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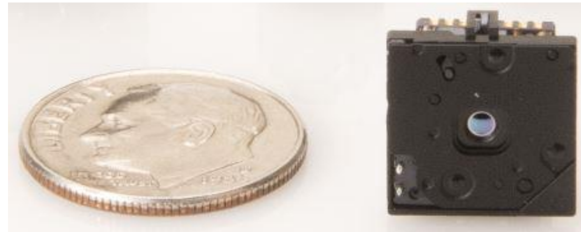
FLIR LEPTON® with Radiometry Datasheet

Document Number: 500-0763-01-09 Rev 110



General Description

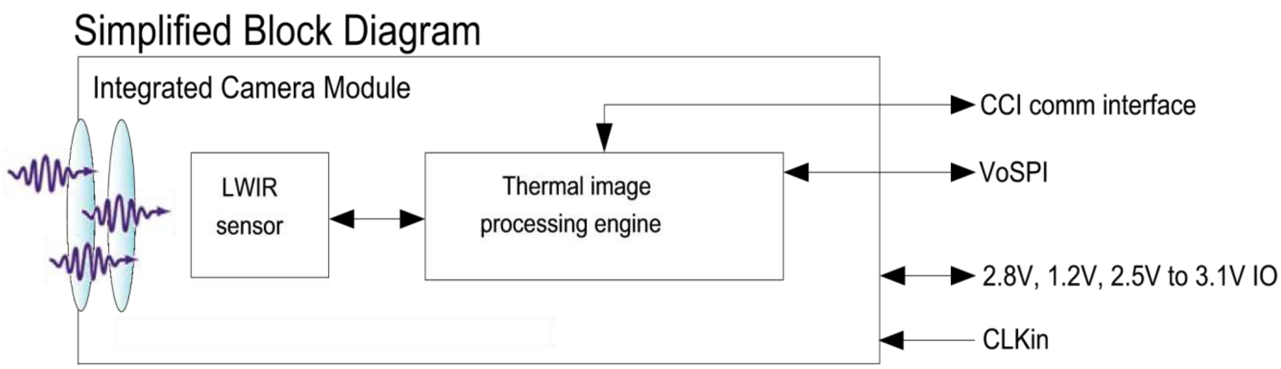
Lepton® with Radiometry is a complete long-wave infrared (LWIR) camera module designed to interface easily into native mobile-device interfaces and other consumer electronics. It captures infrared radiation input in its nominal response wavelength band (from 8 to 14 microns) and outputs a uniform thermal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

Features

- Integral shutter configuration:
  11.5 x 12.7 x 6.9 mm (without socket)
  11.8 x 12.7 x 7.2 mm (with socket)
- 50° HFOV, 60° 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
- Radiometric accuracy (35°C blackbody) greater of:
  - High gain: ±5C @ 25°C
  - Low gain ±10C @ 25°C
- Radiometry software features for temperature measurement including per pixel and frame radiometric output (Tlinear) and spotmeter
- Export compliant frame rate (< 9 Hz)
- SPI video interface
- Two-wire I2C serial control interface
- Uses standard cell-phone-compatible power supplies: 2.8 V to sensor, 1.2 V to digital core, and flexible IO from 2.8 V to 3.1 V
- Fast time to image (< 1.2 sec)
- Low operating power, nominally 150 mW to 160 mW over full temperature range)
- Low power shutdown mode (nominally 5 mW
- 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



Note: All specifications subject to change without notice

Contents

Table of Figures

Revision History

Revision	Date	Description of Change
100	05/03/2016	Lepton with Radiometry release
110	11/12/2016	Updates to include low gain mode feature details

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http://www.FLIR.com

References

Lepton Software Interface Description Document (IDD) - OEM. Document #110-0144-04

Lepton Advanced Radiometry Application Note, Document #102-PS245-75

Mechanical IDD, Document #500-0763-19

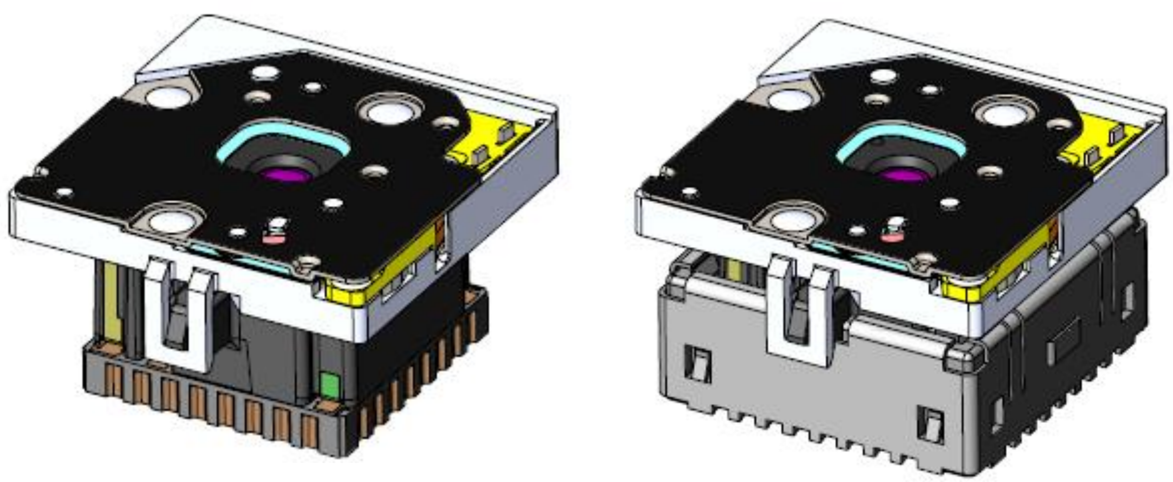
Lepton with Radiometry STEP file

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. A configuration is also provided with an integral shutter assembly that is used to automatically optimize image uniformity on a periodic basis. 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 with Radiometry camera as standalone and mounted in a socket.

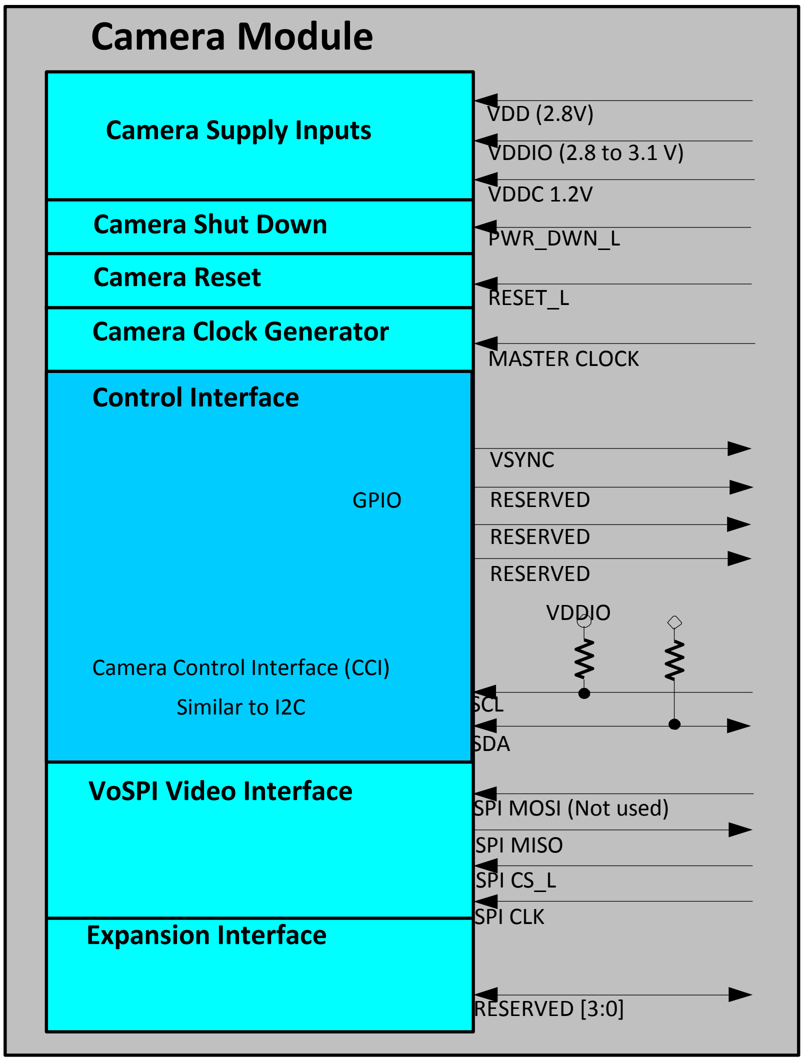
Figure 1- Lepton with Radiometry Camera (with and without socket)



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 contoller.

3.0 KEY SPECIFCATIONS

The key specifications of the Lepton camera module are listed in *Table 1*. See *Figure 3* 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 33*).
Radiometric accuracy	High Gain Mode: Greater of +/-5degC or 5% (typical) Low Gain Mode: Greater of +/-10degC or 10% (typical)
Intra-scene Range	High Gain Mode: -10°C to 140°C (typical) Low Gain Mode: -10°C to 450°C (typical)
Non-uniformity corrections	Shutterless, automatic (with scene motion) Shuttered configuration (for stationary applications)
FOV - horizontal	51°
FOV - diagonal	66°
Depth of field	10 cm to infinity
Lens type	f/1.1 silicon doublet
Optical distortion	9.7%
Output format	User-selectable 14-bit, 8-bit (AGC applied), or 24-bit RGB (AGC and colorization applied)
Solar protection	Integral
Electrical	
Input clock	25-MHz nominal, CMOS IO Voltage Levels (see **Master Clock, *page 19***)
Video data interface	Video over SPI (see **VoSPI Channel,** page *48*)
Control port	CCI (I2C-like), CMOS IO Voltage Levels (see **Command and Control Interface**, page *44*)

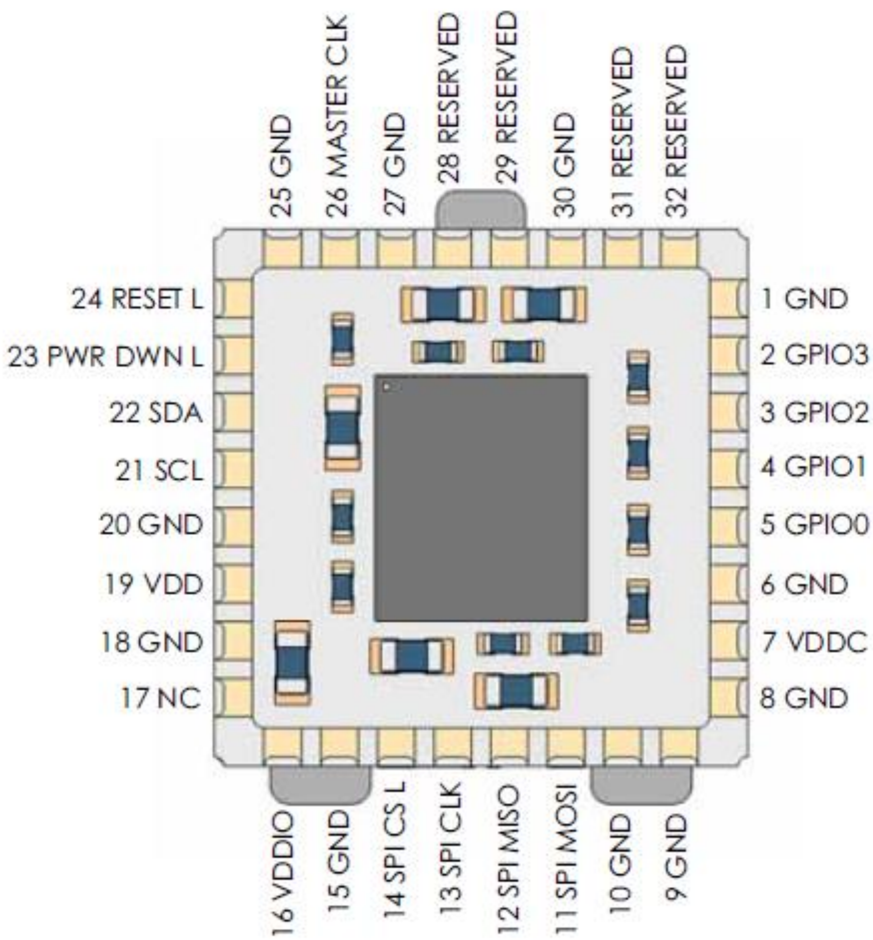
Input supply voltage (nominal)	2.8 V, 1.2 V, 2.8 V to 3.1 V IO (see **DC and Logic Level Specifications,** page *67*)
Power dissipation	Nominally 150 mW at room temperature (operating), 4 mW (shutdown mode)

Table 2- Key Specifications (cont.)

Specification	Description
Mechanical	
Package dimensions – socket version	Integral shutter: 11.8 x 12.7 x 7.2 mm (w × l × h)
Weight	Shuttered configuration: 0.90 grams (typical)
Environmental	
Optimum operating temperature range	-10 °C to +80 °C
Non-operating temperature range	-40 °C to +80 °C
Shock	1500 G @ 0.4 ms

4.0 Lepton Camera Module Pinout

Figure 3 - Pinout Diagram (viewed from bottom)



4.1 Pin Descriptions

The Lepton camera module pin descriptions are shown in *Table 3*.

Table 3 - 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/VSYNC	IN/OUT	VDDIO	Video output synchronization (see **GPIO Modes** page **43**)
3	GPIO2	IN/OUT	VDDIO	Reserved
4	GPIO1	IN/OUT	VDDIO	Reserved
5	GPIO0	IN/OUT	VDDIO	Reserved
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 **48**)
12	SPI_MISO	OUT	VDDIO	Video Over SPI Slave Data Out (see **VoSPI Channel** page **48**)
13	SPI_CLK	IN	VDDIO	Video Over SPI Slave Clock (see **VoSPI Channel** page **48**)
14	SPI_CS_L	IN	VDDIO	Video Over SPI Slave Chip Select, active low (see **VoSPI Channel** page **48**)

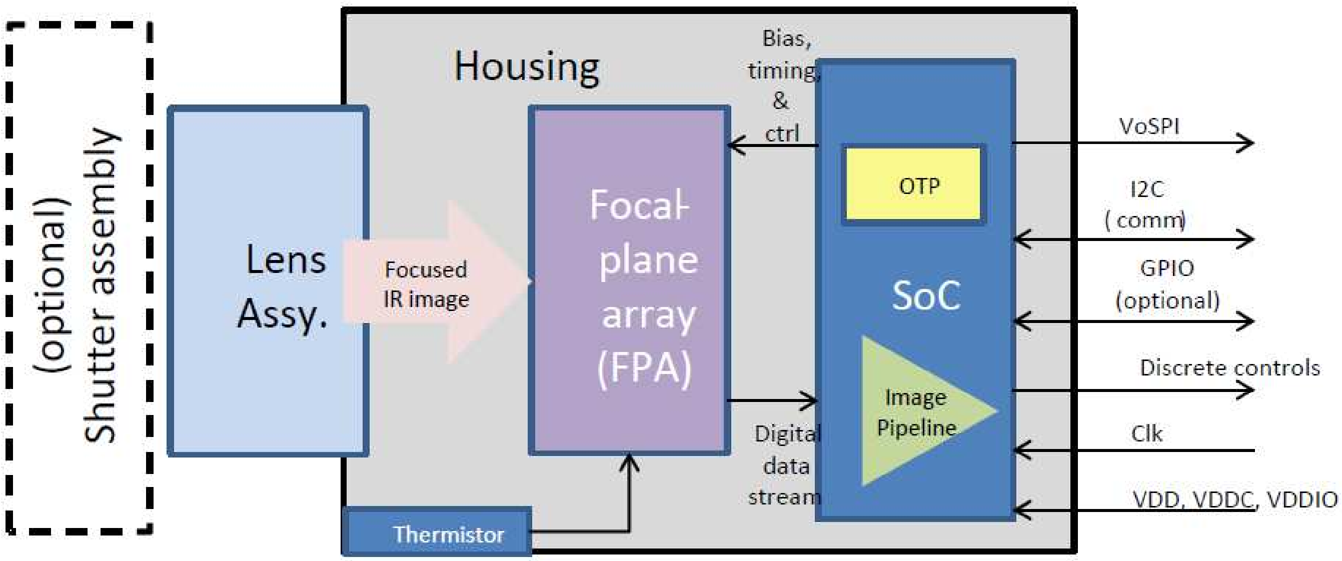
Table 4 - Lepton Camera Module Pin Descriptions (cont.)

Pin #	Pin Name	Signal Type	Signal Level	Description
16	VDDIO	Power	2.8 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 (see **Command and Control Interface**, page **44**)
22	SDA	IN/OUT	VDDIO	Camera Control Interface Data, I2C compatible (see **Command and Control Interface**, page ***44***)
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 **Master Clock**, page **19**)
28	RESERVED			
29	RESERVED			
31	RESERVED			
32	RESERVED			

5.0 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.

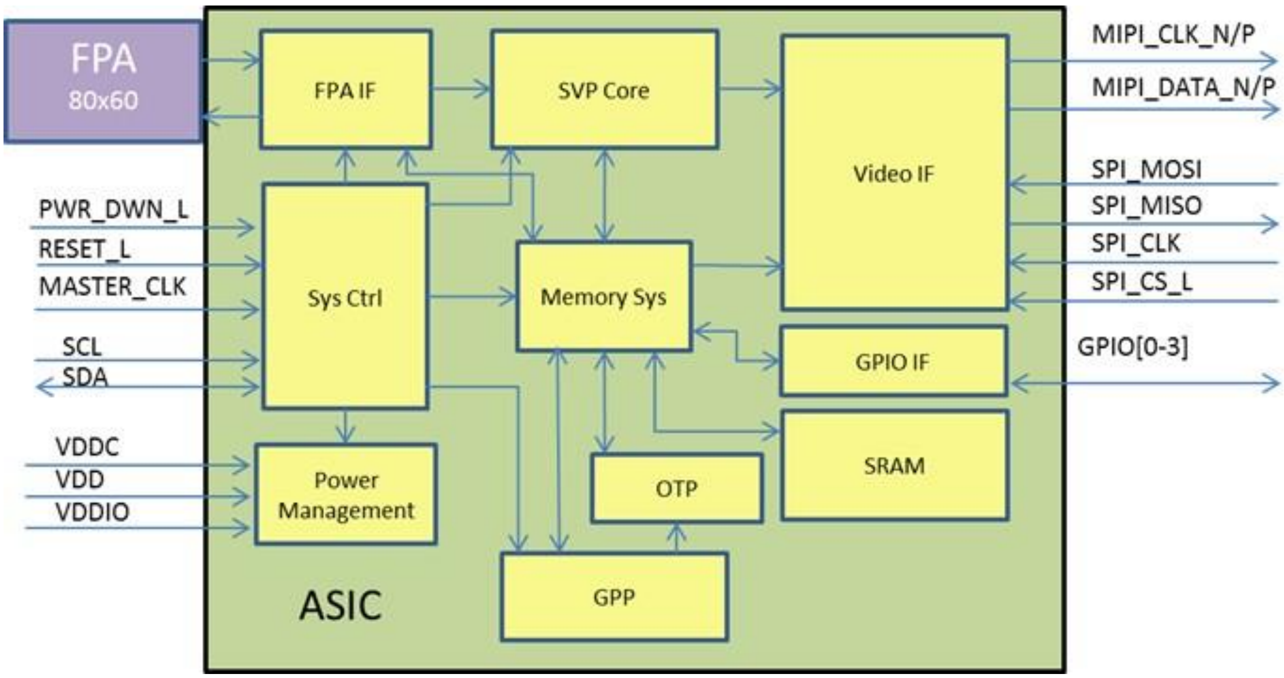
The shutter assembly periodically blocks radiation from the scene and presents a uniform thermal signal to the sensor array, allowing an update to internal correction terms used to improve image quality. For applications in which there is little to no movement of the Lepton camera relative to the scene (for example, fixed-mount security applications), the shutter assembly is recommended. For applications in which there is ample movement (for example, handheld applications), the shutter assembly is less essential although still capable of providing slight improvement to image quality, particularly at start-up and when the ambient temperature varies rapidly.

The serial stream from the FPA is received by a system on a chip (SoC) device, which provides signal processing and output formatting. This device is more fully defined in **Functional Description,** page *16*.

6.0 Functional Description

A detailed block diagram of the Lepton camera module is shown in ***Figure 5***.

Figure 5 - Lepton Detailed Block Diagram



6.1 FPA Interface Module

The FPA Interface module generates timing and control signals to the FPA. It also receives and deserializes the digital data stream from the FPA. The output values of on-board temperature sensors are multiplexed into the pixel data stream, and the FPA Interface module strips these out and accumulates them (to improve SNR).

6.2 System Control (Sys Ctrl) Module

The System Control module provides the phase-lock-loop (PLL) and generates all clocks and resets required for other modules. It also generates other timing events including syncs and the internal watchdog timer. Additionally, it provides the boot controller, random-number generator, and command and control interface (CCI) decode logic.

6.3 Power Management Module

The Power Management module controls the power switches, under direction from the System Control Module.

6.4 Software-based Video Processing (SVP Core) Module

The SVP Core module is an asymmetric multi-core digital signal processor (DSP) engine that provides the full video pipeline, further described in **Video Pipeline,** page **18**.

6.5 Memory System (Memory Sys) Module

The Memory System module provides the memory interface to all of the other modules that require access to SRAM and/or OTP.

6.6 General Purpose Processor (GPP)

The GPP is a central processing unit (CPU) that provides the following functionality:

- Servicing of CCI commands
- Initialization and configuration of the video pipeline
- Power management
- Other housekeeping functions

6.7 Video Interface Module (Video IF)

The Video Interface module receives video data and formats it for VoSPI protocol.

6.8 One-Time Programmable Memory (OTP)

The OTP memory, 384 kBytes total, contains all the non-volatile data for the camera, including the software programs for the SVP Core and GPP as well as calibration data and camera-unique data (such as serial number). There are no requirements for writing OTP memory outside of the Lepton factory.

An optional feature is available to configure the desired defaults (e.g. FFC mode, radiometry configuration, etc.), and write these defaults once by the user to OTP. This feature removes the needs for an initialization sequence at start-up to configure the desired run-time settings. See **User Defaults Feature**, page **46**.

6.9 Static Random-Access Memory (SRAM)

SRAM is the primary volatile memory utilized by all other modules.

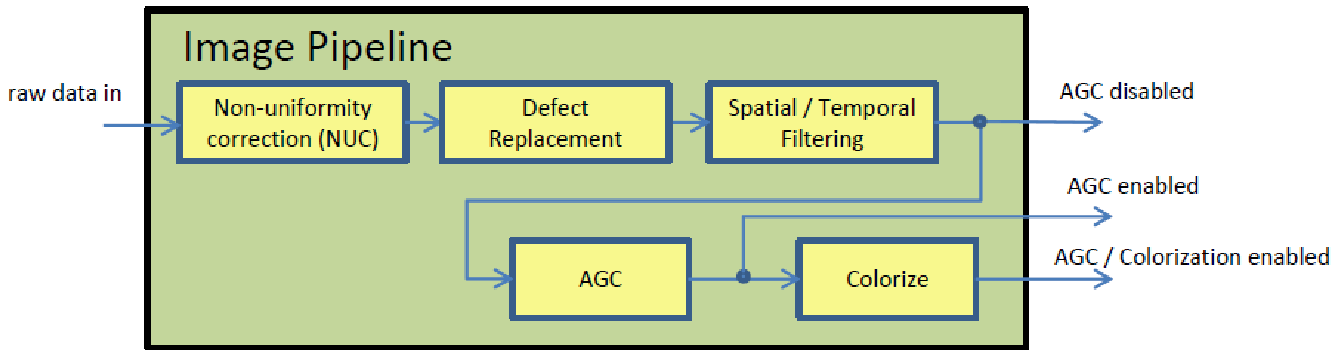
6.10 GPIO Interface Module (GPIO IF)

The General-Purpose Input / Output (GPIO) Interface module implements the GPIO pins, which can be runtime configured (see **GPIO Modes,** page **43**).

6.11 Video Pipeline

A block diagram of the video pipeline is shown in *Figure 6*.

Figure 6 - 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.

6.11.1 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 22.

6.11.2 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.

6.11.3 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.

6.11.4 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. **AGC Modes**, page **38**.

6.11.5 Colorize

The colorize block takes the contrast-enhanced thermal image as input and generates a 24-bit RGB color output. See **Video Output Format Modes**, page **40**.

6.12 Master Clock

In the current Lepton release, the master clock (MASTER_CLOCK) frequency is 25 MHz.

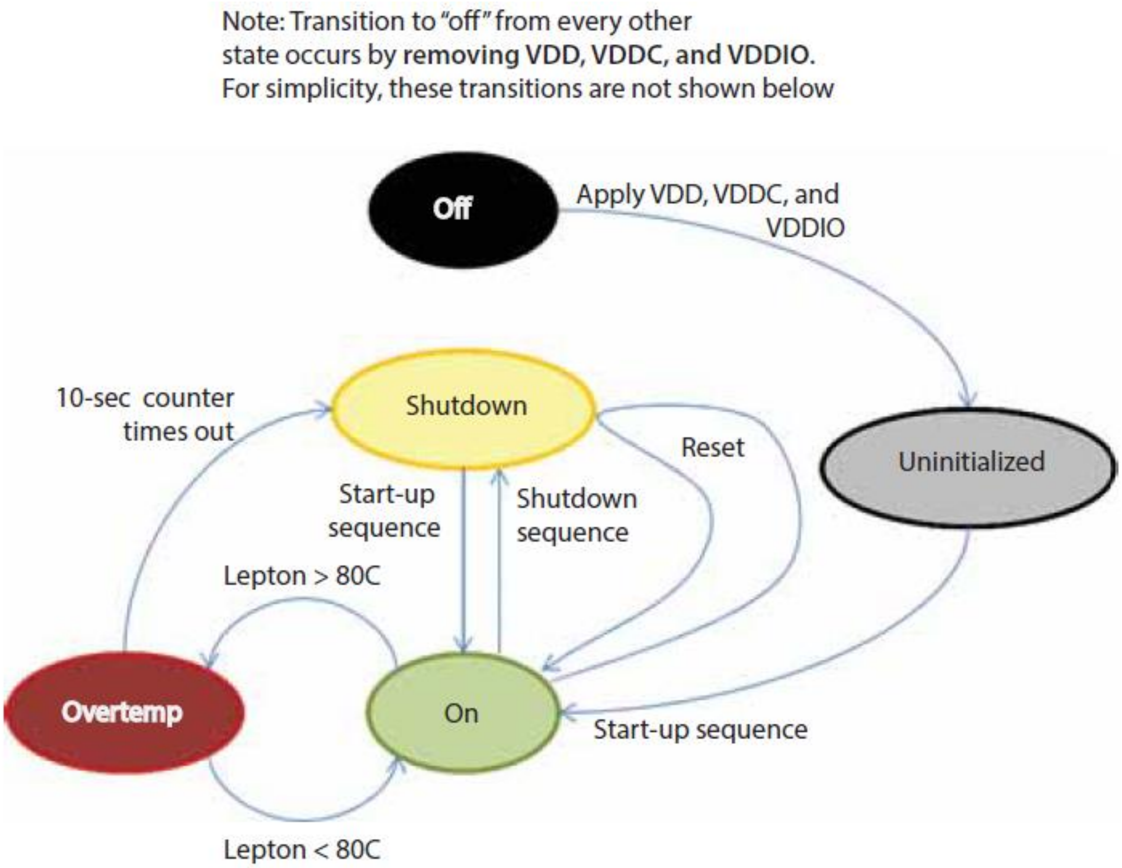
7.0 Operating States and Modes

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

7.1 Power States

Lepton currently provides five power states. As depicted in the state diagram shown in ***Figure 7***, 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 7 - State Diagram Showing Transitions among the Five Power States



The power states are listed here:

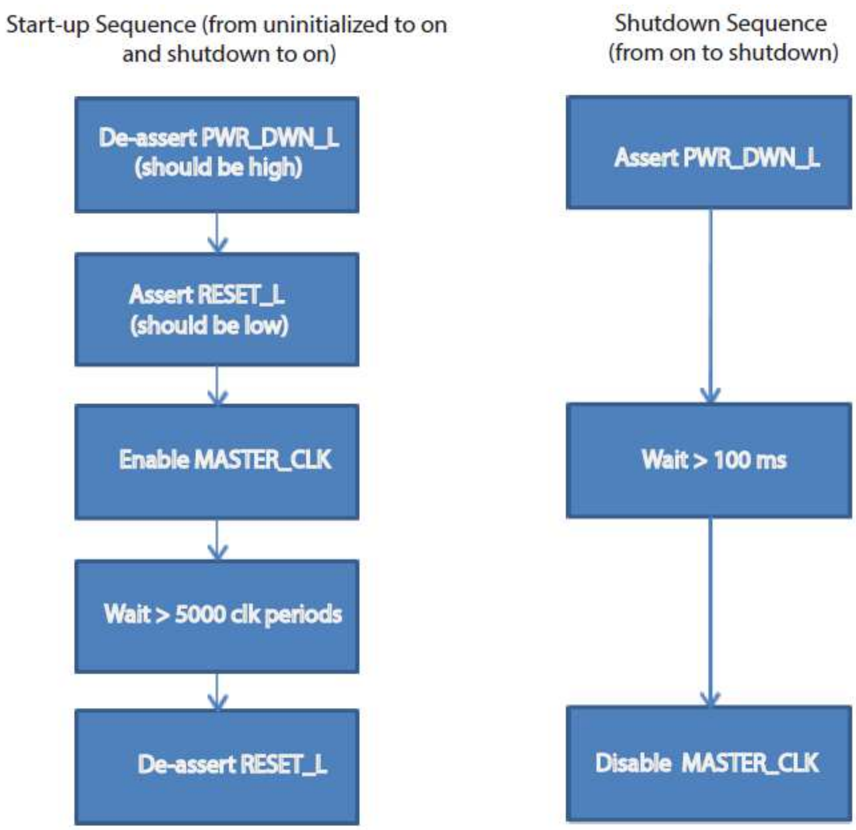
- **Off**: When no voltage is applied, Lepton is in the off state. In the off state, no camera functions are available.
- **Uninitialized**: In the uninitialized state, all voltage forms are applied, but Lepton has not yet been booted and is in an indeterminate state. It is not recommended to leave Lepton in this state as power is not optimized; it should instead be booted to the on-state (and then transitioned back to shutdown if imaging is not required).
- **On**: In the on state, all functions and interfaces are fully available.
- **Shutdown**: In the shutdown state, all voltage forms are applied, but power consumption is approximately 4 mW. In the shutdown state, no functions are available, but it is possible to

transition to the on state via the start-up sequence defined in ***Figure 8***. The shutdown sequence shown in ***Figure 8*** is the recommended transition back to the shutdown state. It is also possible to transition between shutdown 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 8***.

Figure 8 - Lepton Power Sequencing



7.2 FFC States

Lepton is factory calibrated to produce an output image that is highly uniform, such as shown in ***Figure 9 (a)***, when viewing a uniform-temperature scene. However, drift effects over long periods of time degrade uniformity, resulting in imagery which appears grainier ***Figure 9 (b)***) and/or blotchy (***Figure 9 (c)***). Columns and other pixel combinations may drift as a group. These drift effects may occur even while the camera is powered off. 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 and radiometric accuracy.

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 stationary applications and those which need highest quality or quickly available video, 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 9 - 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)

Lepton provides three different FFC modes:

- External
- Manual
- Automatic (default)

In external FFC mode, FFC is only executed upon command, and it should only be commanded when the camera is imaging an external uniform source of a known temperature. To ensure radiometric accuracy in this mode, the user must explicitly update the radiometry shutter mode to "User" and input the temperature of the scene during FFC via the CCI. If in imaging mode only and temperature measurement is not required (radiometry disabled), any uniform source such as a wall will suffice.

Manual FFC mode is also executed only upon command, except that when FFC is commanded, Lepton closes its integral shutter throughout the process. Note that it is not necessary to ensure a uniform external scene of a known temperature before commanding FFC in manual FFC mode because the shutter serves as the uniform source and includes a temperature sensor with automatic input for radiometric measurements.

In automatic FFC, the Lepton camera will automatically perform FFC under the following conditions:

- At start-up
- After a specified period of time (default of 3 minutes) has elapsed since the last FFC
- If the camera temperature has changed by more than a specified value (default of 1.5 Celsius degrees) since the last FFC

The time trigger and the temperature-change trigger described above are both adjustable parameters via the CCI; however, the default values are recommended under most operating conditions. Decreasing the temperature or time interval to FFC more often will provide better radiometric accuracy, but the tradeoff is decrease in useful camera output and radiometry readings due to the increased occurrence of FFC.

The current FFC state is provided through the telemetry line. There are four FFC states, enumerated below and illustrated in ***Figure 10***:

1. **FFC not commanded (default):** In this state, Lepton applies by default a set of factory-generated FFC terms. In automatic FFC mode, this state is generally not seen because Lepton performs automatic FFC at start-up.
2. **FFC imminent:** The camera only enters this state when it is operating in automatic FFC mode. The camera enters “FFC imminent” state at a specified number of frames (default of 52 frames, or approximately 2 seconds) prior to initiating an automatic FFC. The intent of this status is to warn the host that an FFC is about to occur.
3. **FFC in progress:** Lepton enters this state when FFC is commanded from the CCI or when automatic FFC is initiated. The default FFC duration is nominally 23 frames, in which case the camera integrates 8 frames of output as the basis for the correction (the additional frames are overhead). It is possible to configure the FFC to integrate fewer or more frames (from 1 to 128 in powers of 2). Utilizing fewer

frames obviously decreases the FFC period (with diminishing returns due to overhead) whereas utilizing more frames provides greater reduction of spatial noise (also with diminishing returns due to 1/f noise). Figure 11 quantifies the benefit. Radiometry readings are invalid during this state.

4. **FFC complete:** Lepton automatically enters this state whenever a commanded or automatic FFC is completed.

Lepton also provides an "FFC desired" flag in the telemetry line. The "FFC desired" flag is asserted under the same conditions that cause automatic FFC when in automatic FFC mode. That is, 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 = 1.5 Celsius degrees) since the last FFC. In automatic mode, the camera immediately enters "FFC imminent" state when "FFC desired" is true. In manual FFC mode and external FFC mode, the "FFC desired" flag is intended to indicate to the host to command an FFC at the next possible opportunity.

Lepton automatically prohibits the shutter from operating when it detects the temperature to be outside the range -10° C to +80° C. For example, if the camera is operating at a temperature of -15° C, no automatic FFC will be performed, and the camera will ignore any commanded FFC if the FFC mode is "automatic" or "manual." Normal operation of the shutter will automatically resume when the temperature is back within the valid range. A status flag is provided in the telemetry line indicating when shutter lockout is in effect.

Figure 10 - FFC States