Advanced Radiometry

Application Note

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1 Document

1.1 Revision History

Version	Date	Comments
100	9/28/2012	First release

110	05/01/2013	Tau 2.4 Release Updates
120	11/19/2013	Added Manual Calibration Section

1.2 Scope

This document describes advanced radiometric functions available in Tau cameras release 2.4 and later. These functions allow you to obtain temperature measurements of a scene and perform radiometric calibration. Serial commands presented in this document may be subject to change. Consult the latest Software IDD for the most recent summary of commands.

The FLIR website will have the newest version of this document as well as offer access to many other supplemental resources: http://www.flir.com/cvs/cores/resources/

Here is a sample of some of the resources that can be found:

Document Title	Document Number	Description
Tau Quick Start Guide	102-PS242-01	Quick Start Guide for first-time use
FLIR Camera Controller GUI User's Guide	102-PS242-02	Detailed Descriptions for functions and adjustments for FLIR cameras using the FLIR Camera Controller GUI
Tau 2 Product Specification	102-PS242-40	Product specification and feature description
Tau 2 Electrical IDD	102-PS242-41	Written for Electrical Engineers to have all necessary information to interface to a Tau 2 camera
Tau 2/Quark Software IDD	102-PS242-43	Written for Software Engineers to have all necessary information for serial control of Tau 2 and Quark
Assorted Mechanical Drawings and Models	Various	There are drawings and 3D models for various camera configurations for mechanical integration
Application Notes	Various	Written for Systems Engineers and general users of advanced features such as Gain Calibration, Supplemental FFC Calibration, NVFFC Calibration, Camera Link, On-Screen Symbology, AGC/DDE explanation, Camera Mounting, Spectral Response, Optical Interface for lens design, and others.

There is also a large amount of information in the Frequently Asked Questions (FAQ) section on the FLIR website: http://www.flir.com/cvs/cores/knowledgebase/. Additionally, a FLIR Applications Engineer can be contacted at 888.747.FLIR (888.747.3547).

2 Requirements

The Tau camera must have the advanced radiometry option enabled. Only customers who have purchased a "F**R**NLX" or "S**R**NLX" part number (where the "R" indicates advanced radiometry, e.g. 46640019H-FRNLX) or who have OEM specific part numbers with advanced radiometry enabled are able to gain access to the image metric and TLinear features presented in this document. All other customers have access to one spot meter in the center of the image and this spot meter is not moveable. Additionally, radiometric accuracy is lower without advanced radiometry enabled.

- Minimum version of Tau software: 15.X.13.6
- Minimum version of FLIR Camera Controller GUI: 1.0.0.106

3 Advanced radiometry functions

The Tau camera allows you to make absolute temperature measurements in the full image array. The camera is calibrated to be accurate for a scene with 100% emissivity in close proximity to the camera. Many factors influence the accuracy of the measurement of a real scene. Examples of such factors are emissivity of the scene, distance to the scene and atmospheric absorption along the path to the scene, window transmission, thermal gradients in the camera that are affected by mounting technique and character of the enclosure, the thermal state of the camera (i.e. start-up, external heating etc.), the relative temperature of the scene and the camera. Many of these factors can be compensated for if known at the time of use.

The Tau camera compensates for variations of the camera temperature and outputs 14-bit digital video that is stabilized and normalized. That means that a scene with a given temperature will always correspond to a certain digital value in the video independent of the camera temperature. We identify this as “temperature stable video”. There are two types of 14-bit temperature stable video: flux-linear and T-linear. The flux-linear video has a non-linear relationship to the scene temperature, and it is not compensated for scene parameters such as emissivity. The T-linear is compensated for scene parameters and has a simple linear relation to absolute temperature. The 8-bit video and the analog video are optimized for best visual appearance using AGC (automatic gain control) and are not radiometric.

4 Image Metric

The Image Metric command allows the user to retrieve temperature data from a user selectable rectangular ROI (region of interest). The available data is

- Average temperature
- Standard deviation of temperature
- Maximum and minimum temperature
- Pixel location of the maximum and minimum temperature

The Tau camera has one active Image Metric ROI but the location can be changed continuously at about a third of the frame rate. This way a scene can be sampled with an arbitrary number of ROI as long as a lower sampling rate is acceptable.

The temperature readings with the Image Metric are corrected for scene emissivity and window transmission (if applicable) using the corrections described in section 4.2.

The metrics can be obtained with serial command following three steps:

1. Set the ROI to the relevant part of the image.
2. Set the external temperature correction parameters for the scene.
3. Retrieve the data.

4.1 Set ROI

The region of interest for the image metric can be set to any size rectangle from 1x1 pixels to the full frame. To set the ROI, issue the 0x43 SET_SPOT_METER_COORDINATES command (#67) with the following arguments:

	Value (hex)	Comment
Function Code	0x43	SET_SPOT_METER_COORDINATES
Bytes 0-3	0x#### 0x####	Upper left (x,y) coordinates of the ROI. Coordinates are (0,0) for the pixel in the upper left corner of the image. The pixel at coordinates (x,y) is included in the ROI.
Bytes 4-7	0x#### 0x####	Lower right (x,y) coordinates included in the ROI.

The camera responds with the following data:

	Value (hex)	Comment
Bytes 0-1	0x####	Sync flag. (This can be ignored while setting the ROI.)
Bytes 2-3	0x####	Frame counter.

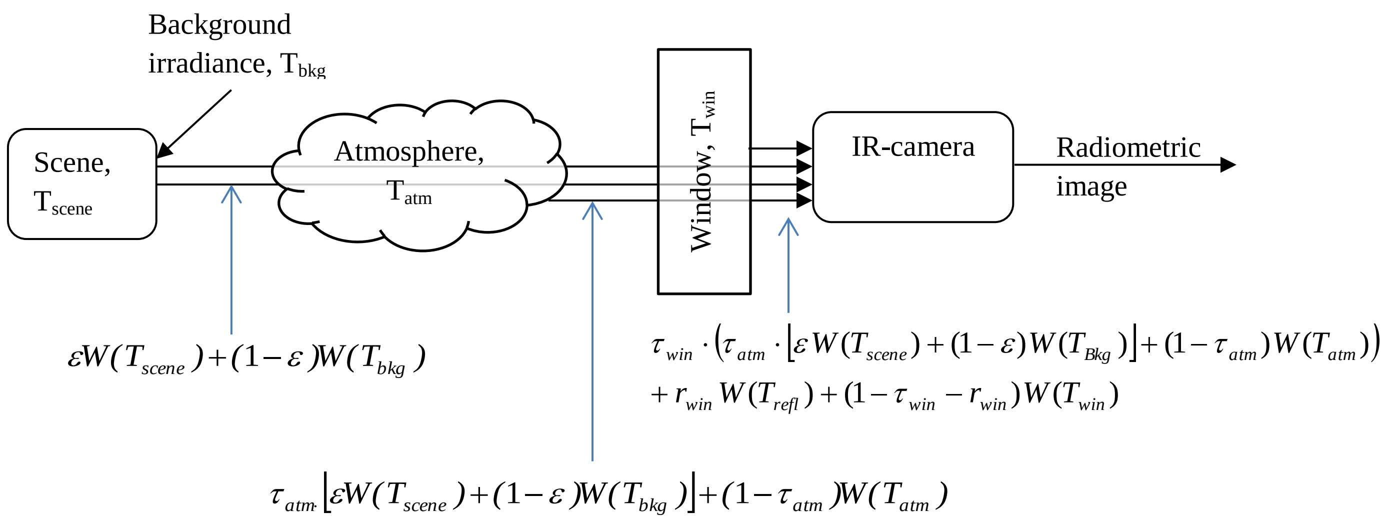
There is one ROI available at any one time but it can be redefined continuously to allow several measurements in several regions in a sequence. The frame counter can be used to verify that the new ROI has been applied when reading data (see section 4.3).

4.2 External parameters

The Tau camera can compensate the temperature reading for scene emissivity and window transmission and reflection (if applicable).

The correction for emissivity and window factors has been extended to include corrections for atmospheric transmission. The model is based on the fact that the radiation from the scene is attenuated by the absorption along the path and the absorbing elements are emitting radiation related to the temperature of the element.

The following model is used for the temperature compensation:



The incident radiation onto the camera is given by

$$S = \tau_{win} \cdot \left(\tau_{atm} \cdot \lfloor \varepsilon W(T_{scene}) + (1-\varepsilon) W(T_{Bkg}) \rfloor + (1-\tau_{atm}) W(T_{atm})\right)$$
$$+ r_{win} W(T_{refl}) + (1-\tau_{win} - r_{win}) W(T_{win})$$

Equation 1

Notation	Description
S	Value of the 14-bit digital video in counts
ε	Emissivity of the scene.
τ_{win}	Transmission coefficient of the window
T_{win}	Window temperature
r_{win}	Window reflection
T_{refl}	Temperature reflected in the window
τ_{atm}	Transmission coefficient of the atmosphere between the scene and the camera
T_{atm}	Atmospheric temperature
T_{bkg}	Background temperature (reflected by the scene)
T_{scene}	Scene temperature
$W(T)$	Radiated flux (in units of counts) as function of the

	temperature of the radiating object. The conversion from temperature to flux can be done using the camera command GET_FLUX_FROM_TEMP (function code 0xB6)

Normally, scene materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil/based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity of 0.97 to 0.98. The allowed value of emissivity and transmission parameters is limited to the range 0.5 – 1.0. Note that in software (and physically) the window reflection cannot exceed (1 –Window transmission). The allowed value of temperature parameters is between -50°C and 327.67°C.

The external parameters are set by issuing the 0xE5 LENS_RESPONSE_ PARAMS command (#229) with the following arguments:

	Value (hex)	Comment
Function Code	0xE5	LENS_RESPONSE_ PARAMS
Bytes 0-1	0x0100	Emissivity, or
Bytes 0-1	0x0101	Background temperature, or
Bytes 0-1	0x0102	Window transmission, or
Bytes 0-1	0x0103	Window temperature, or
Bytes 0-1	0x0104	Atmospheric transmission, or
Bytes 0-1	0x0105	Atmosphere temperature, or
Bytes 0-1	0x0106	Window reflection, or
Bytes 0-1	0x0107	Temperature reflected in window
Argument bytes 2-3	0x####	Emissivity format: 8192 * emissivity, or Temperature format: 100 * deg C, or Transmission format: 8192 * transmission Reflection format: 8192 * reflection

The external parameters are read from the camera using the following format:

	Value (hex)	Comment
Function Code	0xE5	LENS_RESPONSE_ PARAMS
Bytes 0-1	0x0100	Emissivity, or

Bytes 0-1	0x0101	Background temperature, or
Bytes 0-1	0x0102	Window transmission, or
Bytes 0-1	0x0103	Window temperature, or
Bytes 0-1	0x0104	Atmospheric transmission, or
Bytes 0-1	0x0105	Atmosphere temperature, or
Bytes 0-1	0x0106	Window reflection, or
Bytes 0-1	0x0107	Temperature reflected in window
Response bytes 0-1	0x####	Emissivity format: 8192 * emissivity, or Temperature format: 100 * deg C, or Transmission format: 8192 * transmission Reflection format: 8192 * reflection

The temperature of each pixel from the 14-bit digital data can be calculated with appropriate values of emissivity, etc. The conversion between temperature and flux can be performed by issuing the 0xB6 GET_FLUX_FROM_TEMP command (#182) or 0xB7 GET_TEMP_FROM_FLUX command (#183) with the following arguments:

	Value (hex)	Comment
Function Code	0xB6	GET_FLUX_FROM_TEMP
Command bytes 0-1	0x####_####	Temperature in °C times 1000. Valid range is [-40 °C, 1000 °C].
Response bytes	0x####_####	Flux in counts.

	Value (hex)	Comment
Function Code	0xB7	GET_TEMP_FROM_FLUX
Command bytes 0-1	0x####_####	Flux in counts. Valid range is [0, 65535].
Response bytes	0x####_####	Temperature in °C times 1000.

4.3 Retrieve the data

The image metric data is obtained by issuing the 0x43 SET_SPOT_METER_COORDINATES command (#67) with the following arguments:

	Value (hex)	Comment
Function Code	0x43	GET_SPOT_METER_DATA
Bytes 0-1	0x####	0x0000 = reply in counts

		0x0001 = reply in Celsius x 10 0x0002 = reply in Kelvin x 100

The response from the camera has the following format:

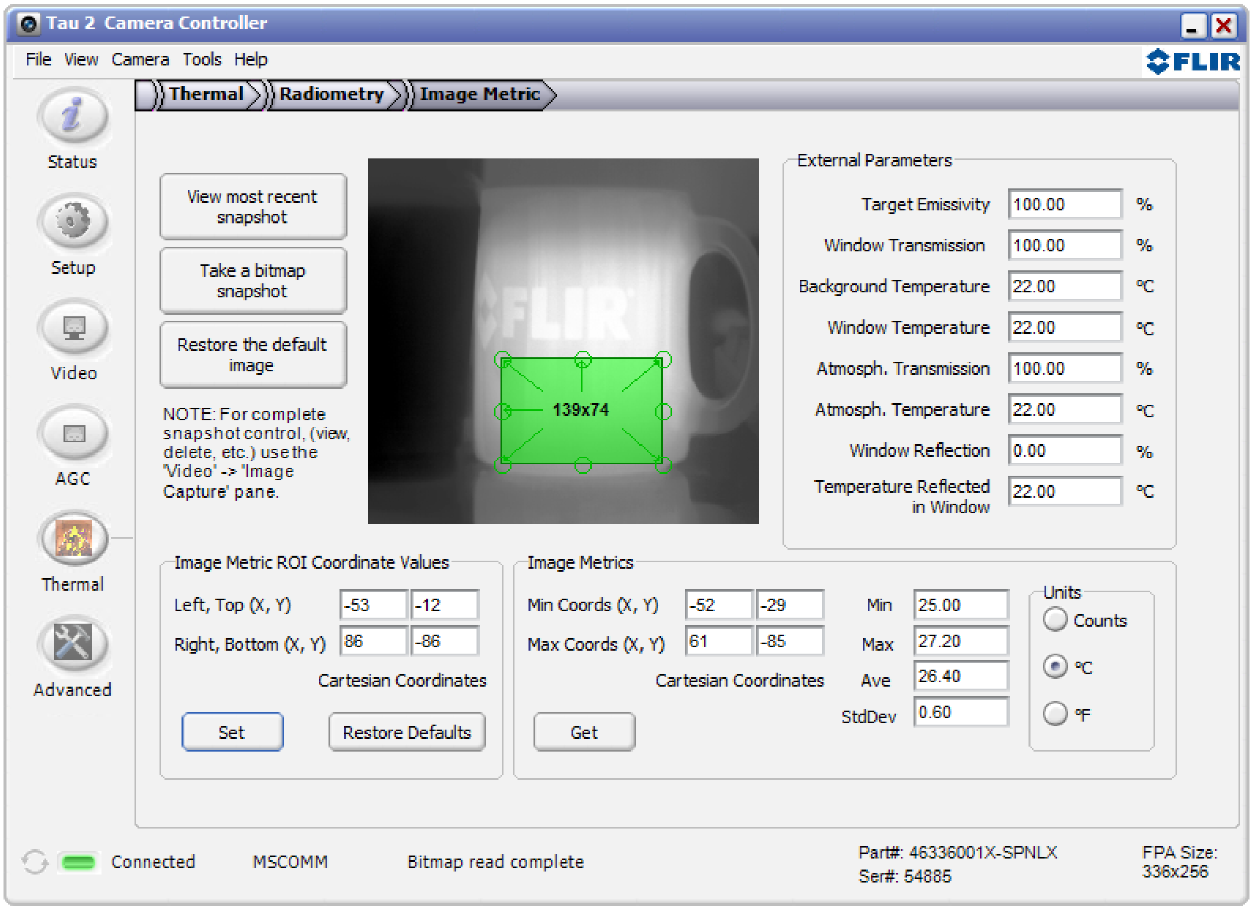
	Value (hex)	Comment
Function Code	0x43	GET_SPOT_METER_DATA
Bytes 0-1	0x####	Sync flag. Data is valid when the flag is 0x0000.
Bytes 2-3	0x####	Frame counter.
Bytes 4-5	0x####	**Average** value in the ROI. The format depends on the parameters in the send command: **0x0000**: Average number of counts times 4. **0x0001**: Average temperature in Celsius times 10 (signed) **0x0002**: Average temperature in Kelvin times 100
Bytes 6-7	0x####	**Standard deviation** in the ROI. Same format as for the average.
Bytes 8-9	0x####	**Minimum** value in the ROI. The format depends on the parameters in the send command: **0x0000**: Minimum value in counts **0x0001**: Same as for average **0x0002**: Same as for average
Bytes 10-11	0x####	**Maximum** value in the ROI. Same format as for minimum.
Bytes 12-15	0x#### 0x####	**Coordinates** (x,y) for the pixel with lowest value. The coordinates are zero based with origin in upper left corner of the image.
Bytes 16-19	0x#### 0x####	**Coordinates** (x,y) for the pixel with highest value.

The sync flag is used to discriminate data during table switch or shutter movements. To guarantee that the image metric readings are related to the last set ROI coordinates the user needs to verify that the frame counter when retrieving data has increased by at least 2 counts since the ROI was last changed. As a consequence the ROI, and a subsequent image metric reading, can be changed at a frequency of approximately one third of the frame rate.

4.4 Image Metric with Camera Controller GUI

The image metric can be used with the FLIR Camera Controller GUI. The interface follows the description above with a few differences.

- The ROI coordinates in the FLIR Camera Controller GUI are relative to the center of the image.
- The units for the image metric data are counts, °C and °F.



5 Radiometric calibration

The Tau camera is delivered with a factory radiometric calibration, but accuracy can sometimes be improved by performing a radiometric calibration with the camera mounted in its final enclosure and in its final environment. The FLIR Camera Controller GUI can be used for a 1-point or a 2-point calibration. It is also possible to extend the calibration to higher order using a custom procedure.

5.1 Preparation

To calibrate the camera it is recommended to use stable and accurate black bodies with high emissivity. For an accurate calibration the camera must be in stable thermal equilibrium. It is recommended to wait at least 15 minutes after start-up before performing a radiometric calibration. The calibration compensates for external parameters (see section 4.2) presently applied in the camera and therefore it is necessary to first set the parameters that are applicable for the configuration during calibration.

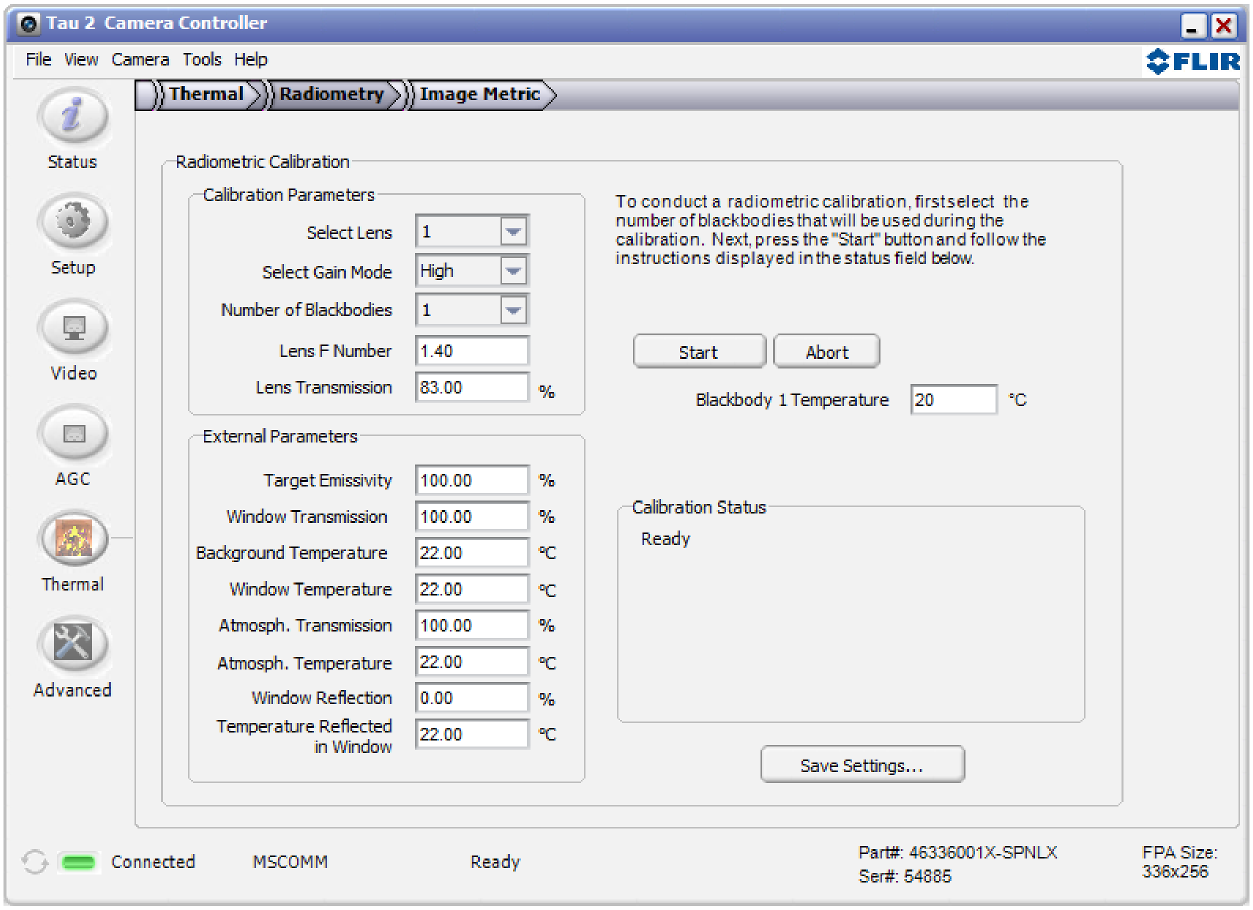
For cameras with advanced radiometry, the calibration is performed using data in the Image Metric ROI. As part of the calibration procedure, the GUI will move the ROI to the center of the image. The camera is calibrated using the measured value within the ROI. Ensure the ROI is set back to the desired location after the calibration has finished before saving settings.

Note: Please ensure that the camera is temperature stable during radiometric calibration and does not vary more than 2C while doing the calibration process. The GUI allows customers to observe the FPA temperature value on the status page.

5.2 1-point calibration

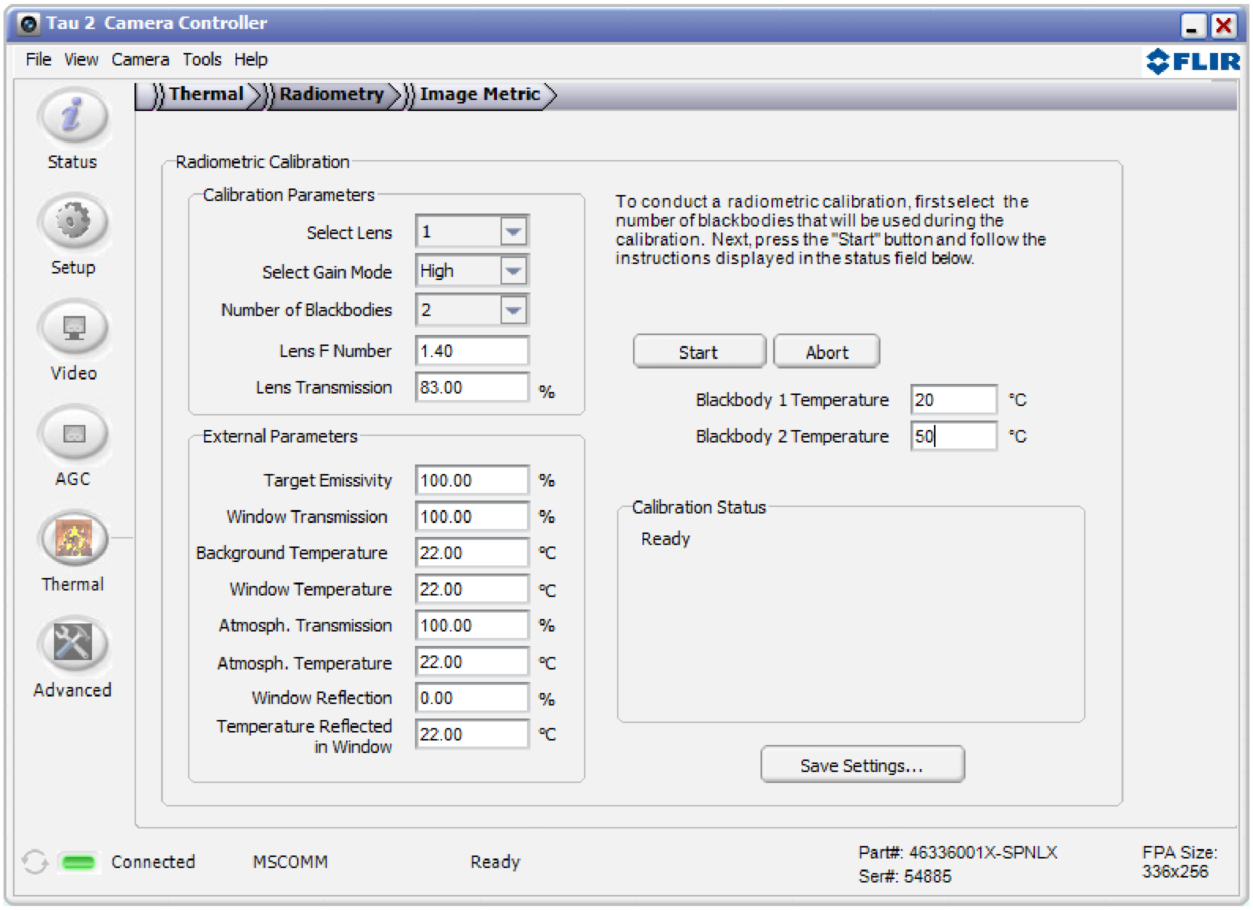
The 1-point calibration adjusts an offset in the conversion from counts to temperature to make the camera measure correctly against the calibration target. Follow these steps to perform a 1-point calibration:

1. Start the FLIR Camera Controller GUI and select the tab Thermal | Radiometry.
2. Select the lens number and gain mode for which to do the calibration. The camera stores 4 sets of calibration terms – one for each lens and gain mode.
3. Select blackbody 1.
4. Set the known temperature in °C of the target blackbody in “Blackbody 1 Temperature”.
5. The F number and lens transmission affects the radiometric accuracy. The FLIR Camera Controller GUI shows the present parameters for the selected lens. If a custom lens is used it is recommended to adjust the F number and transmission to match that lens.
6. Set emissivity, window transmission and background temperature that applies to the calibration situation.
7. Start the calibration process. (The FLIR Camera Controller GUI will guide the user through the rest of the calibration process.)
8. The FLIR Camera Controller GUI checks the stability of the camera.
9. Point the camera to the target and capture data.
10. Test the accuracy against the calibration target after the calibration by pointing at the target and reading the temperature. This can be done either using the on-screen display in the analog video or in the Thermal | Thermal tab in the FLIR Camera Controller GUI.
11. If the accuracy is satisfactory the calibration can be saved by clicking “Save Settings …”. Note that all present settings will be saved to the camera, including lens number, gain mode, image metric ROI, and external parameters.



5.3 2-point calibration

The 2-point calibration process follows the same steps as the 1-point calibration with the addition of an extra blackbody at a different temperature than the first. It is recommended that the temperatures of the two blackbodies differ by at least 25 °C. Verify that the camera measures accurately against both target blackbodies before saving the calibration to the camera.


Tau 2 Camera Controller
File View Camera Tools Help
FLIR
Thermal
Radiometry
Image Metric
Status
Setup
Video
AGC
Thermal
Advanced
Radiometric Calibration
Calibration Parameters
Select Lens 1
Select Gain Mode High
Number of Blackbodies 2
Lens F Number 1.40
Lens Transmission 83.00 %
External Parameters
Target Emissivity 100.00 %
Window Transmission 100.00 %
Background Temperature 22.00 °C
Window Temperature 22.00 °C
Atmosph. Transmission 100.00 %
Atmosph. Temperature 22.00 °C
Window Reflection 0.00 %
Temperature Reflected in Window 22.00 °C
To conduct a radiometric calibration, first select the number of blackbodies that will be used during the calibration. Next, press the "Start" button and follow the instructions displayed in the status field below.
Start
Abort
Blackbody 1 Temperature 20 °C
Blackbody 2 Temperature 50 °C
Calibration Status
Ready
Save Settings...
Connected
MSCOMM
Ready
Part#: 46336001X-SPNLX
Ser#: 54885
FPA Size: 336x256

5.4 Manual calibration

The 1-point and 2-point calibration process implemented in the FLIR Camera Controller GUI can be extended to several blackbodies. First, go through the preparation steps described in section 5.1. Then measure the signal against each of the blackbodies used for calibration. The calibrated parameters for the flux-to-temperature conversion (R, B, F, and O) are obtained by fitting Equation 3(section 8) to the measured data. The new parameters can be entered into the camera using the 0xB9 SET_PLANCK_CONSTANTS command (#185):

	Value (hex)	Comment
Function Code	0xB9	SET_PLANCK_CONSTANTS
Bytes 0-1	0x0200	Sub-command code
Bytes 2-5	0x####_####	R (unsigned)
Bytes 6-9	0x####_####	1000*B (unsigned)
Bytes 10-13	0x####_####	1000*F (unsigned)
Bytes 14-17	0x####_####	1000*O (signed)

When the new parameters are entered into the camera it is recommended to test the accuracy against several blackbodies before saving the settings.

Below is an example of what data points could look like and calculated conversion parameters (RBFO).

Blackbody T [°C]	Average signal [counts]	Fitted temperature [°C]
20	3947	19.99
40	5003	40.04
60	6259	59.96
80	7734	80.02
100	9410	100.00

The data points (Average signal) were fitted to Equation 3 with a fixed value of F=1.0 and the resulting values are RBFO = [428523, 1483.385, 1.0, 1211.504]. The fitted temperatures were obtained by applying the inverse of Equation 3with the new RBFO values to the average signal in the table.

In the example we assumed that the external parameters are: emissivity = 100%, atmospheric transmission = 100%, window transmission = 100%. If any of these parameters are less than 100% it will be necessary to compensate using Equation 1 (section 4.2). Notice however that the compensation depends on the function *W(T)* that is being calibrated.

6 TLinear

The image metric feature allows the customer to make absolute, per pixel temperature measurements in the full image array by defining regions of interest and acquiring statistics on the ROI. The TLinear feature allows the signal output of the Tau camera to be configured as linear in scene temperature, hence the feature title “TLinear”, as opposed to linear in radiometric flux. The TLinear option allows the 14-bit LVDS and CMOS outputs to contain temperature data in each frame.

TLinear provides the ability to analyze the temperature data for multiple regions in the array simultaneously. Because the information is encoded in the digital data, the temperature information is updated on a frame-by-frame basis. The end-customer may choose to generate their own "image metric" type data with whichever statistics may be useful for general processing or analytics or define a non-symmetric region of interest with the TLinear data.

The TLinear output data can be configured into one of two different resolution modes by the user: high resolution (0.04K/digital count) or low resolution (0.4K/digital count) mode. The TLinear low resolution mode should be used in conjunction with low gain mode to allow for measuring high scene temperatures. Refer to document #102-PS242-40 for details regarding low gain mode.

6.1 Enabling/Disabling TLinear

The Tlinear enable or disable bit may be set using the 0x8E TLIN_COMMANDS command (#142) with the TLIN_ENABLE subcommand, as described below. The TLinear enable/disable configuration may be saved for power persistence via the 0x01 SET_DEFAULTS command (#1).

	Value (hex)	Comment
Function Code	0x8E	TLIN_COMMANDS
Bytes 0-1	0x0040	TLIN_ENABLE subcommand
Bytes 2-3	0x####	TLinear Disable = 0x0000 TLinear Enable = 0x0001

6.2 TLinear Resolution

The resolution of the TLinear output can be set by issuing the 0x8E TLIN_COMMANDS command (#142) with the TLIN_OUTPUT_RESOLUTION subcommand, as described below. The current resolution can be found by sending the same command and sub-command without the resolution argument (i.e. Function Code: 0x8E Bytes 0-1: 0x0010); the reply will indicate whether the current setting is low resolution or high resolution with the same convention as the set command. The resolution configuration may be saved for power persistence via the 0x01 SET_DEFAULTS command (#1).

	Value (hex)	Comment
Function Code	0x8E	TLIN_COMMANDS
Bytes 0-1	0x0010	TLIN_OUTPUT_RESOLUTION subcommand
Bytes 2-3	0x####	Low Resolution = 0x0000 High Resolution = 0x0001

6.3 TLinear Output

With TLinear enabled and the resolution known, the 14-bit digital output can be interpreted as temperature with the simple conversion below:

$$S \cdot Res = T_{scene}$$

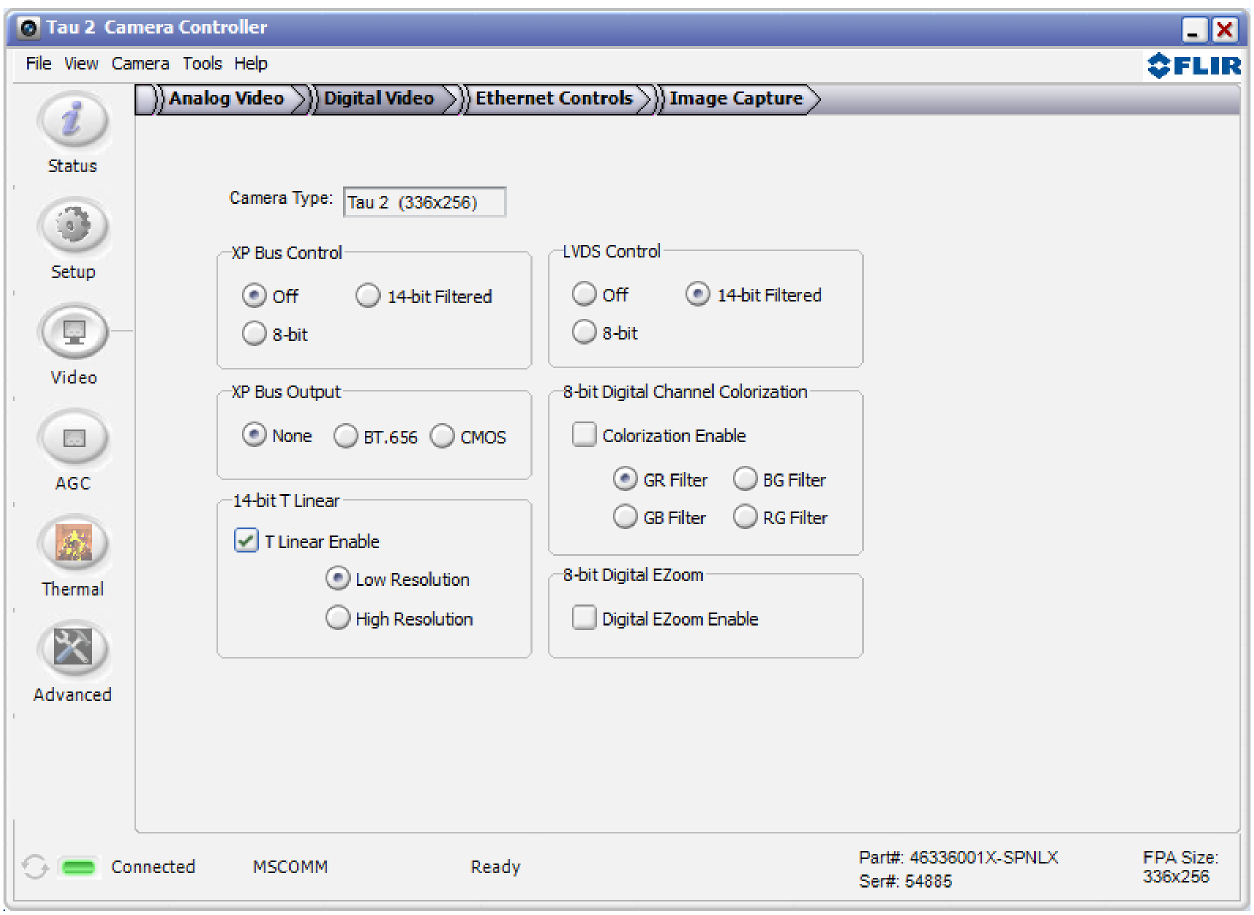
Equation 2

Notation	Description
S	Value of the pixel in14-bit digital video counts
Res	0.4 Kelvin/count for low resolution, 14-bit data 0.04 Kelvin/count for high resolution, 14-bit data
T_{scene}	Temperature of the scene in Kelvin

6.4 TLinear with Camera Controller GUI

The TLinear feature affects the digital output, and therefore the controls for the feature can be found on the "Digital Video" tab of the FLIR Camera Controller GUI. The image below shows the camera configured for TLinear enabled with low resolution. The TLinear feature only affects the 14-bit digital output, so the user must ensure either the CMOS or LVDS digital output is in 14-bit mode by using the controls on the same tab.

For these settings to be power cycle persistent, the "Save Settings" button should be selected on the "Setup" tab of the GUI.



7 External FFC

When the camera performs a flat field correction (FFC) using the shutter it also adjusts the radiometric offset to match the temperature of the shutter. It is possible to provide the camera with temperature information about the temperature of the external FFC reference by issuing the 0x4D SHUTTER_TEMP command (#77) with the following arguments:

	Value (hex)	Comment
Function Code	0x4D	SHUTTER_TEMP
Bytes 0-1	0x####	Value of the external shutter in °C times 100 (signed). The value 0x8000 has the special meaning of letting the camera use the estimated temperature of the internal shutter. The default value is 0x8000 which is appropriate when using the internal shutter.

When the camera uses the provided external shutter temperature for radiometric offset at the FFC it does not perform any corrections of the kind described in section 4.2. The camera assumes that the external shutter has 100% emissivity and that there is no absorption by atmosphere or window between the shutter and the lens.

8 Flux to temperature conversion

The 14-bit video is stabilized and normalized such that a scene with a given temperature will always correspond to a certain digital value in the video independent of the camera temperature. This signal *S* is called flux (*W*) linear since it is linear to the radiometric flux within a certain spectral band. The flux linear signal is related to temperature by the temperature-to-flux equation

$$S = W(T) = \frac{R}{exp(B/T_K) - F} + O$$

Equation 3

The RBFO parameters can be extracted from the camera using the 0xB9 GET_PLANCK_CONSTANTS command (#185):

	Value (hex)	Comment
Function Code	0xB9	GET_PLANCK_CONSTANTS
Bytes 0-1	0x0200	Sub-command code

The response from the camera has the following format:

	Value (hex)	Comment
Bytes 0-3	0x####_####	R (unsigned)
Bytes 4-7	0x####_####	1000*B (unsigned)

Bytes 8-11	0x####_####	1000*F (unsigned)
Bytes 12-15	0x####_####	1000*O (signed)

The conversion parameters depend on the present lens number and gain mode (low or high gain). The temperature in Equation 3 Equation 3 is in units of Kelvin. The conversion from flux to temperature is performed using the inverse of Equation 3. Compensation for emissivity and other external parameters shall be done before applying flux to temperature conversion (see section 4.2).

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 is 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.

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