	0	0.63	TBD	Volts
RESET	High-level input voltage RESET	1.71	[4]	--	TBD	Volts
RESET	Low-level input voltage RESET	--	0	0.45	TBD	Volts

Note(s)

1. *3V3 rise time from 0V to minimum voltage shall not exceed 1 msec.*
2. *Typical current varies with settings. See Section 12.2.*
3. *The maximum value shown is during shutter actuation. During other times, maximum value is TBD.*
4. *The RESET pin should be left floating in the high-level input state.*

TABLE 16: DC AND LOGIC LEVELS – COOLER ELECTRONICS

PARAMETER	DESCRIPTION	MIN	NOMINAL	MAX	RIPPLE, P-P MAX	UNITS
12V	Cooler Voltage	11.0	12.0	13.0	TBD	Volts
STANDBY	Standby (Disabled State)	1.7	3.3	3.6	--	Volts
STANDBY	Standby (Enabled State)	0	0	0.8	--	Volts
I_12V	Supply current for Cooler	--	TBD	TBD	N/A	A

12.2 Power Consumption

Camera and Cooler electronics power consumption is dependent upon five primary variables:

- Operating temperature
- Whether the cooler state is in cooldown vs. steady state (FPA temperature)
- Whether the frame averager function is enabled (see Section 5.1)
- Whether the USB channel is streaming video (see Section 8.2.2)
- Shutter state (integral shutter configuration)

12.2.1 Steady State

When the Dewar package has cooled down to the intended setpoint and the cooler is operating only to maintain setpoint, the unit is said to be in "steady state" operation. Power dissipation for both the cooler electronics and camera electronics increases non-linearly with operational temperature. Initial data in Figure 44 below shows the "worst-case" configuration (averager disabled, USB video streaming) power consumption from room temperature to the highest extreme operational temperature of 71 °C. Air flow and basic heat sinking considerations were made during this "typical" data collection scenario.

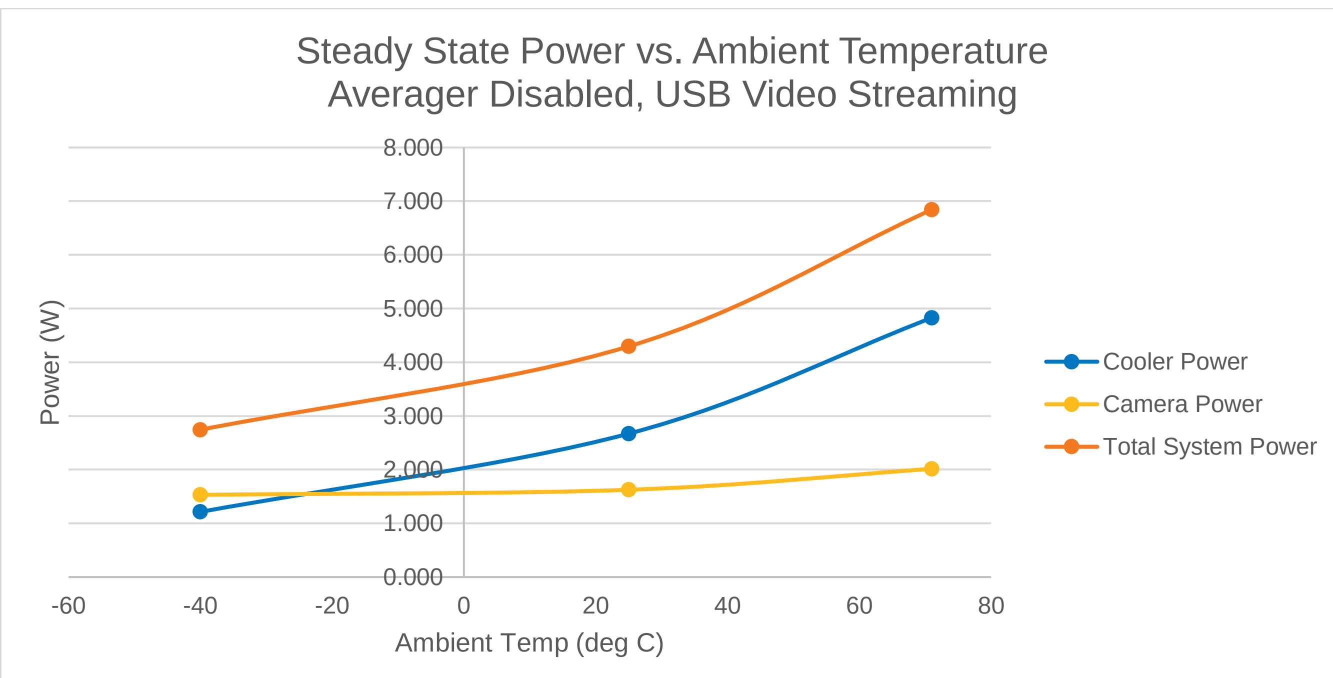


FIGURE 44: TYPICAL POWER VARIATION OVER TEMPERATURE FOR "WORST CASE" CONFIGURATION

Table 17 below summarizes the expected, typical power consumption at steady state at both room temperature operation and the maximum operating temperature for the entire system.

TABLE 17: TYPICAL POWER CONSUMPTION AT STEADY STATE

CATEGORY	CRITERIA	TYPICAL	TYPICAL COMBINED SYSTEM POWER
Steady State, Room Temperature Ambient (23 °C)	Power Dissipation (Camera Electronics)	< 1.5 W	< 4.5 W
	Power Dissipation (Cooler Electronics)	< 3.0 W	
Steady State, High Temperature Ambient (71 °C)	Power Dissipation (Camera Electronics)	< 2.0 W	< 7.0 W
	Power Dissipation (Cooler Electronics)	< 5.0 W	

12.2.2 Cooldown

The initial power consumption for the cooler electronics during the “cooldown” period is when the system reaches its peak power consumption (approximately the first four minutes after power application). Note that it is possible to trade peak power consumption during cooldown for time to image; this feature is not currently available to the user but can be configured at the factory. Table 18 below summarizes the expected, peak power consumption during cooldown at both room temperature operation and the maximum operating temperature for the cooler electronics only.

The total system power will include the camera electronics power dissipation contribution. The user may intentionally wait to apply power to the camera electronics until cooldown is achieved such that the peak cooler input power to cool the system down has already been reached before increasing the total system power with the camera electronics power dissipation.

TABLE 18: TYPICAL POWER CONSUMPTION PEAK DURING COOLDOWN

CATEGORY	CRITERIA	MAXIMUM	PEAK COMBINED SYSTEM POWER
Peak Power during Cooldown, Room Temperature Ambient (23 °C)	Power Dissipation (Camera Electronics)	< 1.5 W	< 9.5W
	Power Dissipation (Cooler Electronics)	< 8 W	
Peak Power during Cooldown, High Temperature Ambient (71 °C)	Power Dissipation (Camera Electronics)	< 2 W	< 12W
	Power Dissipation (Cooler Electronics)	< 10 W	

12.3 Absolute Ratings

Electrical stresses beyond those listed in Table 19 and Table 20 may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under the recommended operating conditions listed in Table 15 is not implied. Exposure to absolute rated conditions for extended periods of time may affect device reliability.

TABLE 19: ABSOLUTE RATINGS – CAMERA ELECTRONICS

PARAMETER	ABSOLUTE MINIMUM RATING	ABSOLUTE MAXIMUM RATING
Camera Voltage (3V3)	-0.3V	3.63V
USB VBUS	-0.3V	5.25V
Voltage on any GPIO pin	-0.3V	2.1V
Voltage on RESET pin	-0.3V	6.0V
Voltage on any USB signal pin	-0.3V	5.25V
Camera Electronics Ambient Temperature	-40 °C	85 °C
Camera Electronics Junction Temperature (referred to herein as “Core Temperature”)	-40 °C	105 °C

TABLE 20: ABSOLUTE RATINGS – COOLER ELECTRONICS

PARAMETER	ABSOLUTE MINIMUM RATING	ABSOLUTE MAXIMUM RATING
Cooler Voltage (12V)	0V	17V
Voltage on Standby Pin	-0.5V	3.9V
Cooler Electronics Ambient Temperature	-40 °C	85 °C
Cooler Electronics Junction Temperature	-40 °C	105 °C

13 ENVIRONMENTAL SPECIFICATIONS AND RELIABILITY

13.1 Environmental Specifications

Environmental stresses beyond those listed in Table 21 may cause permanent damage to the device. Exposure to absolute-maximum-rated conditions for extended periods of time may affect device reliability.

TABLE 21: ENVIRONMENTAL SPECIFICATIONS

STRESS	MAXIMUM RATING
Operating Temperature Range[1]	-40 °C to 71 °C
Storage Temperature[2]	-57 °C to 80 °C
Altitude (pressure)	12 km altitude equivalent
Relative Humidity	5% to 95% non-condensing
Thermal Shock	Air-to-air, 5 °C/min across operating temperature extremes
Mechanical Shock[3]	150g, 0.5msec half-sine pulse, (X-axis) 300g, 0.5msec half-sine pulse, (Y-axis) 600g, 0.5msec half-sine pulse, (Z-axis)
Vibration[4]	5.8 Grms, 1hr

Note(s)

1. *Operating temperature refers to ambient temperature with proper air flow and heat sinking.*
2. *Prolonged high temperature storage may cause vacuum degradation which increases power and decreases the overall lifetime of the product.*
3. *Axis definitions defined in Figure 41.*
4. *Specific vibration profile defined in Figure 45.*

total G's	5.784716
freq	g^2/hz
20	0.001
20	0.02
1000	0.02
2000	0.01
2000	0.001

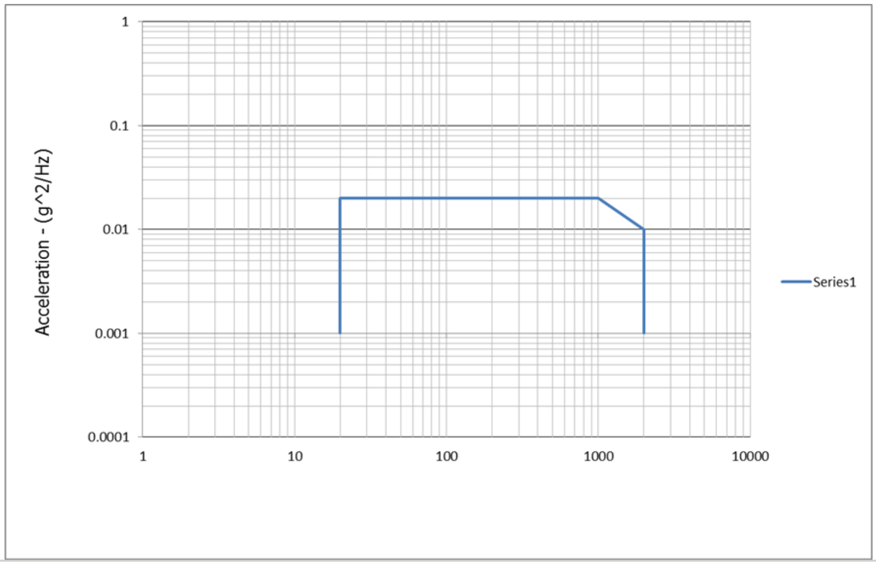


FIGURE 45: VIBRATION PROFILE

13.2 Reliability

Reliability or overall product lifetime is dependent on the linear cryocooler component. Reliability testing is performed using the Standard Advanced Dewar Assembly (SADA) II profile in which the cooler is exposed to various ambient temperatures and power cycles. Table 22 summarizes the expected reliability performance of Neutrino LC.

TABLE 22: RELIABILITY SPECIFICATIONS

SPECIFICATION	VALUE
Reliability	10,000 hours

[1] W.E. Salazar, "Status Report on the Linear Drive Coolers for the Department of Defense Standard Advanced Dewar Assembly (SADA)", Cryocoolers 12, R.G Ross Jr., Ed., Plenum Press, New York (2003), pp. 17 – 25.

13.3 Audible Noise

Neutrino LC employs an integral linear cryogenic cooler; linear cryogenic coolers are acoustically quiet and provide lower audible noise levels in comparison to the traditional rotary cryogenic cooler.

The audible noise levels presented in Table 23 below are captured using an integrating sound level meter (ISLM) at a distance of 7" away from the Neutrino LC at steady state operation under the specified ambient temperature conditions.

TABLE 23: AUDIBLE NOISE SPECIFICATIONS

SPECIFICATION	VALUE
Audible Noise @ 23 °C ambient	< 48 dB (typical)
Audible Noise @ 71 °C ambient	< 53 dB (typical)

13.4 Exported Vibration

Linear cryogenic coolers, such as the cooler integral to Neutrino LC, provide low levels of vibration export in comparison to the traditional rotary cryogenic cooler. The vibration export is quantified by the exported force metric along the lengthwise axis at an operational frequency of 95Hz, as defined in Table 24.

TABLE 24: EXPORTED VIBRATION

SPECIFICATION	VALUE
Vibration export @ 95hz, axis perpendicular to the image plane	< 0.700 n

14 COMPLIANCE WITH ENVIRONMENTAL DIRECTIVES

Neutrino LC complies with the following directives and regulations:

- Directive 2002/96/ EC, "Waste Electrical and Electronic Equipment (WEEE)".
- Regulation (EC) 1907/2006, "Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)

15 ACCESSORIES

A number of accessories were designed to aid in the integration and development of the Neutrino LC camera. Certain accessories were designed for use with Boson originally but are compatible with Neutrino LC camera electronics. These are listed below and described in more detail in the sections to follow.

- Neutrino LC USB VPC Kit (421-0061-01)
- Neutrino LC USB / Analog Video Power Connector (VPC) Kit (421-0062-01)
- Boson Camera Link Accessory (250-0609-00)
- Neutrino LC Utility Kit (421-0074-00)
- Neutrino LC Development Kit (421-0071-00)
- Demonstration Lens (322-0487-00)

NOTE: Boson accessory boards are compatible with Neutrino LC, but the fasteners are different between the two products. Neutrino LC accepts 0-80 fasteners and using the incorrect fasteners (e.g. Boson M 1.6) can result in damage to the frame. The “-01” versions of the USB kits provide the fasteners specific to Neutrino LC.

15.1 USB VPC Kit (421-0061-01)

The USB VPC kit turns the Neutrino LC camera into a webcam. Camera electronics power, digital video, and comm are all via USB2. The kit includes a 3-foot USB-A to USB-C cable.

15.2 USB / Analog VPC Kit (421-0062-01)

The USB / Analog VPC kit is identical to the USB VPC kit except that includes a custom 6-foot cable with a BNC pigtail providing an additional analog video signal (NTSC-compliant).

15.3 Camera Link Accessory (250-0609-00)

The Camera Link accessory converts Neutrino LC’s CMOS video signal into a Camera-Link-compliant output, with physical interface via a standard SDR-26 receptacle. Communication and power to the Neutrino LC camera electronics is provided via a standard USB-3 micro-B (Super Speed) receptacle. Note that a USB-2 micro-B cable is an acceptable alternative to a USB-3 micro-B cable for communication and power.

15.4 Utility Kit (421-0074-00)

The Utility accessory board provides all output options on a single PCB, and the kit includes a wire harness to the cooler interface. The accessory board converts Neutrino LC's CMOS video signal into a Camera-Link-compliant output, with physical interface via a standard SDR-26 receptacle. Communication and power to the Neutrino LC camera electronics is provided via a standard USB-3 micro-B (Super Speed) receptacle. Note that a USB-2 micro-B cable is an acceptable alternative to a USB-3 micro-B cable for communication and power. Analog output and external sync input/output signals are also provided with standard MCX connectors.

15.5 Development Kit (421-0071-01)

The Development accessory board provides all output options on a single PCB and additionally provides easy access to the full 80-pin camera interface for development. The kit includes a flex cable between the board and the camera (such that the camera can be pointed in a lab environment) and a wire harness to the cooler interface. Camera Link accessory converts Neutrino LC's CMOS video signal into a Camera-Link-compliant output, with physical interface via a standard SDR-26 receptacle. Power to the board and camera electronics is provided separately via standard banana plug receptacles. Communication to the camera electronics is provided via a standard USB-3 micro-B (Super Speed) receptacle. Note that a USB-2 micro-B cable is an acceptable alternative to a USB-3 micro-B cable for communication and power.

15.6 Demonstration Lens (322-0487-00)

The demonstration lens accessory is a 22mm fixed focal length, f/5.5 lens providing a 25° horizontal field of view (HFOV). The accessory includes a mechanical housing for the lens which bolts directly to the Neutrino LC faceplate and allows for focus capability (tool included) via keyed lens barrel and threaded barrel/housing with a locking screw. This accessory is compatible with both shuttered and shutter-less configurations.

16 REFERENCES

16.1 TELEDYNE FLIR Documents

DOCUMENT NUMBER	DOCUMENT TITLE
102-2020-42	Neutrino LC Software IDD
102-2020-43	Neutrino LC Release Notification
4250640XXX-XXXXX	Neutrino LC Mechanical Interface Description Drawing (varies by part number)
102-PS242-100-XX	Various Boson Application Notes (not all are applicable)

16.2 External Documents

DOCUMENT NUMBER	DOCUMENT TITLE
Directive 2002/96/ EC	Waste Electrical and Electronic Equipment (WEEE)
Regulation (EC) 1907/2006	Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)

16.3 Abbreviations / Acronyms

ABBREVIATION/ ACRONYM	COMPONENTS
4CC	Four Character Code
ACE	Adaptive Contrast Enhancement
AGC	Automatic Gain Control
API	Application Program Interface
AR	Anti-Reflection
BPR	Bad Pixel Replacement
CCI	Command and Control Interface
CDM	Charged-Device Model
CMOS	Complementary Metal-Oxide-Semiconductor
CRC	Cyclical Redundancy Check
DDE	Digital Detail Enhancement
DVE	Driver’s Vision Enhancer
EMC	Electromagnetic Compatibility
ESD	Electrostatic Damage
FFC	Flat Field Correction
FOV	Field of View
FPA	Focal Plane Array
FPN	Fixed Pattern Noise
GPIO	General Purpose Input / Output
GUI	Graphical User Interface
HBM	Human Body Model
HEQ	Histogram Equalization
HFOV	Horizontal Field of View
I2C	Inter-Integrated Circuit
IDD	Interface Description Drawing / Document
IIR	Infinite Impulse Response
IP	Ingress Protection (also Intellectual Property)
LUT	Look-Up Table
LWIR	Long Wave Infrared
MISO	Master In / Slave Out
MM	Machine Model
MOSI	Master-Out / Slave In
MTBF	Mean Time Between Failure

ABBREVIATION/ ACRONYM	COMPONENTS
MTF	Modulation Transfer Function
NETD	Noise Equivalent Temperature Difference
NFOV	Narrow Field of View
NUC	Non-Uniformity Correction
NVFFC	Nonvolatile FFC
QVGA	Quarter VGA, Quarter Video Graphic Array
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
RGB	Red, Green, Blue (color space used to represent digital video)
RoHS	Reduction of Hazardous Substances
ROI	Region of Interest
ROIC	Readout Integrated Circuit
UART	Universal Asynchronous Receiver / Transmitter
USB	Universal Serial Bus
UVC	USB Video-Device Class
SBNUC	Scene-Based Non-Uniformity Correction
SDIO	Secure Digital Input Output
SDK	Software Developers' Kit
SFFC	Supplemental FFC
SNR	Signal-to-Noise Ratio
SSN	Silent Shutterless NUC
SWAP	Size, Weight, and Power
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
TBD	To Be Determined
SoC	System on a Chip
VGA	Video Graphic Array
VOx	Vanadium Oxide
WEEE	Waste Electrical and Electronic Equipment
WFOV	Wide Field of View
YCrCb	Luma, Red Chrominance, Blue Chrominance (color space used to represent digital video)

If you have questions that are not covered in this manual contact FLIR Commercial Systems Customer Support (SBA-Cores@flir.com) for additional information. Contact Customer Support for questions related to the use of open-source software in this product. And contact Customer Support prior to returning a camera which is in need of service.

This documentation and the requirements specified herein are subject to change without notice.

This equipment must be disposed of as electronic waste.

Contact your nearest FLIR Commercial Systems, Inc. representative for instructions on how to return the product to FLIR for proper disposal.

FCC Notice. This device is a subassembly designed for incorporation into other products in order to provide an infrared camera function. It is not an end-product fit for consumer use. When incorporated into a host device, the end-product will generate, use, and radiate radio frequency energy that may cause radio interference. As such, the end-product incorporating this subassembly must be tested and approved under the rules of the Federal Communications Commission (FCC) before the end-product may be offered for sale or lease, advertised, imported, sold, or leased in the United States. The FCC regulations are designed to provide reasonable protection against interference to radio communications. See 47 C.F.R. §§ 2.803 and 15.1 et seq.

Industry Canada Notice. This device is a subassembly designed for incorporation into other products in order to provide an infrared camera function. It is not an end-product fit for consumer use. When incorporated into a host device, the end-product will generate, use, and radiate radio frequency energy that may cause radio interference. As such, the end-product incorporating this subassembly must be tested for compliance with the Interference-Causing Equipment Standard, Digital Apparatus, ICES-003, of Industry Canada before the product incorporating this device may be: manufactured or offered for sale or lease, imported, distributed, sold, or leased in Canada.

Avis d'Industrie Canada. Cet appareil est un sous-ensemble conçu pour être intégré à un autre produit afin de fournir une fonction de caméra infrarouge. Ce n'est pas un produit final destiné aux consommateurs. Une fois intégré à un dispositif hôte, le produit final va générer, utiliser et émettre de l'énergie radiofréquence qui pourrait provoquer de l'interférence radio. En tant que tel, le produit final intégrant ce sous-ensemble doit être testé pour en vérifier la conformité avec la Norme sur le matériel brouilleur pour les appareils numériques (NMB-003) d'Industrie Canada avant que le produit intégrant ce dispositif puisse être fabriqué, mis en vente ou en location, importé, distribué, vendu ou loué au Canada.

EU Notice. This device is a subassembly or component intended only for product evaluation, development or incorporation into other products in order to provide an infrared camera function. It is not a finished end-product fit for general consumer use. Persons handling this device must have appropriate electronics training and observe good engineering practice standards. As such, this product does not fall within the scope of the European Union (EU) directives regarding electromagnetic compatibility (EMC). Any end-product intended for general consumer use that incorporates this device must be tested in accordance and comply with all applicable EU EMC and other relevant directives.