FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet

General Description

Lepton® is a complete long-wave infrared (LWIR) camera module designed to interface easily into native mobile-device interfaces and other consumer electronics. It captures infrared radiation input in its nominal response wavelength band (from 8 to 14 microns) and outputs a uniform thermal image.

Features

- Dimensions:

  8.5 x 11.7 x 5.6 mm (without socket),
  10.6 x 11.7 x 5.9 mm (including socket)

- 51-deg HFOV, 63.5-deg diagonal (f/1.1 silicon doublet)
- LWIR sensor, wavelength 8 to 14 μm
- 80 (h) × 60 (v) active pixels
- Thermal sensitivity <50 mK
- Integrated digital thermal image processing functions, including automatic thermal environment compensation, noise filters, non-uniformity correction, and gain control
- Optional temperature-stable output to support radiometric processing
- Export compliant frame rate (< 9 Hz)
- MIPI and SPI video interfaces
- Two-wire I2C-like serial-control interface
- Uses standard cell-phone-compatible power supplies: 2.8V to sensor, 1.2V to digital core, and flexible IO from 2.5V to 3.1V
- Fast time to image (< 0.5 sec)

- Low operating power, nominally 150 mW (< 160 mW over full temperature range)
- Low power standby mode
- RoHS compliant
- 32-pin socket interface to standard Molex or similar side-contact connector

Applications

- Mobile phones
- Gesture recognition
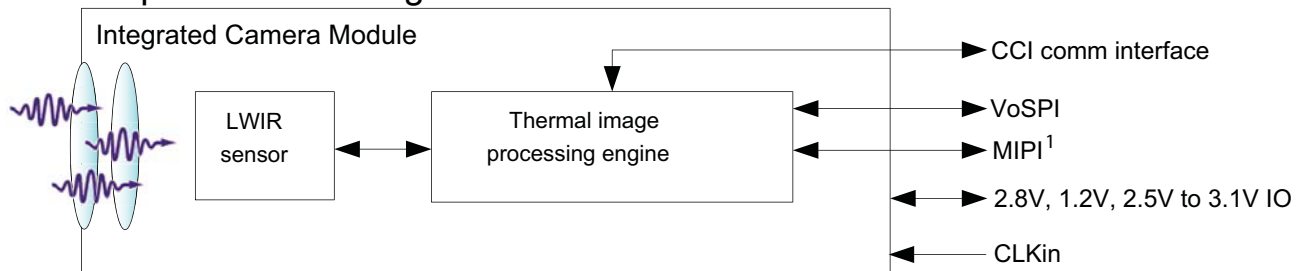- Building automation
- Thermal imaging
- Night vision

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Simplified Block Diagram

Integrated Camera Module

LWIR sensor ⟷ Thermal image processing engine

→ CCI comm interface
→ VoSPI
→ MIPI[1]
→ 2.8V, 1.2V, 2.5V to 3.1V IO
→ CLKin

1. Feature anticipated in a future product release

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Note: All specifications subject to change without notice

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Revision History

Revision	Date	Description of Change
1.0	5/1/2014	Initial release
1.1	7/7/2014	Updated to cover new features of the Lepton 2.0 release.
1.2	9/23/2014	Minor corrections
1.2.3	10/15/2014	Formatting and minor corrections

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References

Lepton Software Interface Description Document (IDD) - Public. Document #110-0144-03.

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1.0   Device Overview

Lepton is an infrared camera system that integrates a fixed-focus lens assembly, an 80x60 long-wave infrared (LWIR) microbolometer sensor array, and signal-processing electronics. Easy to integrate and operate, Lepton is intended for mobile devices as well as any other application requiring very small footprint, very low power, and instant-on operation. Lepton can be operated in its default mode or configured into other modes through a command and control interface (CCI).

Figure 1 shows a view of the Lepton camera, both as standalone and mounted in a socket.

Figure 1   **Lepton Camera (with and without socket)**
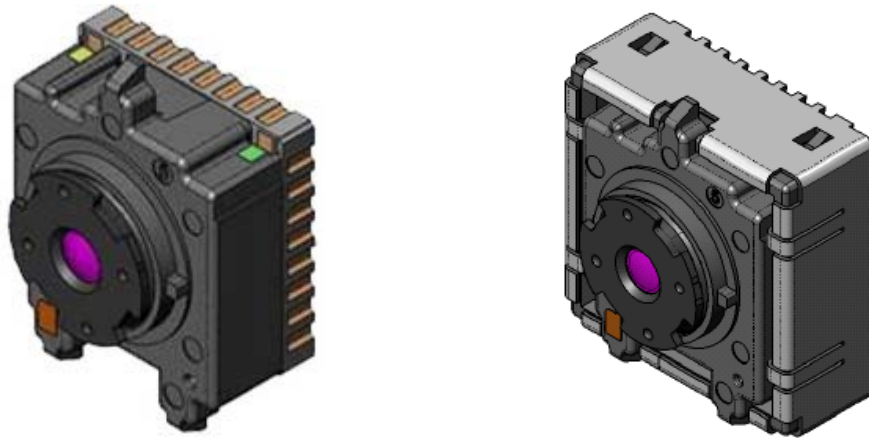
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2.0   Applications

A typical application using the Lepton camera module is shown in *Figure 2*.

Figure 2   Typical Application
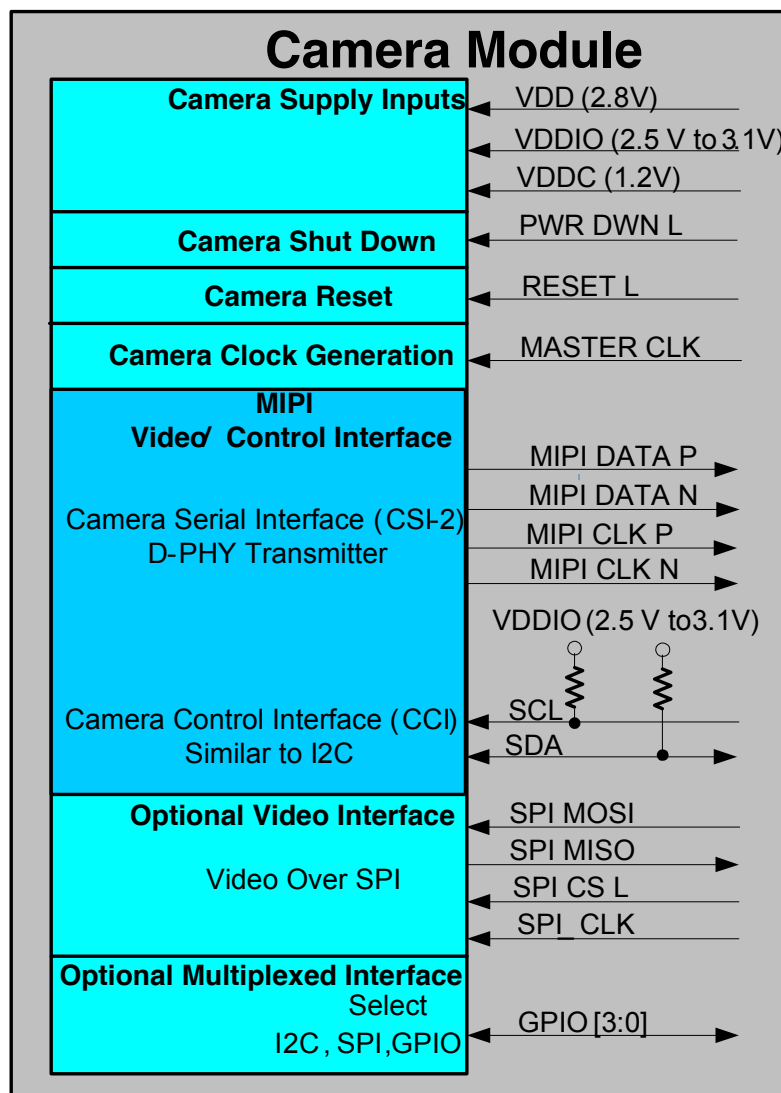
Note:
(1) The CCI pullup resistors are required and must be handled
     outside the camera module by a host controller
(2)   MIPI is not currently supported
                              .

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3.0   Key Specifications

The key specifications of the Lepton camera module are listed in *Table 1*. See *Figure 3 on page 8* for the corresponding package pinout diagram.

Table 1   Key Specifications

Specification	Description
Overview	
Function	Passive thermal imaging module for mobile equipment
Sensor technology	Uncooled VOx microbolometer
Spectral range	Longwave infrared, 8 µm to 14 µm
Array format	80 × 60, progressive scan
Pixel size	17 µm
Effective frame rate	8.6 Hz (exportable)
Thermal sensitivity	<50 mK (0.050° C)
Temperature compensation	Automatic. Output image independent of camera temperature (optional mode - see *Radiometry Modes, page 22*).
Non-uniformity corrections	Automatic (with scene motion)
FOV - horizontal	51°
FOV - diagonal	63.5°
Depth of field	10 cm to infinity
Lens type	f/1.1 silicon doublet
Output format	User-selectable 14-bit, 8-bit (AGC applied)
Solar protection	Integral
Electrical	
Input clock	25-MHz nominal, CMOS IO Voltage Levels (see *Operating States and Modes, page 13*)
Video data interface	Video over SPI (see *VoSPI Channel, page 28*)
Control port	CCI (I2C-like), CMOS IO Voltage Levels (see *Command and Control Interface, page 27*)
Input supply voltage (nominal)	2.8 V, 1.2 V, 2.5 V to 3.1 V IO (see *DC and Logic Level Specifications, page 45*)
Power dissipation	Nominally 150 mW at room temperature (operating), 4 mW (standby)
Mechanical	
Package dimensions – socket version	8.5 × 11.7 × 5.6 mm (w × l × h)
Weight	0.55 grams (typ)
Environmental	
Optimum operating temperature range	-10 °C to +65 °C
Non-operating temperature range	-40 °C to +80 °C
Shock	1500 G @ 0.4 ms

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4.0   Lepton Camera Module Pinout Diagram

Figure 3   Pinout Diagram (viewed from back of camera module)
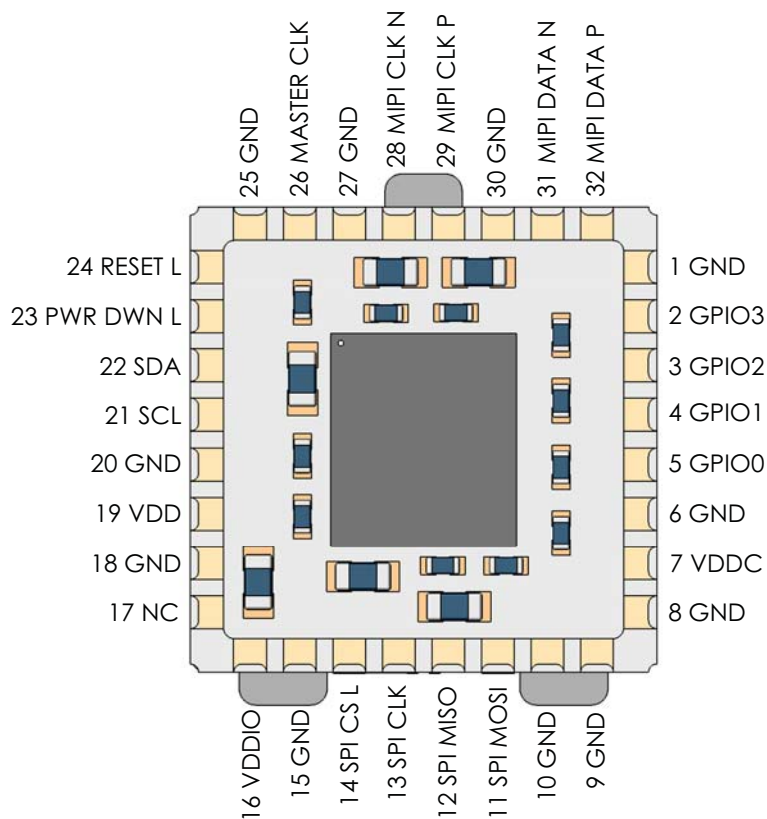
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5.0 Pin Descriptions

The Lepton camera module pin descriptions are shown in *Table 2*.

Table 2 Lepton Camera Module Pin Descriptions

Pin #	Pin Name	Signal Type	Signal Level	Description
1, 6, 8, 9, 10, 15, 18, 20, 25, 27, 30	GND	Power	GND	Common Ground
2	GPIO3	IN/OUT	VDDIO	The GPIOmultiplexed functions are optional and configurable. The GPIO pins are unused in the current release.
3	GPIO2	IN/OUT	VDDIO	
4	GPIO1	IN/OUT	VDDIO	
5	GPIO0	IN/OUT	VDDIO	
7	VDDC	Power	1.2V	Supply for MIPI Core, PLL, ASIC Core (1.2V +/- 5%)
11	SPI_MOSI	IN	VDDIO	Video Over SPI Slave Data In (see *VoSPI Channel, page 28*)
12	SPI_MISO	OUT	VDDIO	Video Over SPI Slave Data Out (see *VoSPI Channel, page 28*)
13	SPI_CLK	IN	VDDIO	Video Over SPI Slave Clock (see *VoSPI Channel, page 28*)
14	SPI_CS_L	IN	VDDIO	Video Over SPI Slave Chip Select, active low (see *VoSPI Channel, page 28*)
16	VDDIO	Power	2.5 V — 3.1 V	Supply used for System IO
17	No connection	—	—	—
19	VDD	Power	2.8V	Supply for Sensor (2.8V +/- 3%).
21	SCL	IN	VDDIO	Camera Control Interface Clock, I2C compatible
22	SDA	IN/OUT	VDDIO	Camera Control Interface Data, I2C compatible

Table 2   Lepton Camera Module Pin Descriptions *(continued)*

Pin #	Pin Name	Signal Type	Signal Level	Description
23	PWR_DWN_L	IN	VDDIO	This active low signal shuts down the camera
24	RESET_L	IN	VDDIO	This active low signal resets the camera
26	MASTER_CLK	IN	VDDIO	ASIC Master Clock Input (see *Operating States and Modes, page 13*)
28	MIPI_CLK_N	OUT	Diff Pair	MIPI Digital Video Clock Negative[1]
29	MIPI_CLK_P	OUT	Diff Pair	MIPI Digital Video Clock Positive[1]
31	MIPI_DATA_N	OUT	Diff Pair	MIPI Digital Video Data Negative[1]
32	MIPI_DATA_P	OUT	Diff Pair	MIPI Digital Video Data Positive[1]

Note(s)

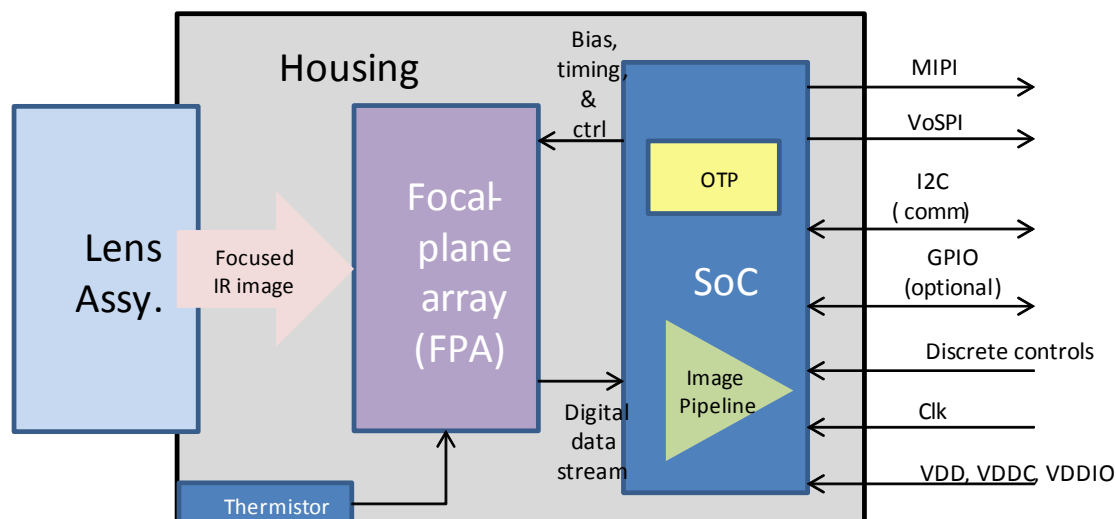1. MIPI is not currently supported. Let the MIPI pins float.

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6.0 System Architecture

A simplified architectural diagram of the Lepton camera module is shown in *Figure 4*.

Figure 4   Lepton Architecture

The lens assembly focuses infrared radiation from the scene onto an 80x60 array of thermal detectors with 17-micron pitch. Each detector element is a vanadium-oxide (VOx) microbolometer whose temperature fluctuates in response to incident flux. The change in temperature causes a proportional change in each microbolometer's resistance. VOx provides a high temperature coefficient of resistance (TCR) and low 1/f noise, resulting in excellent thermal sensitivity and stable uniformity. The microbolometer array is grown monolithically on top of a readout integrated circuit (ROIC) to comprise the complete focal plane array (FPA). Once per frame, the ROIC senses the resistance of each detector by applying a bias voltage and integrating the resulting current for a finite period of time called the integration period.

The serial stream from the FPA is received by a system on a chip (SoC) device, which provides signal processing and output formatting. The image pipeline is defined in *Video Pipeline, page 12*.
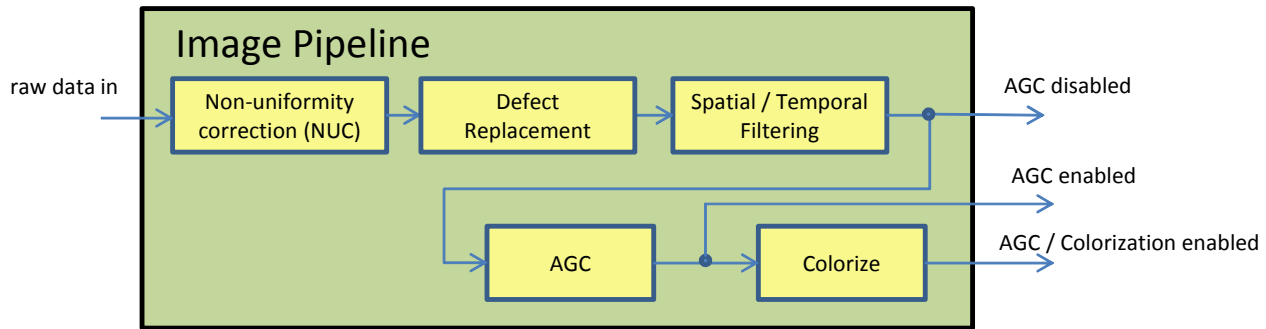
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7.0 Video Pipeline

A block diagram of the video pipeline is shown in *Figure 5*.

Figure 5   Lepton Video Pipeline Block Diagram

The video pipeline includes non-uniformity correction (NUC), defect replacement, spatial and temporal filtering, automatic gain correction (AGC), and colorization.

7.1 NUC

The non-uniformity correction (NUC) block applies correction terms to ensure that the camera produces a uniform output for each pixel when imaging a uniform thermal scene. Factory-calibrated terms are applied to compensate for temperature effects, pixel response variations, and lens-illumination roll-off. To compensate for temporal drift, the NUC block also applies an offset term that can be periodically updated at runtime via a process called flat-field correction (FFC). The FFC process is further described in *FFC States, page 17*.

7.2 Defect Replacement

The defect-replacement block substitutes for any pixels identified as defective during factory calibration or during runtime. The replacement algorithm assesses the values of neighboring pixels and calculates an optimum replacement value. The typical number of defective pixels is ≤1.

7.3 Spatial / Temporal Filtering

The image pipeline includes a number of sophisticated image filters designed to enhance signal-to-noise ratio (SNR) by eliminating temporal noise and residual non-uniformity. The filtering suite includes a scene-based non-uniformity correction (SBNUC) algorithm which relies on motion within the scene to isolate fixed pattern noise (FPN) from image content.

7.4 AGC

The AGC algorithm for converting the full-resolution (14-bit) thermal image into a contrast-enhanced image suitable for display is a histogram-based non-linear mapping function. See *AGC Modes, page 25*.

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7.5 Colorize

The colorize block takes the contrast-enhanced thermal image as input and generates a 24-bit RGB color output. This feature is anticipated in a future release and is not currently accessible.

8.0 Operating States and Modes

Lepton provides a number of operating states and modes, more completely defined in the sections that follow:

- *Power States, page 13*
- *FFC States, page 17*
- *Telemetry Modes, page 19*
- *Radiometry Modes, page 22*
- *AGC Modes, page 25*
- *Interface Descriptions, page 27*

8.1 Power States

Lepton currently provides five power states. As depicted in the state diagram shown in *Figure 6*, most of the transitions among the power states are the result of explicit action from the host. The automatic transition to and from the overtemp state is an exception. In the figure, transitions that require specific host-side action are shown in bold. Automatic transitions are not bolded.
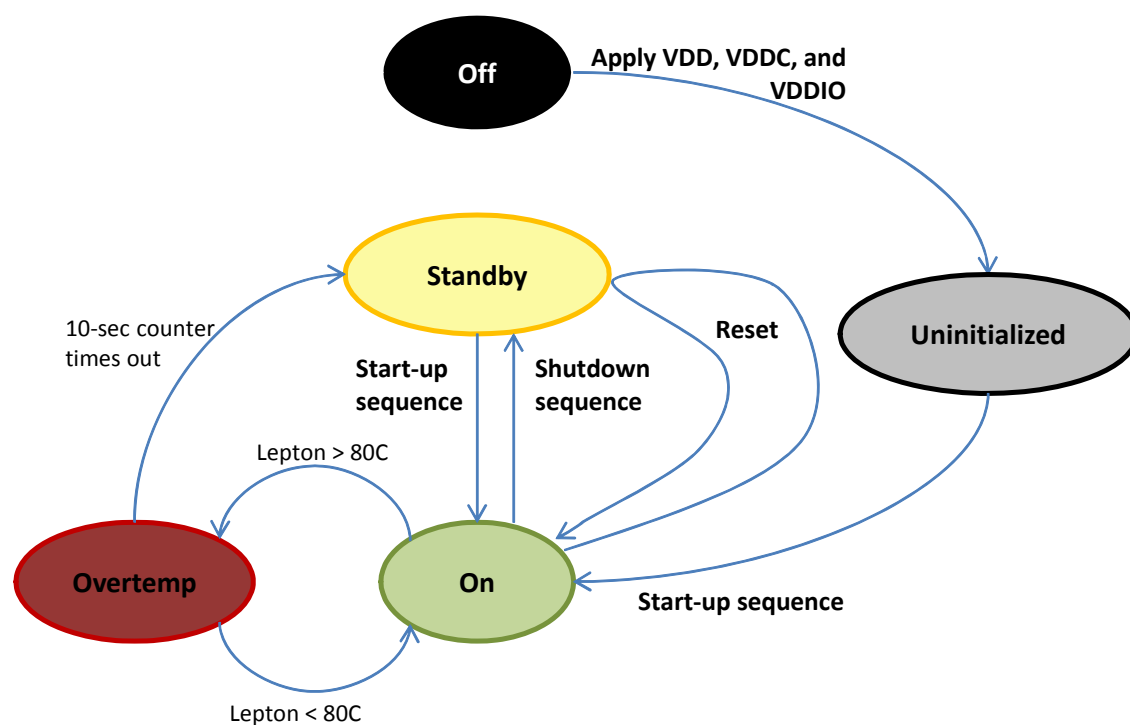
Figure 6   State Diagram Showing Transitions among the Five Power States

Note: Transition to "off" from every other state occurs by **removing VDD, VDDC, and VDDIO**. For simplicity, these transitions are not shown below.

The power states are listed here:

- **Off**: When no voltage is applied, Lepton is in the off state. In the off state, no camera functions are available.
- **Uninitialized**: In the uninitialized state, all voltage forms are applied, but Lepton has not yet been booted and is in an indeterminate state. It is not recommended to leave Lepton in this state as power is not optimized; it should instead be booted to the on-state (and then transitioned back to standby if imaging is not required).
- **On**: In the on state, all functions and interfaces are fully available.
- **Standby**: In the standby state, all voltage forms are applied, but power consumption is approximately 4 mW. In the standby state, no functions are available, but it is possible to transition to the on state via the start-up sequence defined in *Figure 7 on page 16*. The shutdown sequence shown in *Figure 7 on page 16* is the recommended transition back to the standby state. It is also possible to transition between standby and on states via software commands, as further defined in the software IDD.
- **Overtemp**: The overtemp state is automatically entered when the Lepton senses that its temperature has exceeded approximately 80 °C. Upon entering the overtemp state, Lepton enables a "shutdown imminent" status bit in the telemetry line and starts a 10-second counter. If the temperature of the Lepton falls below 80 °C before the counter times out, the "shutdown imminent" bit is cleared and the system transitions back to the on state. If the counter does time out, Lepton automatically transitions to the standby state.

Power sequencing is as shown in *Figure 7*.

Figure 7   Power Sequencing

Start-up Sequence
(from uninitialized to on and standby to on)

- De-assert PWR_DWN_L (should be high)
- Assert RESET_L (should be low)
- Enable MASTER_CLK
- Wait $\geq$ 5000 clk periods
- De-assert RESET_L
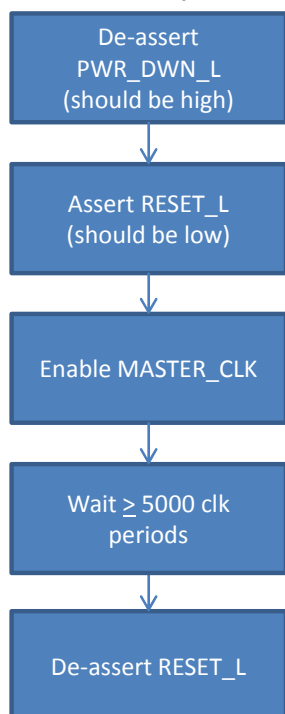
Shutdown Sequence
(from on to standby)
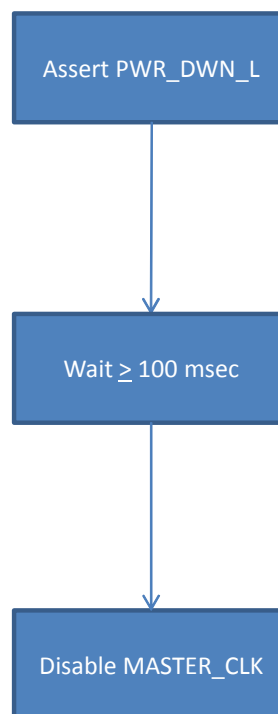
- Assert PWR_DWN_L
- Wait $\geq$ 100 msec
- Disable MASTER_CLK

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8.2   FFC States

Lepton is factory calibrated to produce an output image that is highly uniform, such as shown in *Figure 8* (a), when viewing a uniform-temperature scene. However, drift effects over long periods of time degrade uniformity, resulting in imagery which appears more grainy (*Figure 8* (b)) and/or blotchy (*Figure 8* (c)). Operation over a wide temperature range (for example, powering on at -10 °C and heating to 65 °C) will also have a detrimental effect on image quality.

For scenarios in which there is ample scene movement, such as most handheld applications, Lepton is capable of automatically compensating for drift effects using an internal algorithm called scene-based non-uniformity correction (scene-based NUC or SBNUC). However, for use cases in which the scene is essentially stationary, such as fixed-mount applications, scene-based NUC is less effective. In those applications, it is recommended 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 automatically recalibrated to produce the most optimal image quality. The sensor is briefly exposed to a uniform thermal scene, and the camera updates the NUC terms to ensure uniform output. The entire FFC process takes less than a second.

Figure 8   Examples of Good Uniformity, Graininess, and Blotchiness

(a) Highly uniform image

(b) Grainy image
(high-spatial frequency noise)

(c) Blotchy image
(low-spatial frequency noise)
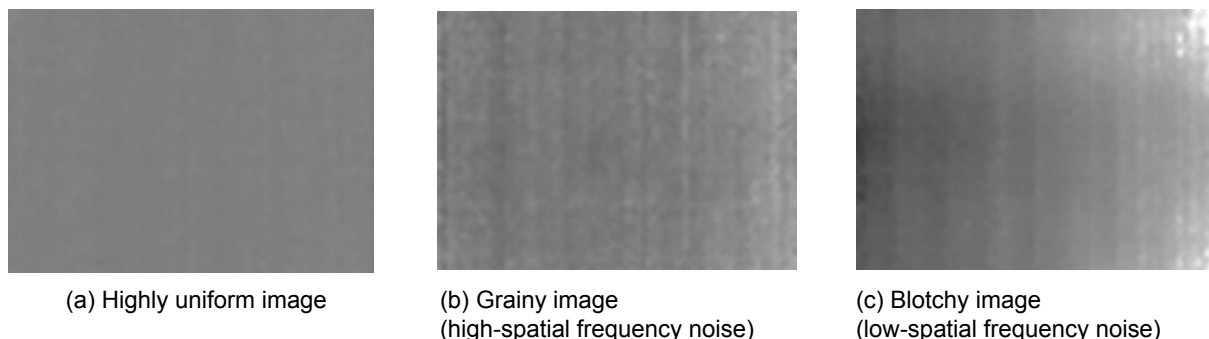
The current FFC state is provided through the telemetry line. There are three FFC states, as illustrated in *Figure 9 on page 18*:

1. **FFC not commanded** (default): In this state, Lepton applies by default a set of factory-generated FFC terms.

2. **FFC in progress**: Lepton enters this state when FFC is commanded. The default FFC duration is nominally 23 frames.

3. **FFC complete**: Lepton automatically enters this state whenever FFC is completed.

Lepton also provides an "FFC desired" flag in the telemetry line. The "FFC desired" flag is asserted at start-up, when a specified period (default = 3 minutes) has elapsed since the last FFC, or when the sensor temperature has changed by a specified value (default = 3 Celsius degrees) since the last FFC. The "FFC desired" flag is intended to indicate to the host to command an FFC at the next possible opportunity.
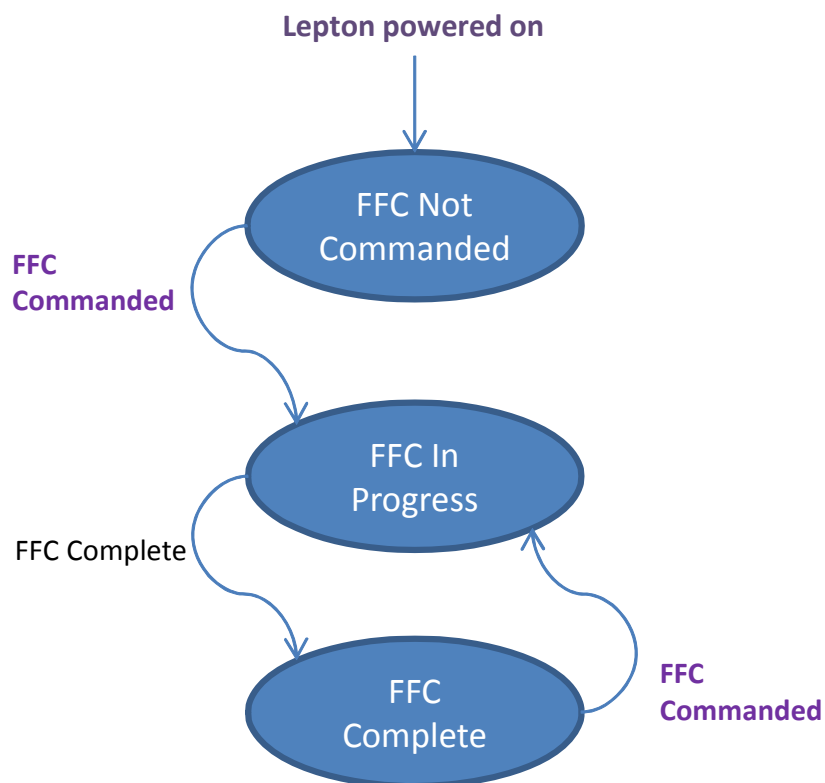
Figure 9   FFC States

8.3   Telemetry Modes

There are three telemetry modes that affect the video output signal:

- **Telemetry disabled** (default)
- **Telemetry as header**
- **Telemetry as footer**

Explicit commands over the CCI select each mode. The contents and encoding of the telemetry data are shown in *Table 3*. Note that the second and third lines (line B and line C) are reserved for future growth and contain no information at this time.

Table 3   Telemetry Data Content and Encoding

Telemetry Row	Word start	Word End	Number of 16-bit Words	Name	Notes
A	0	0	1	Telemetry Revision	Format = major (byte 1), minor rev (byte 0).
A	1	2	2	Time Counter	32 bit counter in units of msec elapsed since boot-up
A	3	4	2	Status Bits	See *Table 4 on page 21*
A	5	12	8	Module serial #	
A	13	16	4	Software revision	
A	17	19	4	Reserved	
A	20	21	2	Frame Counter	32-bit counter of output frames
A	22	22	1	Frame Mean	
A	23	23	1	FPA Temp	In counts (prior to conversion to Kelvin)
A	24	24	1	FPA Temp	In Kelvin x 100
A	25	25	1	Housing Temp	In counts (prior to conversion to Kelvin)

Table 3   Telemetry Data Content and Encoding *(continued)*

Telemetry Row	Word start	Word End	Number of 16-bit Words	Name	Notes
A	26	26	1	Housing Temp	In Kelvin x 100
A	27	28	2	Reserved	
A	29	29	1	FPA Temp at last FFC	Updated every FFC. Units are Kelvin x100
A	30	31	2	Time Counter at last FFC	Updated every FFC. Units are msec
A	32	32	1	Housing temp at last FFC	Updated every FFC. Units are Kelvin x100
A	33	33	1	Reserved	
A	34	37	4	AGC ROI	(top, left, bottom, right)
A	38	38	1	AGC Clip-Limit High	See *AGC, page 12*
A	39	39	1	AGC Clip-Limit Low	
A	40	73	34	Reserved	
A	74	74	1	Log2 of FFC frames	See *FFC States, page 17*
A	75	79	5	Reserved	
B	0	79	80	Reserved	
C	0	78	79	Reserved	

Table 4 shows the encoding of the status bits (Telemetry Row A, Words 3 and 4).

Table 4   Status Bit Encoding (Telemetry Row A, words 3 and 4)

Bit start	Bit end	Number of Bits	Name	Notes
0			Reserved	
3	3	1	FFC Desired[1]	0 = FFC not desired 1 = FFC desired
4	5	2	FFC State[1]	Telemetry Revision 8: 00 = FFC never commanded 01 = FFC in progress 10 = FFC complete 11 = undefined Telemetry Revision 9: 00 = FFC never commanded 01 = Reserved 10 = FFC in progress 11 = FFC complete
6	11	6	Reserved	
12	12	1	AGC State	0=Disabled 1=Enabled
13	19	7	Reserved	
20	20	1	Overtemp shut down imminent	Goes true 10 seconds before shutdown (see *Power States, page 13*)
21	31	11	Reserved	

Note(s)

1. See *FFC States, page 17*.

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8.4   Radiometry Modes

There are two radiometry modes that affect the video output signal:

■   **Radiometry disabled (default)**
■   **Radiometry enabled**

The radiometric modes affect the transfer function between incident flux (scene temperature) and pixel output. From an image-quality standpoint, both radiometry modes produce nearly identical performance (no change in NEDT), and either mode is appropriate for strict imaging applications. However, for applications in which it is intended to convert the Lepton output signal to one proportional to scene temperature, the radiometry-enabled mode is preferred because the conversion is constant over the full operating temperature range of the camera. Note that the following discussion assumes AGC is disabled (see *AGC Modes, page 25*). If AGC is enabled, the differences between the two radiometry modes are completely obscured by the AGC algorithm. In other words, with AGC enabled, any differences in signal output between radiometry-disabled and radiometry-enabled modes are negligible.

8.4.1   Radiometry Disabled

With radiometry disabled, the output of a given pixel is intended to be near the middle of the 14-bit range (~8192) when viewing a scene with a temperature equal to the temperature of the camera. Furthermore, the responsivity, which is defined as the change in pixel output value for a change in scene temperature, varies over the camera's operating temperature range. The resulting output for three different scene temperatures is illustrated hypothetically in *Figure 10* (note that the figure is for illustration purposes and not perfectly representative).
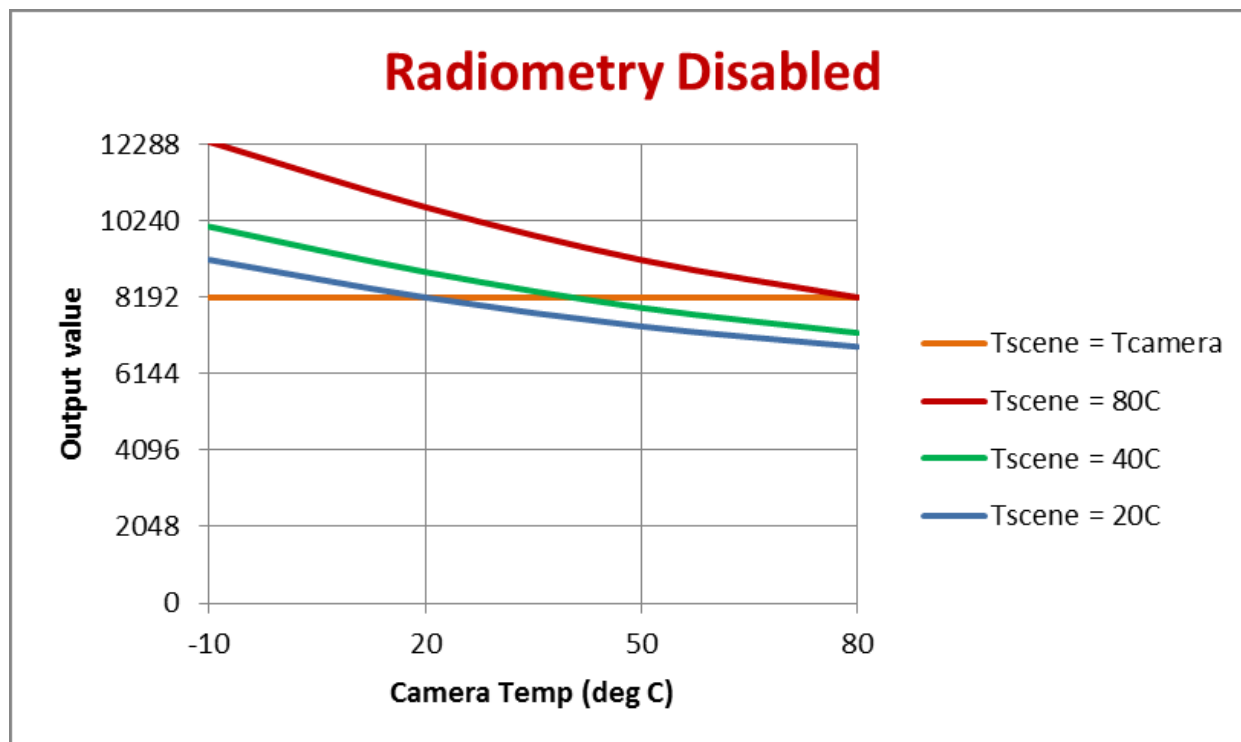
Figure 10   Hypothetical Illustration of Camera Output vs. Camera Temperature in Radiometry-disabled Mode

8.4.2   Radiometry Enabled

With radiometry enabled, Lepton performs internal adjustments to the signal level such that in principle the output is independent of the camera's own temperature. The resulting output for three different scene temperatures is illustrated hypothetically in *Figure 11*. Notice in *Figure 11* that the output is only a function of scene temperature, not camera temperature (again, the figure is for illustration purposes only and not perfectly representative. In practice, there is slight output variation as camera temperature changes, particularly when the temperature change is rapid). Also notice that responsivity is also independent of camera temperature; that is, the difference in output between two different scene temperatures is a constant, as opposed to in *Figure 10 on page 23*, where it decreases with increasing camera temperature.

Figure 11   Hypothetical Illustration of Camera Output vs. Camera Temperature in Radiometry-enabled Mode
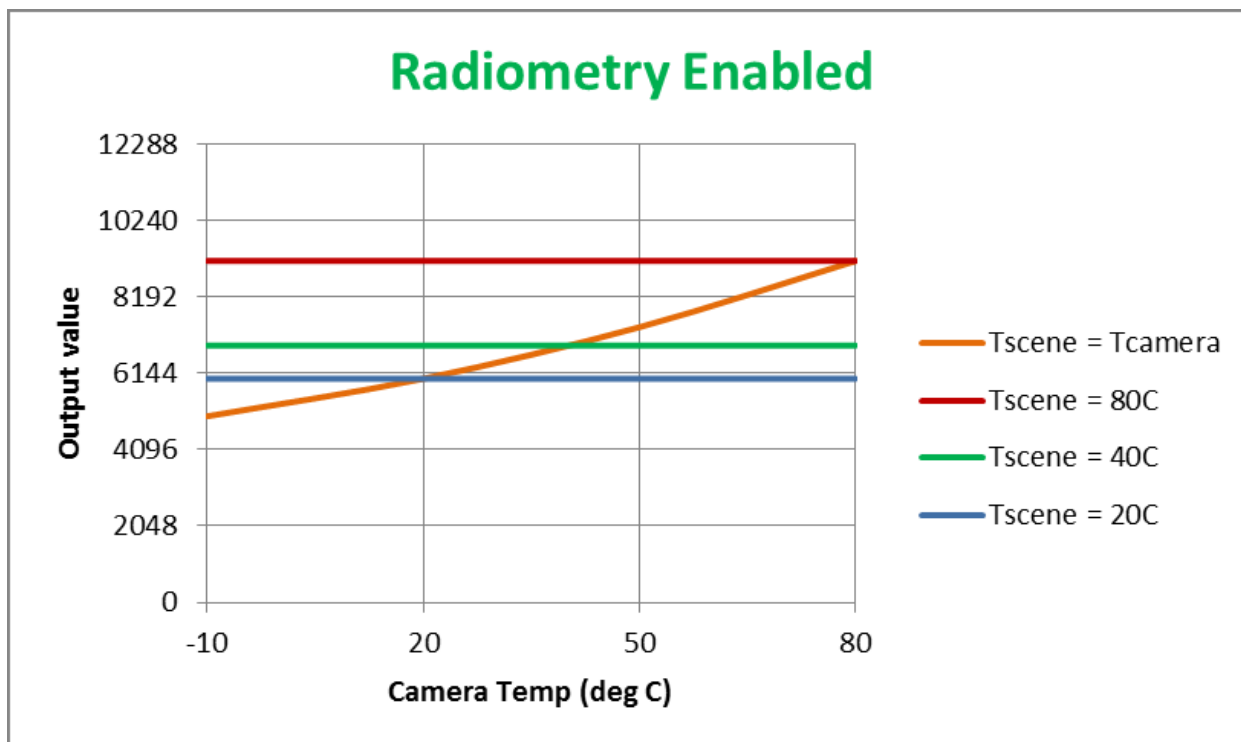
8.5   AGC Modes

There are two AGC modes:

- ■ **AGC disabled** (default)
- ■ **AGC enabled**

AGC is a process whereby the large dynamic range of the infrared sensor is collapsed to a range more appropriate for a display system. For Lepton, this is a 14-bit to 8-bit conversion. In its most simplistic form, AGC can be a linear mapping from 14-bit to 8-bit; however, a simple linear AGC is generally incapable of providing pleasing imagery in all imaging conditions. For example, when a scene includes both cold and hot regions (for example, a hot object in front of a cold background as illustrated in *Figure 13 on page 26*), linear AGC can produce an output image in which most pixels are mapped to either full black or full white with very little use of the grayshades (8-bit values) in between. Because of this limitation of linear AGC, a more sophisticated algorithm is preferred.

Similar to most AGC algorithms that optimize the use of grayshades, Lepton's is histogram-based. Essentially a histogram counts the number of pixels in each frame that have a given 14-bit value. *Figure 12 on page 25* illustrates the concept for a 3x3 pixel area.

Figure 12   Illustration of a Histogram for a 3x3 Pixel Area
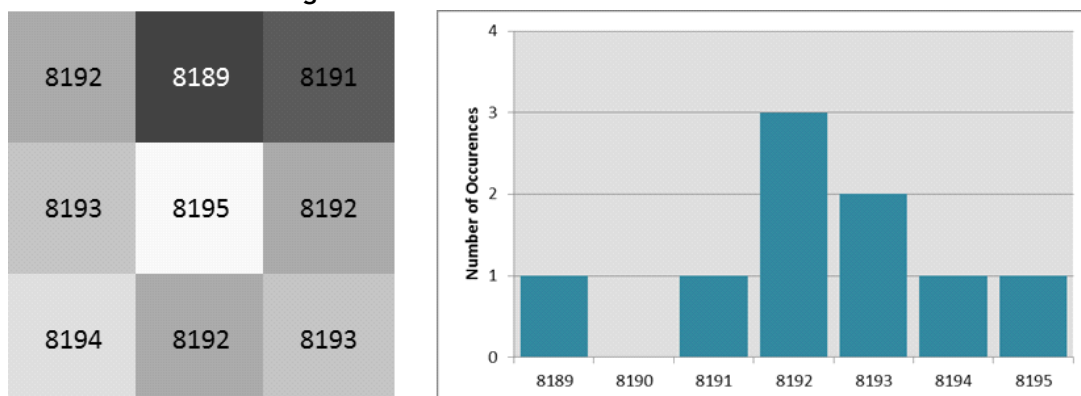
Classic histogram equalization uses the cumulative histogram as a mapping function between 14-bit and 8-bit. The intent is to devote the most grayshades to those portions of the input range occupied by the most pixels. For example, an image consisting of 60% sky devotes 60% of the available grayshades to the sky, leaving only 40% for the remainder of the image. By comparison, linear AGC "wastes" grayshades when there are gaps in the histogram, whereas classic histogram equalization allocates no grayshades to the gaps. This behavior is in principle an efficient use of the available grayshades, but there are a few drawbacks:

- ■ The resulting contrast between an object and a much colder (or hotter) background can be rendered poor by the fact the algorithm "collapses" the separation between such that the object is only 1 grayshade above the background. This phenomenon is illustrated in *Figure 13*.

■ Too much emphasis can be placed on background clutter, particularly when a mostly isothermal background comprises a large fraction of the total image area. This is also illustrated in *Figure 13*.

The Lepton AGC algorithm is a modified version of classic histogram equalization that mitigates these shortcomings. One such modification is a parameter called "clip limit high." It clips the maximum population of any single bin, limiting the influence of heavily populated bins on the mapping function. Another parameter utilized by the Lepton algorithm is called "clip limit low." It adds a constant value to every non-zero bin in the histogram, resulting in additional contrast between portions of the histogram separated by gaps. *Figure 13* is an example showing the benefit of the Lepton clip parameters.

Figure 13   Comparison of Linear AGC and Classic/Lepton Variant of Histogram Equalization

(a) Linear AGC   (b) Classic Histogram Equalization   (c) Lepton's Variant of Histogram Equalization
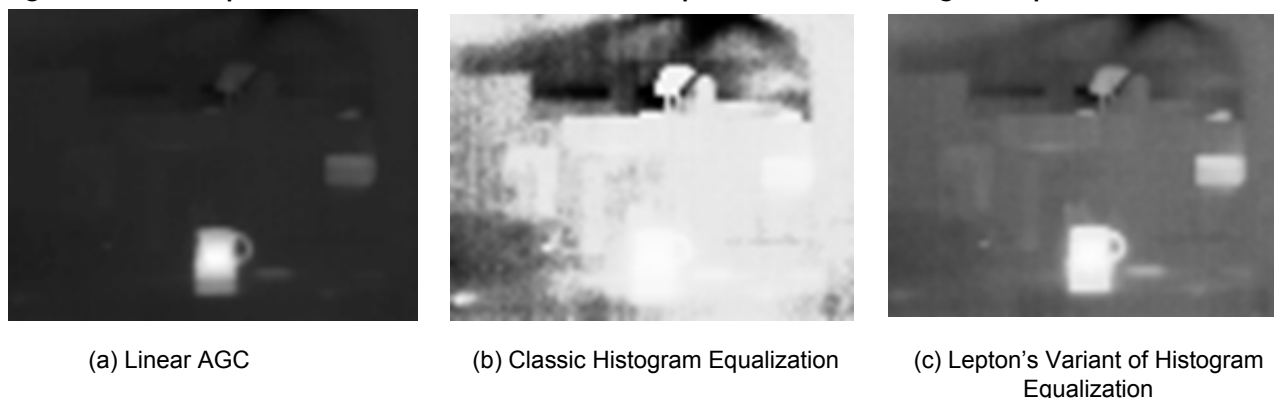
A high value of clip limit high results in a mapping more like classic histogram equalization, whereas a low value results in mapping more like linear AGC. For clip limit low, the opposite is true: a high value results in a mapping more like linear AGC, whereas a low value results in a mapping more like classic histogram equalization. The default values of both parameters produce a good compromise between the two; however, because optimum AGC is highly subjective and often application dependent, customers are encouraged to experiment to find settings most appropriate for the target application.

By default, the histogram used to generate Lepton's 14-bit to 8-bit mapping function is collected from the full array. In some applications, it is desirable to have the AGC algorithm ignore a portion of the scene when collecting the histogram. For example, in some applications it may be beneficial to optimize the display to a region of interest (ROI) in the central portion of the image. When the AGC ROI is set to a subset of the full image, any scene content located outside of the ROI is not included in the histogram and therefore does not affect the mapping function (note: this does not mean the portion outside of the ROI is not displayed or that AGC is not applied there, only that those portions outside the AGC ROI do not influence the mapping function).

9.0   Interface Descriptions

9.1   Command and Control Interface

Lepton provides a command and control interface (CCI) via a two-wire interface similar to I2C (the only difference relative to the true I2C standard is that all Lepton registers are 16 bits wide and consequently, only 16-bit transfers are allowed). The CCI address is 0x2A. The interface is described in detail in a separate document, the Lepton Software Interface Description Document (IDD), FLIR document #110-0144-03. Generally speaking, all commands issued through the CCI take the form of a "get" (reading data), a "set" (writing data), or a "run" (executing a function). *Table 5* shows a partial list of parameters / features controllable through the CCI.

Table 5   Partial List of Parameters Controllable through the CCI

Parameter	Power-On Default	Section in this document	Telemetry Line Location
AGC Mode	Disabled	*AGC Modes, page 25*	A3-4
AGC ROI	(0,0,79,59)	*AGC Modes, page 25*	A34-A37
AGC Dampening Factor	64	*AGC Modes, page 25*	A42
AGC Clip Limit High	4800	*AGC Modes, page 25*	A38
AGC Clip Limit Low	512	*AGC Modes, page 25*	A39
SYS Telemetry Mode	Disabled	*Telemetry Modes, page 19*	n/a
SYS Telemetry Location	Footer	*Telemetry Modes, page 19*	n/a
SYS Number of Frames to Average	8	*FFC States, page 17*	A74
VID Color LUT Select	Fusion	*Interface Descriptions, page 27*	n/a
VID User Color LUT Upload/Download	n/a	*Interface Descriptions, page 27*	n/a

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9.2   VoSPI Channel

The Lepton VoSPI protocol allows efficient and verifiable transfer of video over a SPI channel. The protocol is packet-based with no embedded timing signals and no requirement for flow control. The host (master) initiates all transactions and controls the clock speed. Data can be pulled from the Lepton (the slave) at a flexible rate. This flexibility is depicted in *Figure 14*, which shows the use of a relatively slow clock utilizing most of the available frame period as well as the use of a fast clock that bursts frame data. Once all data for a given frame is read, the master has the option to stop the clock and/or deassert the chip select until the next available frame. Alternatively, the master can simply leave the clock and chip select enabled, in which case Lepton transmits discard packets until the next valid video data is available.

Figure 14   VoSPI Flexible Clock Rate
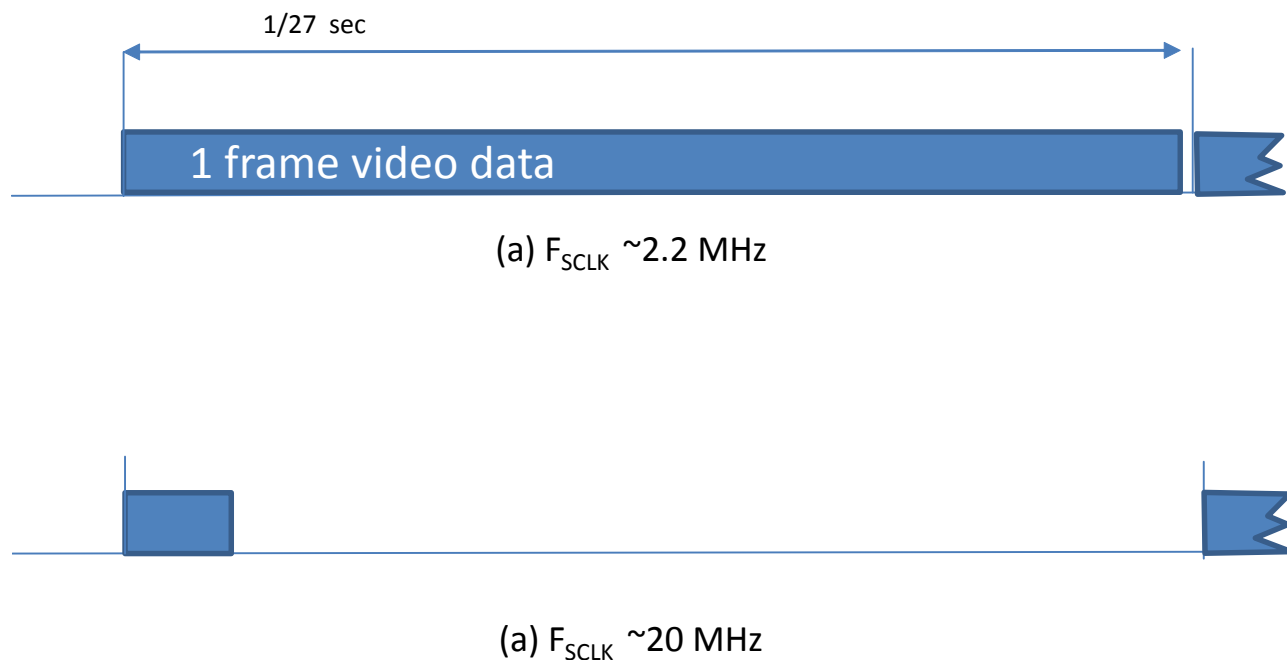
1/27 sec

1 frame video data

(a) F_{SCLK} ~2.2 MHz

(a) F_{SCLK} ~20 MHz

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9.2.1   VoSPI Physical Interface

As illustrated in *Figure 15*, VoSPI utilizes 3 of the 4 lines of a typical SPI channel:

- ■   SCK (Serial Clock)
- ■   /CS (Chip Select, active low),
- ■   MISO (Master In/Slave Out).

Figure 15   VoSPI I/O
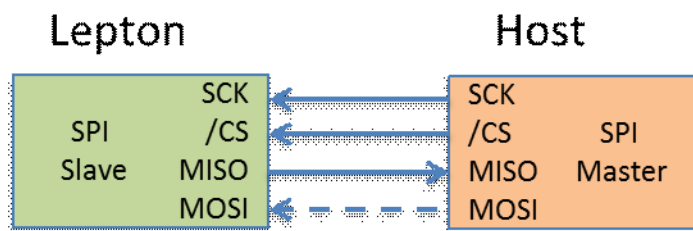
The MOSI (Master Out/Slave In) signal is not currently employed and should be grounded. Implementations are restricted to a single master and single slave. The Lepton uses SPI Mode 3 (CPOL=1, CPHA=1); SCK is HIGH when idle. Data is set up by the Lepton on the falling edge of SCK and should be sampled by the host controller on the rising edge. See *Figure 16*. Data is transferred most-significant byte first and in big-endian order. *Figure 17* provides an example of the transmission of the value 0x8C08.
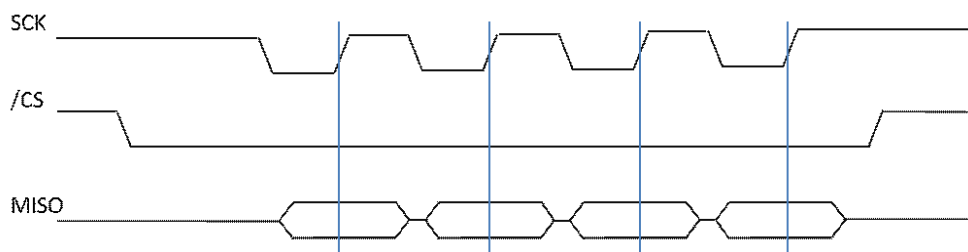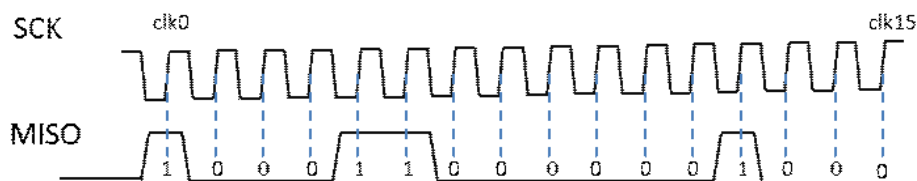
Figure 16   SPI Mode 3 (CPOL=1, CPHA=1)

Figure 17   SPI Bit Order (transmission of 0x8C08)

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The maximum clock rate is 20 MHz. The minimum clock rate is a function of the number of bits of data per frame that need to be retrieved. As described in the sections that follow, the number of bits of data varies depending upon user settings (video format mode, telemetry mode). For default conditions (Raw14 mode, telemetry disabled), there are 60 video packets per frame, each 1312 bits long, at approximately 25.9 frames per second. Therefore, the minimum rate is on the order of 2 MHz.

9.2.2   VoSPI Protocol

VoSPI is built on a collection of object types as defined hierarchically below.

- **VoSPI Packet**: The Lepton VoSPI protocol is based on a single standardized VoSPI packet, the minimum "transaction" between master and slave. Each video packet contains data for a single video line or telemetry line. In addition to video packets, the VoSPI protocol includes discard packets that are provided when no video packets are available.
- **VoSPI Frame**: A VoSPI frame is defined as a continuous sequence of VoSPI packets consisting of a full frame's worth of pixel data.
- **VoSPI Stream**: A VoSPI stream is defined as a continuous sequence of VoSPI frames.

As summarized in *Table 6 on page 30*, the number of packets per frame varies depending upon telemetry mode.

Table 6   Packet Length and Number of Video Packets per Frame as a Function of User Settings

Video Format Mode	Telemetry Mode	
	Telemetry Disabled	Telemetry Enabled
Raw14	Video packets per frame: 60	Video packets per frame: 63

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9.2.2.1 VoSPI Packets

As depicted in *Figure 18*, each packet contains a 4-byte header followed by a 160-byte payload.

Figure 18   **Generic VoSPI Packet**

ID	CRC	Payload
4 bytes		160 bytes

For video packets, the header includes a 2-byte ID and a 2-byte CRC. The ID field is a 12-bit packet number as shown in *Figure 19* (the leading 4 bits of the ID field are reserved and are not part of the packet number). Note that packet numbering restarts at zero on each new frame. The CRC portion of the packet header contains a 16-bit cyclic redundancy check (CRC), computed using the following polynomial:

$$x^{16} + x^{12} + x^5 + x^0$$

The CRC is calculated over the entire packet, including the ID and CRC fields. However, the four most-significant bits of the ID and all sixteen bits of the CRC are set to zero for calculation of the CRC. There is no requirement for the host to verify the CRC. However, if the host does find a CRC mismatch, it is recommended to re-synchronize the VoSPI stream to prevent potential misalignment.

Figure 19   **Video Packet**

ID	CRC	Payload
xNNN (16 bits)	CRC (16 bits)	Video pixels for one video line

At the beginning of SPI video transmission until synchronization is achieved (see *VoSPI Stream, page 33*) and also in the idle period between frames, Lepton transmits discard packets until it has a new frame from its imaging pipeline. As shown in *Figure 20*, the 2-byte ID field for discard packets is always xFxx (where 'x' signifies a "don't care" condition). Note that VoSPI-enabled cameras do not have vertical resolution approaching 3840 lines (0xF00), and therefore it is never possible for the ID field in a discard packet to be mistaken for a video line.

Figure 20   **Discard Packet**

ID	CRC	Payload
xFxx	xxxx	Discard data (same number of bytes as video packets)

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The payload is 160 bytes long. Excluding telemetry lines[1], each packet contains pixel data for all 80 pixels in a single video line (with AGC disabled, the first two bits of each pixel's two-byte word are always set to 0; if AGC is enabled, the first eight bits are set to 0).

This is illustrated in the following payload encoding figures.

Figure 21   Raw14 Mode: 1 video line per 160-byte payload

Byte 0	Byte 1	Byte 2	Byte 3	…	Byte 158	Byte 159
Line m Pixel 0		Line m Pixel 1		…	Line m Pixel 79	

9.2.2.2 VoSPI Frames

A single Lepton frame contains data from all 60 rows of the sensor. However, the total number of video packets is not necessarily 60; the exact number depends upon user settings, specifically the telemetry mode (disabled, as header, or as footer). *Table 7* shows the number of packets per frame and the contents of each packet for all of the various combinations.

Table 7   Video Packet Contents Per Frame as a Function of Video Format and Telemetry-mode Settings

Telemetry Mode	Configuration		
	As header	As footer	Disabled
Packet 0	Telemetry line A	FPA Row 0	FPA Row 0
Packet 1	Telemetry line B	FPA Row 1	FPA Row 1
Packet 2	Telemetry line C	FPA Row 2	FPA Row 2
Packet 3	FPA Row 0	FPA Row 3	FPA Row 3
…	…	…	…
Packet 29	FPA Row 26	FPA Row 29	FPA Row 29
Packet 30	FPA Row 27	FPA Row 30	FPA Row 30
Packet 31	FPA Row 28	FPA Row 31	FPA Row 31
Packet 32	FPA Row 29	FPA Row 32	FPA Row 32

Note(s)

1. See *Telemetry Modes, page 19* for payload contents of the telemetry lines

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Table 7   Video Packet Contents Per Frame as a Function of Video Format and Telemetry-mode Settings

	Configuration		
...	…	…	…
Packet 59	FPA Row 56	FPA Row 59	FPA Row 59
Packet 60	FPA Row 57	Telemetry line A	n/a
Packet 61	FPA Row 58	Telemetry line B	n/a
Packet 63	FPA Row 59	Telemetry line C	n/a

9.2.2.3 VoSPI Stream

A VoSPI stream is simply a continuous sequence of VoSPI frames following a synchronization event. Provided that synchronization is maintained, a VoSPI stream can continue indefinitely. Note that the frame rate of the stream is nominally just below 27 Hz, allowing easy interface to a display system without the need for host-side frame buffering. However, the rate of *unique* frames is just below 9 Hz to comply with US export restrictions. For each unique frame, two duplicates follow in the VoSPI stream. This pattern is illustrated in *Figure 22*, with unique frames shown in blue and duplicates shown in gray. In some applications, it might be beneficial to identify the first of the three identical frames (the frame with the least latency). The 32-bit frame counter provided in the telemetry lines (see *Telemetry Modes, page 19*) can be used for this purpose. It only increments on new frames, which is also illustrated in *Figure 22*.

Figure 22   Frame Counter for Successive Frames
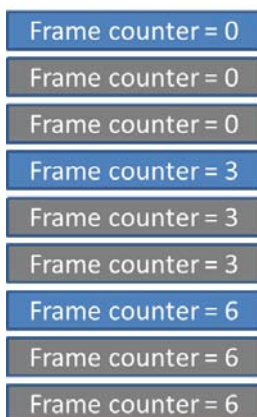
> **NOTE:** Blue frames are different than the previous frames, gray frames are identical to the previous blue frame.

9.2.2.3.1 Establishing/Re-Establishing Sync

The basic process for establishing synchronization is listed below:

- Deassert /CS and idle SCK for at least 5 frame periods (>185 msec). This step ensures a timeout of the VoSPI interface, which puts the Lepton in the proper state to establish (or re-establish) synchronization.
- Assert /CS and enable SCLK. This action causes the Lepton to start transmission of a first packet.
- Examine the ID field of the packet, identifying a discard packet. Read out the entire packet.
- Continue reading packets. When a new frame is available (should be less than 39 msec after asserting /CS and reading the first packet), the first video packet will be transmitted. The master and slave are now synchronized.

9.2.2.3.2 Maintaining Sync

There are three main violations that can result in a loss of synchronization:

- Intra-packet timeout. Once a packet starts, it must be completely clocked out within 3 line periods. Provided that VoSPI clock rate is appropriately selected and that /CS is not de-asserted (or SCLK disrupted) in the midst of the packet transfer, an intra-packet timeout is an unexpected event.
- Failing to read out all packets for a given frame before the next frame is available. Two examples of this violation are shown in *Figure 24* and *Figure 25 on page 35*. Note that the vertical blue line shown in the illustrations represents an internal frame-sync signal that indicates a new frame is ready for read-out.
- Failing to read out all available frames. This violation is depicted in *Figure 26 on page 35*. Note that the requirement to read out all frames applies to both the unique and the duplicate frames.

A CRC error does not result in an automatic loss of synchronization. However, as mentioned previously, it is recommended to intentionally re-synchronize (de-assert /CS for >185 msec) following a CRC error.

The following figures are examples of violations that result in a loss of synchronization.

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Figure 23   Valid Frame Timing (no loss of synchronization)
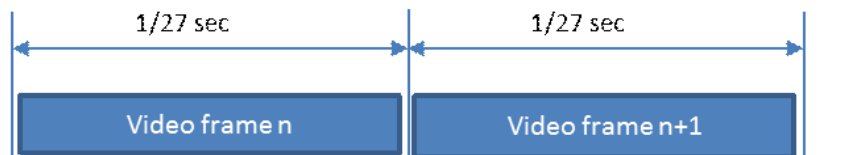

Figure 24   Clock Too Slow - Failure to Read an Entire Frame Within the Frame Period

Figure 25   Intra-frame Delay Too Long - Failure to Read Out an Entire Frame Before the Next is Available
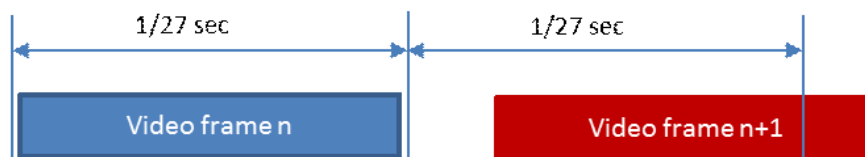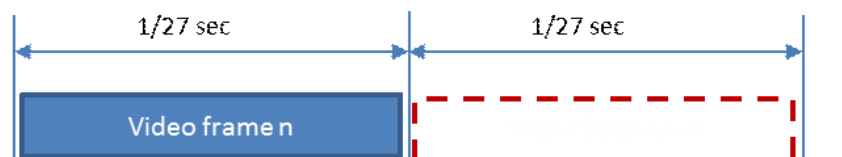

Figure 26   Failure to Read Out an Available Frame

9.3   MIPI Interface

An optional MIPI interface will be supplied in a later release of Lepton.

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10.0 Thermal Camera Basics

It is noteworthy that the integration period for a thermal detector does not have the same impact on image formation as it does for a photon detector, such as a typical CMOS array. A photon detector converts incoming photons to electrons with near-instantaneous response time but only collects information from the scene during the integration period. In other words, high-speed phenomena (such as a strobed signal) can be missed entirely if the resulting photons are incident at a point in time when the detector is not integrating. A thermal detector, on the other hand, is always changing temperature in response to incident radiation. That is to say, it is always "active" regardless of whether or not it is being actively integrated. The integration period only refers to the time that resistance is being sensed by integration of current, not the time the sensor is actively responding to irradiance from the scene. The ability to detect high-speed phenomena is more a function of the detector's thermal time constant, which governs the rate of temperature change. For Lepton, the detector time constant is on the order of 12 msec, which means that an instantaneous irradiance change will result in a temperature change of the detector as shown in *Figure 27*.

Figure 27   Illustration of Lepton Detector Time Constant
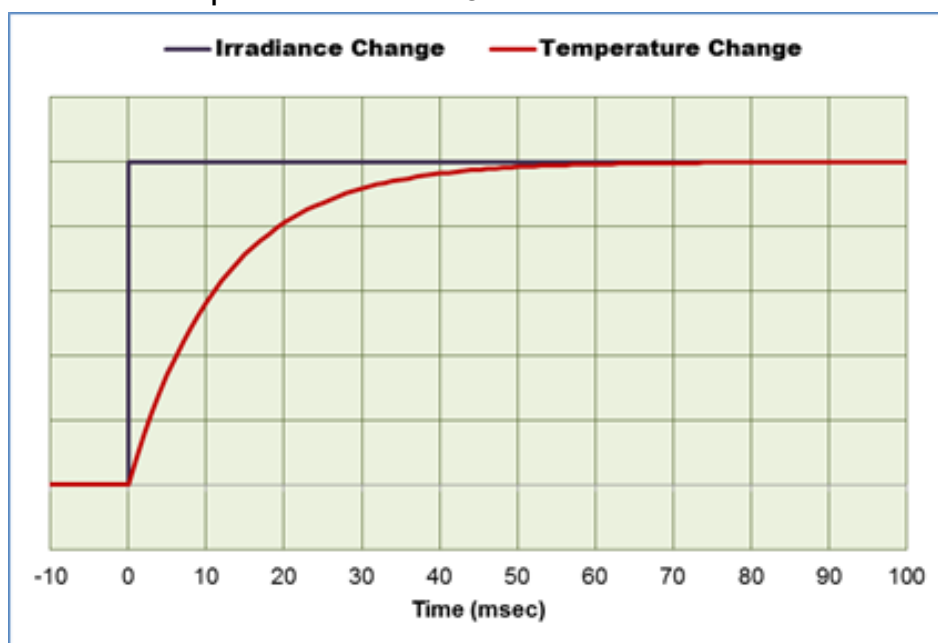
In addition to integrating signal current, the ROIC also digitizes and multiplexes the signal from each detector into a serial stream. And the Lepton ROIC digitizes data from an on-chip temperature sensor as well as a thermistor attached to the camera housing. An anti-reflection (AR) coated window is bonded above the sensor array via a wafer-level packaging (WLP) process, encapsulating the array in a vacuum. The purpose of the vacuum is to provide high thermal resistance between the microbolometer elements and the ROIC substrate, allowing for maximum temperature change in response to incident radiation.

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11.0 Mounting Specifications

The Lepton camera mounting dimensions are shown in *Figure 28*.

Figure 28   Lepton Camera Mounting Dimensions
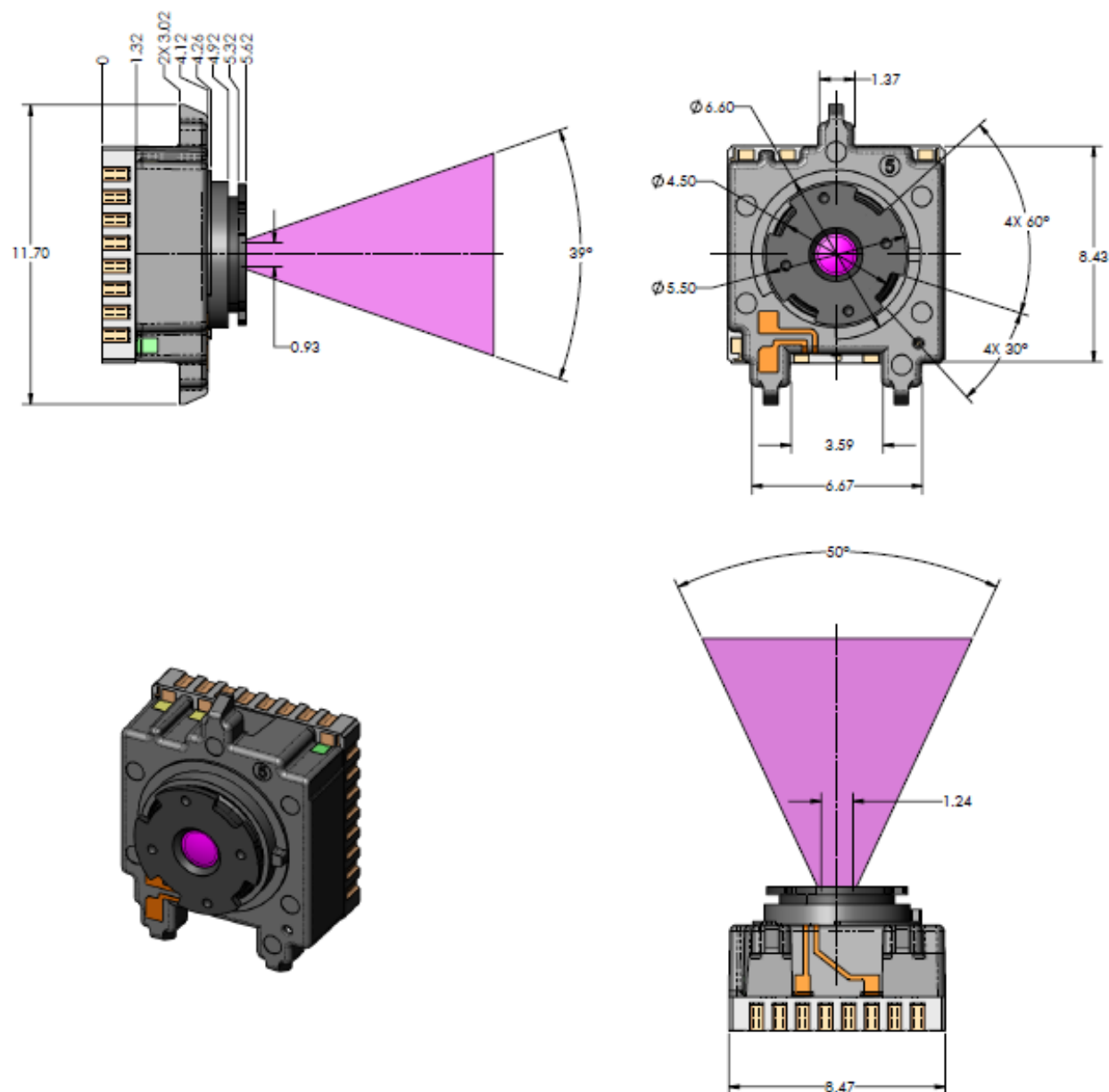
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11.1 Socket Information

The Lepton module is compatible with two commercially-available sockets, Molex 1052028-1001 and Molex 105028-2011, illustrated in *Figure 29* below. The former makes electrical contact on the upper surface of a printed circuit board, the latter to the lower surface (with a cutout in the board that allows the socket to pass through). *Figure 30* depicts both socket configurations mounted on a PCB.

Figure 29   Two Commercially-available Sockets (both from Molex) Compatible with Lepton
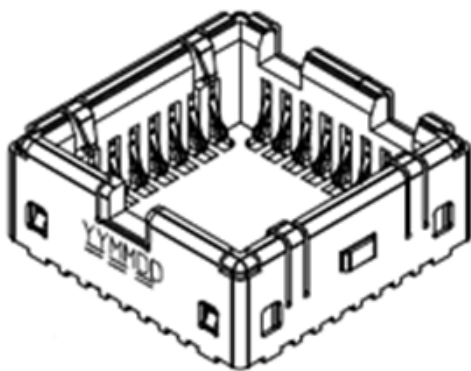
105028-1001   105028-2011
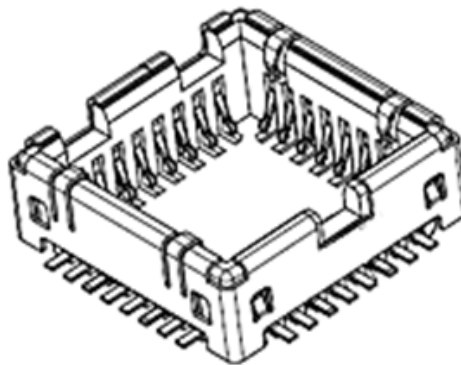
Figure 30   Both Sockets Mounted on a PCB
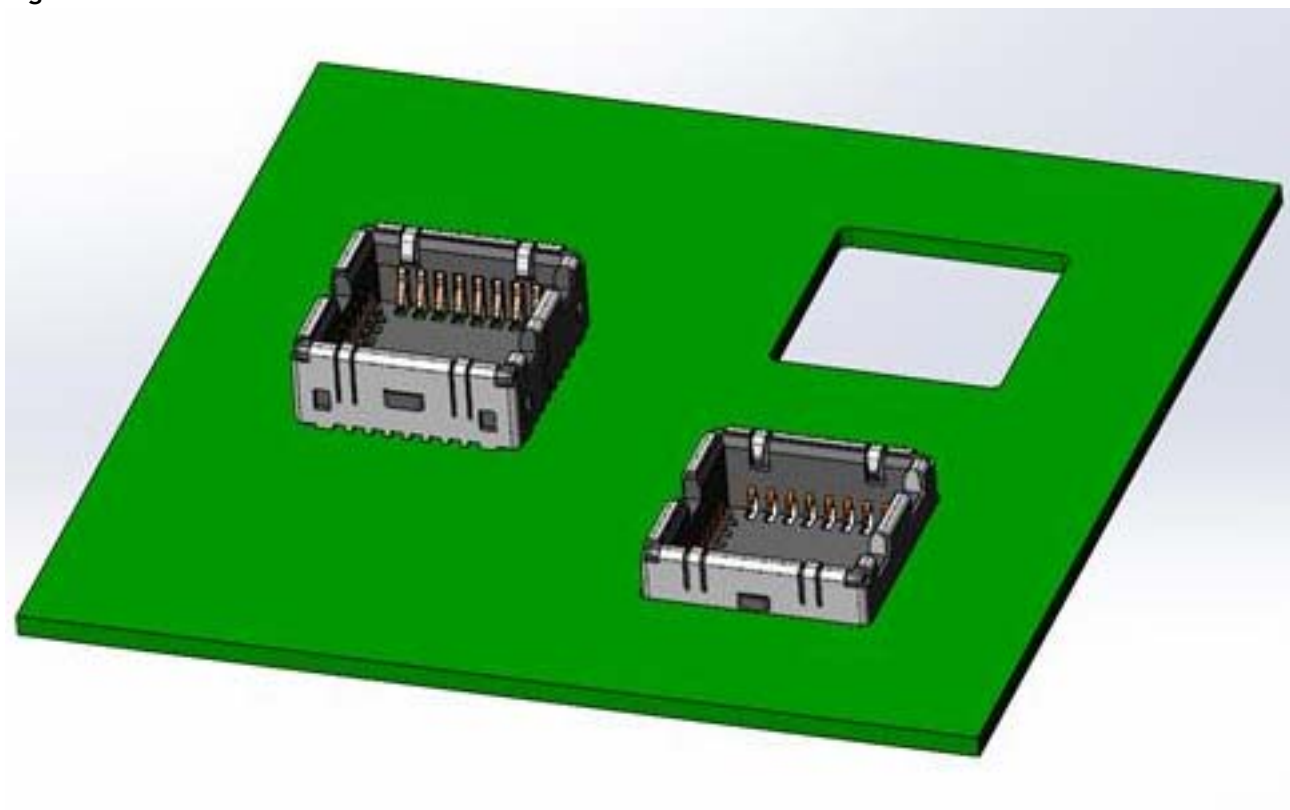
11.2 Mechanical Considerations

The socket is not intended to retain the Lepton assembly under high-shock conditions. It is recommended to incorporate front-side retention such as illustrated in *Figure 31*.

Figure 31   Recommended Approach to Retaining Lepton in the end Application
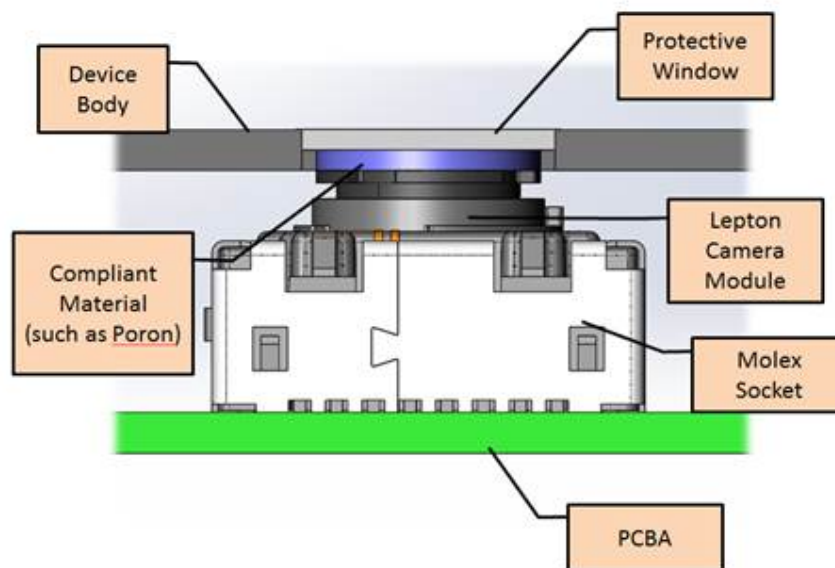
The Lepton camera is not a sealed assembly. Consequently, for most applications it is recommended to locate the assembly behind a sealed protective window. Common materials for LWIR windows include silicon, germanium, and zinc selenide (LWIR absorption in silicon is on the order of 15%/mm, which means NEDT is adversely affected using a silicon window. Bulk absorption in germanium and zinc selenide is negligible, and performance is essentially unchanged provided both surfaces of the window are anti-reflection (AR) coated.) Note that the window should be sized large enough to avoid encroaching upon the optical keepout zone (see *Optical Considerations, page 41*).

11.3 Thermal Considerations

It is important to minimize any temperature gradient across the camera. The sensor should be mounted in such a fashion so as to isolate it from heat loads such as electronics, heaters, and non-symmetric external heating.

The surrounding area must be able to support and withstand the dissipation of up to 160 mW of heat by the camera.

11.4 Optical Considerations

The optical keepout zone is shown in *Figure 32*. To avoid mechanical vignetting, do not impinge upon the keepout zone

Figure 32   Optical Keepout Zone
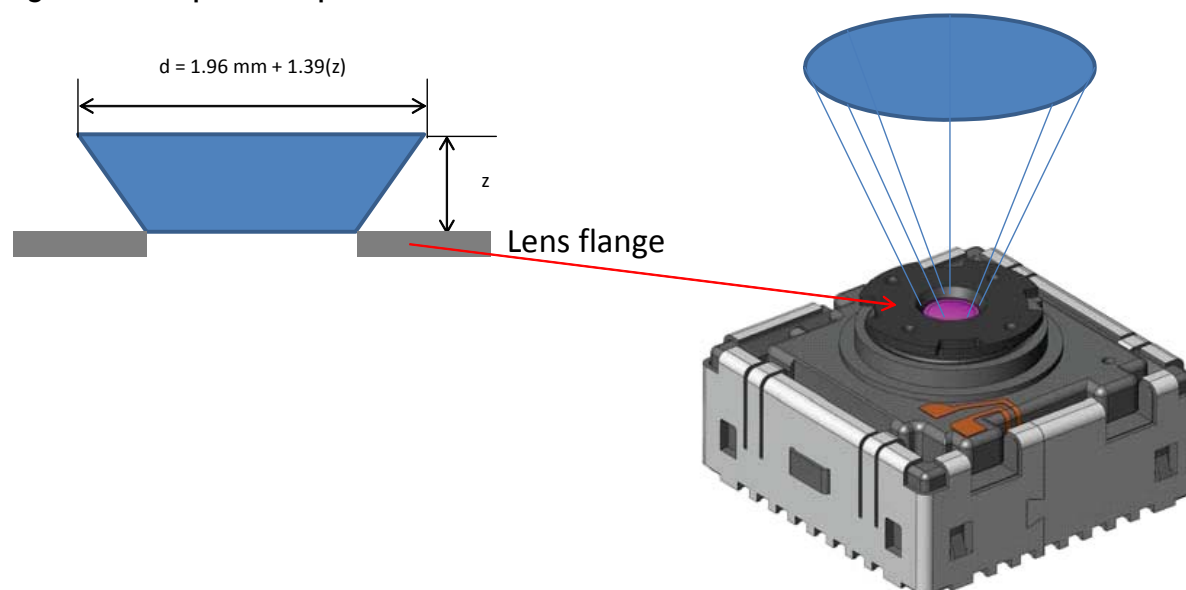
d = 1.96 mm + 1.39(z)

z

Lens flange

12.0 Image Characteristics

The information given in *Table 8* applies across the full operating temperature range.

Table 8 Image Characteristics

Parameter	Description	Value
NETD	Noise Equivalent Temperature Difference (random temporal noise)	<50 mK (20 mK typical)
Intrascene Range	Minimum and maximum scene temperature	0 K to >400 K
Operability	Number of non-defective pixels	>99.0% (<1 defect typical)
Clusters	Number of adjacent defective pixels "Adjacent" means any of the 8 nearest neighbors (or nearest 5 for an edge pixel, nearest 3 for a corner).	Unallowed[1]

Note(s)

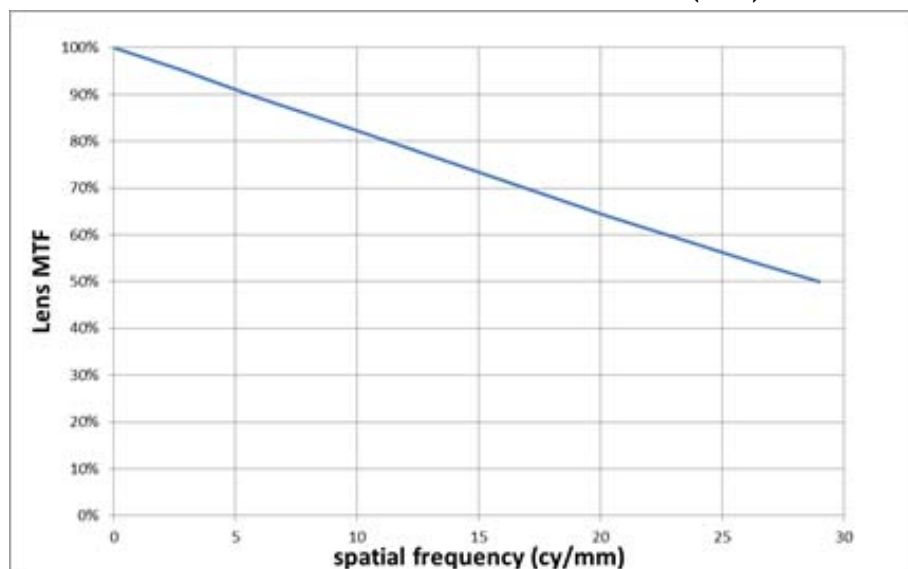1. : Only single-pixel defects are allowed (no clusters)

The nominal curve of on-axis modulation transfer function (MTF) for the Lepton lens assembly is shown for reference in *Figure 33*.

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Figure 33   Nominal Curve of On-axis Modulation Transfer Function (MTF)

13.0 Spectral Response

For reference, *Figure 34* depicts the spectral response of the Lepton camera

Figure 34   Normalized Response as a Function of Signal Wavelength
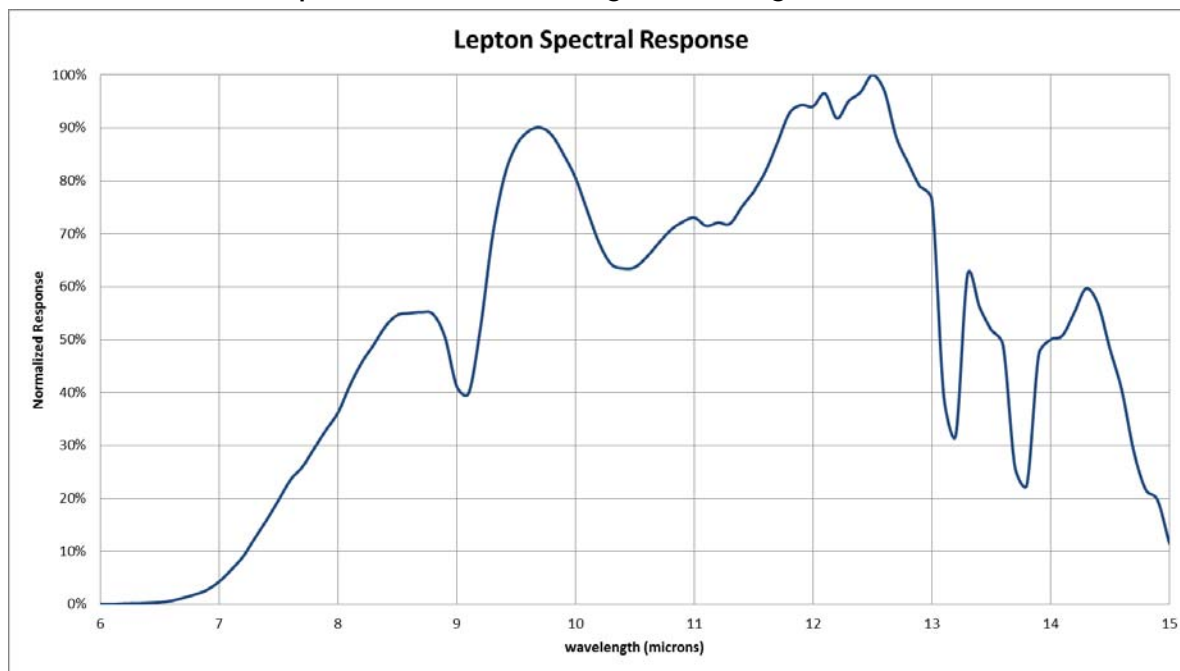
14.0 Electrical Specifications

14.1 DC and Logic Level Specifications

Table 9 DC and Logic Levels

Symbol	Parameter	Min	Typ	Max	Units
VDDC	Core Voltage (primary power for the Lepton internal ASIC)	1.14	1.20	1.26	Volts
VDD	Sensor Voltage (primary power for the Lepton internal sensor chip)	2.72	2.80	2.88	Volts
VDDIO	I/O Voltage (primary power for the Lepton I/O ring)	2.5	—	3.1	Volts
I_DDC	Supply current for core (VDDC)	76	84	110	mA
I_DD	Supply current for sensor (VDD)	12	14	16[1]	mA
I_DDIO	Supply current for I/O ring (VDDIO)	1	2	4	mA

Note(s)

1. Maximum at 65 degrees C

14.2 AC Electrical Characteristics

Table 10 AC Electrical Characteristics

Parameter	Min	Typ	Max	Units
MASTER_CLK, F_{clk}	TBD	25 MHz	TBD	Master clock rate
MASTER_CLK, $F_{clk\ duty}$	45%	50%	55%	Master clock duty cycle
MASTER_CLK, t_r	--	--	TBD	Clock rise time (10% to 90%)
MASTER_CLK, t_f	--	--	TBD	Clock fall time (90% to 10%)
SPI_CLK, F_{clk}	See note[1]		20 MHz	VoSPI clock rate
SPI_CLK, $F_{clk\ duty}$	45%	50%	55%	SPI-clock duty cycle

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Table 10 AC Electrical Characteristics *(continued)*

Parameter	Min	Typ	Max	Units
SPI_CLK, t_r	--	--	TBD	SPI clock rise time (10% to 90%)
SPI_CLK, t_f	--	--	TBD	SPI clock fall time (90% to 10%)
SCL, F_{clk}			1 MHz	I2C clock rate
SCL, $F_{clk\ duty}$	45%	50%	55%	I2C-clock duty cycle
SCL_CLK, t_r	--	--	TBD	I2C clock rise time (10% to 90%)
SCL_CLK, t_f	--	--	TBD	I2C clock fall time (90% to 10%)

Note(s)

1. As described in *VoSPI Protocol, page 30*, the minimum VoSPI clock frequency is dependent upon the requirement to read out all video packets for a given frame within the frame period. The size and number of video packets vary with user settings.

15.0 Absolute Maximum Ratings

Electrical stresses beyond those listed in *Table 11* may cause permanent damage to the device. These are stress rating only, and functional operation of the device at these or any other conditions beyond those indicated under the recommended operating conditions listed in *Table 9 on page 45* is not implied. Exposure to absolute-maximum-rated conditions for extended periods of time may affect device reliability.

Table 11 Absolute Maximum Ratings

Parameter	Absolute Maximum Rating
Core Voltage (VDDC)	1.5 V
Sensor Voltage (VDD)	4.8 V
I/O Voltage (VDDIO)	4.8 V
Voltage on any I/O pin	4.8 V

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16.0 Environmental Specifications

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

Table 12 Environmental Specifications

Stress	Maximum Rating
Operating Temperature Range	-10° C to 65° C (-20° C to 75° C with some possible performance degradation)
Maximum Operating Temperature	80 °C[1]
Storage Temperature	-40° C to 80° C
Altitude (pressure)	12 km altitude equivalent
Relative Humidity	95%
Thermal Shock	Air-to-air across operating temp. extremes (-10° C to 65° C, 65° C to -10° C)
Mechanical Shock	1500 g, 0.4 msec
Vibration	Transportation profile, 4.3 grms
ESD	Human Body Model (HBM), 2kV Charged Device Model (CDM), 500V

Note(s)
1. Lepton contains an automatic shutdown feature when its internal temperature exceeds the maximum safe operating value. See *Power States, page 13*.

16.1 Compliance with Environmental Directives

Lepton complies with the following directives and regulations:

- Directive 2002/95/EC, "Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)"
- Directive 2002/96/ EC, "Waste Electrical and Electronic Equipment (WEEE)".
- Regulation (EC) 1907/2006, "Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)"

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17.0 Abbreviations and Acronyms

Abbreviation	Description
AGC	Automatic Gain Control
AR	Anti-reflection
CCI	Command and Control Interface
CRC	Cyclic Redundancy Check
DSP	Digital Signal Processor
EMC	Electromagnetic Compatibility
FFC	Flat Field Correction
FOV	Field of View
FPA	Focal Plane Array
FPN	Fixed Pattern Noise
GPIO	General Purpose IO
HFOV	Horizontal Field of View
I2C	Inter-Integrated Circuit
IDD	Interface Description Document
LWIR	Long Wave Infrared
MIPI	Mobile Industry Processor Interface
MISO	Maser In/Slave Out
MOSI	Master Out/Slave In
NEDT	Noise Equivalent Differential Temperature
NUC	Non-Uniformity Correction
OTP	One-Time Programmable
PLL	Phase-Lock Loop
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
RoHS	Reduction of Hazardous Substances

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ROIC	Readout Integrated Circuit
SBNUC	Scene-based Non-uniformity Correction
SNR	Signal to Noise Ratio
SoC	System on a Chip
SPI	Serial Peripheral Interface
SVP	Software-based Video Processing
TCR	Temperature Coefficient of Resistance
TWI	Two-wire Interface
VoSPI	Video Over SPI
VOx	Vanadium-oxide
WEEE	Waste Electrical and Electronic Equipment
WLP	Wafer-level Packaging

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If you have questions that are not covered in this manual, or need service, contact FLIR Commercial Systems Customer Support at 805.964.9797 for additional information prior to returning a camera.

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 fo1r 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.

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