1/2-Inch Megapixel CMOS Digital Image Sensor

MT9M001C12STM (Monochrome)

For the latest data sheet, refer to Micron's Web site: www.micron.com\imaging

Features
- Micron® DigitalClarity™ CMOS imaging technology
- Array Format (5:4): 1,280H x 1,024V (1,310,720 active pixels). Total (incl. dark pixels): 1,312H x 1,048V (1,374,976 pixels)
- Frame Rate: 30 fps progressive scan; programmable
- Shutter: Electronic Rolling Shutter (ERS)
- Window Size: SXGA; programmable to any smaller format (VGA, QVGA, CIF, QCIF, etc.)
- Programmable Controls: Gain, frame rate, frame size

Applications
- Digital still cameras
- Digital video cameras
- PC cameras

General Description

The Micron® Imaging MT9M001 is an SXGA-format with a 1/2-inch CMOS active-pixel digital image sensor. The active imaging pixel array of 1,280H x 1,024V. It incorporates sophisticated camera functions on-chip such as windowing, column and row skip mode, and snapshot mode. It is programmable through a simple two-wire serial interface.

This megapixel CMOS image sensor features Digital-Clarity—Micron's breakthrough low-noise CMOS imaging technology that achieves CCD image quality (based on signal-to-noise ratio and low-light sensitivity) while maintaining the inherent size, cost, and integration advantages of CMOS.

Table 1: Key Performance Parameters

Parameter		Value
Optical format		1/2-inch (5:4)
Active imager size		6.66mm(H) x 5.32mm(V)
Active pixels		1,280H x 1,024V
Pixel size		5.2µm x 5.2µm
Shutter type		Electronic rolling shutter (ERS)
Maximum data rate/ master clock		48 MPS/48 MHz
Frame rate	SXGA (1280 x 1024)	30 fps progressive scan; programmable
ADC resolution		10-bit, on-chip
Responsivity		2.1 V/lux-sec
Dynamic range		68.2dB
SNR_{MAX}		45dB
Supply voltage		3.0V—3.6V, 3.3V nominal
Power consumption		363mW at 3.3V (operating); 294mW (standby)
Operating temperature		0°C to +70°C
Packaging		48-pin CLCC

The sensor can be operated in its default mode or programmed by the user for frame size, exposure, gain setting, and other parameters. The default mode outputs an SXGA-size image at 30 frames per second (fps). An on-chip analog-to-digital converter (ADC) provides 10 bits per pixel. FRAME_VALID and LINE_VALID signals are output on dedicated pins, along with a pixel clock that is synchronous with valid data.

Ordering Information

Table 2: Available Part Numbers

Part Number	Description
MT9M001C12STM	48-pin CLCC (lead free)

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General Description

Figure 1: 48-Pin CLCC Package Pinout Diagram

Figure 2: Block Diagram
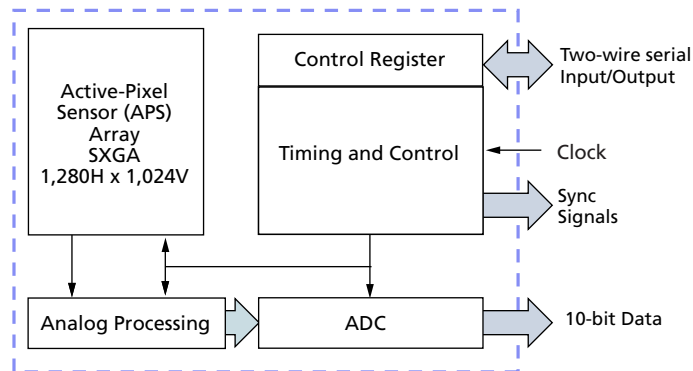
Table 3:   Pin Descriptions

Pin Numbers	Symbol	Type	Description
29	CLKIN	Input	Clock in. Master clock into sensor (48 MHz maximum).
13	OE#	Input	Output enable. OE# when HIGH places outputs DOUT<0:9>, FRAME_VALID, LINE_VALID, PIXCLK, and STROBE into a tri-state configuration.
10	RESET#	Input	Reset. Activates (LOW) asynchronous reset of sensor. All registers assume factory defaults.
46	SCLK	Input	Serial clock. Clock for serial interface.
7	STANDBY	Input	Standby. Activates (HIGH) standby mode, disables analog bias circuitry for power saving mode.
8	TRIGGER	Input	Trigger. Activates (HIGH) snapshot sequence.
45	SDATA	Input/Output	Serial data. Serial data bus, requires 1.5$K\Omega$ resistor to 3.3V for pull-up.
24–28, 32–36	DOUT<0–9>	Output	Data out. Pixel data output bits 0:9, DOUT<9> (MSB), DOUT<0> (LSB).
41	FRAME_VALID	Output	Frame valid. Output is pulsed HIGH during frame of valid pixel data.
40	LINE_VALID	Output	Line valid. Output is pulsed HIGH during line of selectable valid pixel data (see Reg0x20 for options).
31	PIXCLK	Output	Pixel clock. Pixel data outputs are valid during falling edge of this clock. Frequency = (master clock).
39	STROBE	Output	Strobe. Output is pulsed HIGH to indicate sensor reset operation of pixel array has completed.
15,17,18,21, 47, 48	AGND	Supply	Analog ground. Provide isolated ground for analog block and pixel array.
5, 23, 38, 43	DGND	Supply	Digital ground. Provide isolated ground for digital block.
16, 20	VAA	Supply	Analog power. Provide power supply for analog block, 3.3V ±0.3V.
1	VAAPIX	Supply	Analog pixel power. Provide power supply for pixel array, 3.3V ±0.3V (3.3V).
4, 22, 37	VDD	Supply	Digital power. Provide power supply for digital block, 3.3V ±0.3V.
2, 3 ,6, 9, 11, 12,14, 19, 30, 42, 44	NC	—	No connect. These pins must be left unconnected.

Pixel Data Format

Pixel Array Structure

The MT9M001 pixel array is configured as 1,312 columns by 1,048 rows (shown in Figure 3). The first 16 columns and the first eight rows of pixels are optically black, and can be used to monitor the black level. The last seven columns and the last seven rows of pixels are also optically black. The black row data is used internally for the automatic black level adjustment. However, the black rows can also be read out by setting the sensor to raw data output mode (Reg0x20, bit 11 = 1). There are 1,289 columns by 1,033 rows of optically active pixels, which provides a four-pixel boundary around the SXGA (1,280 x 1,024) image.

Figure 3:   Pixel Array Description
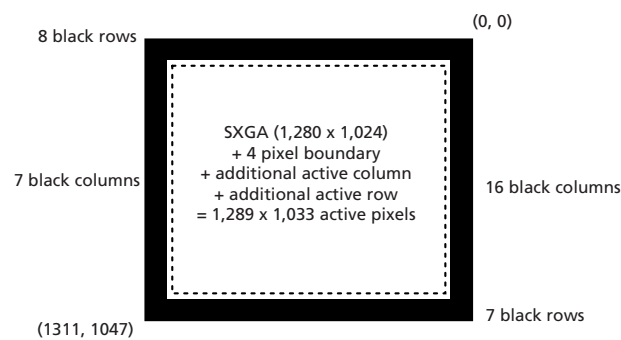
Figure 4:   Pixel Pattern Detail (Top Right Corner)
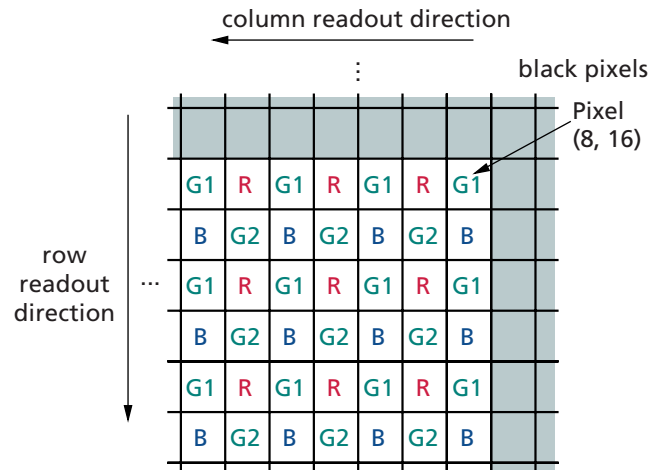
Output Data Format

The MT9M001 image data is read out in a progressive scan. Valid image data is surrounded by horizontal blanking and vertical blanking, as shown in Figure 5. The amount of horizontal blanking and vertical blanking is programmable through Reg0x05 and Reg0x06, respectively. LINE_VALID is HIGH during the shaded region of the figure. FRAME_VALID timing is described in "Output Data Timing" on page 8.

Figure 5:   Spatial Illustration of Image Readout
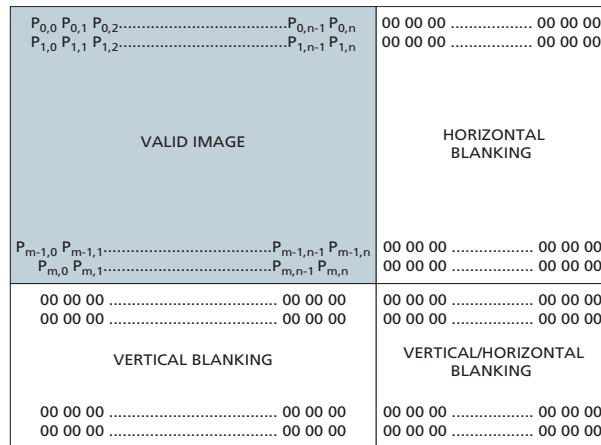
Output Data Timing

The data output of the MT9M001 is synchronized with the PIXCLK output. When LINE_VALID is HIGH, one 10-bit pixel datum is output every PIXCLK period.

Figure 6: Timing Example of Pixel Data
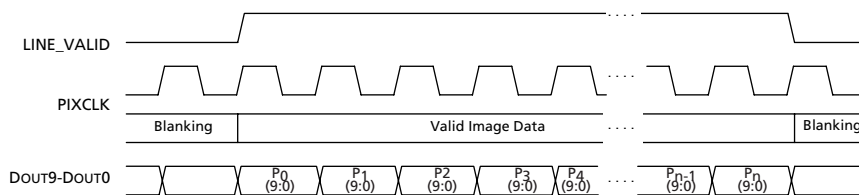
The rising edges of the PIXCLK signal are nominally timed to occur on the rising DOUT edges. This allows PIXCLK to be used as a clock to latch the data. DOUT data is valid on the falling edge of PIXCLK. The PIXCLK is HIGH while master clock is HIGH and then LOW while master clock is LOW. It is continuously enabled, even during the blanking period. The parameters P1, A P2, and Q in Figure 7 are defined in Table 4.

Figure 7: Row Timing and FRAME_VALID/LINE_VALID Signals
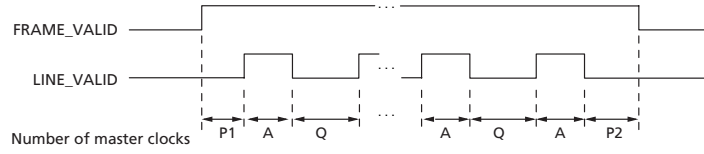
Frame Timing Formulas
Table 4: Frame Timing

Parameter	Name	Equation (MASTER CLOCK)	Default Timing	Notes
A	Active Data Time	(Reg0x04 + 1)	1,280 pixel clocks = 26.7µs	1
P_1	Frame Start Blanking	(242)	242 pixel clocks = 5.04µs	
P_2	Frame End Blanking	(2 + Reg0x05 - 19) (MIN Reg0x05 value = 19)	2 pixel clocks = 0.042µs	2
$Q = P_1 + P_2$	Horizontal Blanking	(244 + Reg0x05 - 19) (MIN Reg0x05 value = 19)	244 pixel clocks = 5.08µs	2
A + Q	Row Time	((Reg0x04 + 1) + (244 + Reg0x05 - 19))	1,524 pixel clocks = 31.75µs	
V	Vertical Blanking	(Reg0x06 + 1) x (A + Q) (MIN Reg0x06 value = 15)	39,624 pixel clocks = 825.5µs	
N_{ROWS} x (A + Q)	Frame Valid Time	(Reg0x03 + 1) x (A + Q)	1,560,576 pixel clocks = 32.51ms	
F	Total Frame Time	(Reg0x03 + 1 + Reg0x06 + 1) x (A + Q)	1,600,200 pixel clocks = 33.34ms	

Notes: 1. Row skip mode should have no effect on the integration time. Column skip mode changes the effective value of Column Size (Reg0x04) as follows:
Column Skip 2 => R4eff = (int(R4 / 4) x 2) + 1
Column Skip 4 => R4eff = (int(R4 / 8) x 2) + 1
Column Skip 8 => R4eff = (int(R4 / 16) x 2) + 1
where the int() function truncates to the next lowest integer. Now use R4eff in the equation for row time instead of R4
2. Default for Reg0x05 = 9. However, sensor ignores any value for Reg0x05 less than 19.

Sensor timing is shown above in terms of pixel clock and master clock cycles (please refer to Figure 6). The recommended master clock frequency is 48 MHz. The vertical blank and total frame time equations assume that the number of integration rows (bits 13 through 0 of Reg0x09) is less than the number of active plus blanking rows (Reg0x03 + 1 + Reg0x06 + 1). If this is not the case, the number of integration rows must be used instead to determine the frame time, as shown in Table 5.

Table 5: Frame Time—Long Integration Time

Parameter	Name	Equation (master clock)	Default Timing
V'	Vertical Blanking (long integration time)	(Reg0x09 – Reg0x03) x (A + Q)	39,624 pixel clocks = 82.5µs
F'	Total Frame Time (long integration time)	(Reg0x09 + 1) x (A + Q)	1,600,200 pixel clocks = 33.34ms

Serial Bus Description

Registers are written to and read from the MT9M001 through the two-wire serial interface bus. The sensor is a two-wire serial interface slave and is controlled by the serial clock (SCLK), which is driven by the serial interface master. Data is transferred into and out of the MT9M001 through the serial data (SDATA) line. The SDATA line is pulled up to 3.3V off-chip by a 1.5KΩ resistor. Either the slave or master device can pull the SDATA line down—the serial interface protocol determines which device is allowed to pull the SDATA line down at any given time.

Protocol

The two-wire serial interface defines several different transmission codes, as follows:

- a start bit
- the slave device eight-bit address
- a(an) (no) acknowledge bit
- an 8-bit message
- a stop bit

Sequence

A typical read or write sequence begins by the master sending a start bit. After the start bit, the master sends the slave device's eight-bit address. The last bit of the address determines if the request will be a read or a write, where a "0" indicates a write and a "1" indicates a read. The slave device acknowledges its address by sending an acknowledge bit back to the master.

If the request was a write, the master then transfers the 8-bit register address to which a write should take place. The slave sends an acknowledge bit to indicate that the register address has been received. The master then transfers the data eight bits at a time, with the slave sending an acknowledge bit after each eight bits. The MT9M001 uses 16-bit data for its internal registers, thus requiring two 8-bit transfers to write to one register. After 16 bits are transferred, the register address is automatically incremented, so that the next 16 bits are written to the next register address. The master stops writing by sending a start or stop bit.

A typical read sequence is executed as follows. First the master sends the write-mode slave address and 8-bit register address, just as in the write request. The master then sends a start bit and the read-mode slave address. The master then clocks out the register data eight bits at a time. The master sends an acknowledge bit after each 8-bit transfer. The register address is auto-incremented after every 16 bits is transferred. The data transfer is stopped when the master sends a no-acknowledge bit.

Bus Idle State

The bus is idle when both the data and clock lines are HIGH. Control of the bus is initiated with a start bit, and the bus is released with a stop bit. Only the master can generate the start and stop bits.

Start Bit

The start bit is defined as a HIGH-to-LOW transition of the data line while the clock line is HIGH.

Stop Bit

The stop bit is defined as a LOW-to-HIGH transition of the data line while the clock line is HIGH.

Slave Address

The 8-bit address of a two-wire serial interface device consists of seven bits of address and 1 bit of direction. A "0" (0xBA) in the LSB (least significant bit) of the address indicates the write mode, and a "1" (0xBB) indicates read mode.

Data Bit Transfer

One data bit is transferred during each clock pulse. The serial interface clock pulse is provided by the master. The data must be stable during the HIGH period of the two-wire serial interface clock—it can only change when the serial clock is LOW. Data is transferred eight bits at a time, followed by an acknowledge bit.

Acknowledge Bit

The master generates the acknowledge clock pulse. The transmitter (which is the master when writing, or the slave when reading) releases the data line, and the receiver indicates an acknowledge bit by pulling the data line LOW during the acknowledge clock pulse.

No-Acknowledge Bit

The no-acknowledge bit is generated when the data line is not pulled down by the receiver during the acknowledge clock pulse. A no-acknowledge bit is used to terminate a read sequence.

Two-Wire Serial Interface Sample Write and Read Sequences

16-Bit Write Sequence

A typical write sequence for writing 16 bits to a register is shown in Figure 8. A start bit given by the master, followed by the write address, starts the sequence. The image sensor will then give an acknowledge bit and expects the register address to come first, followed by the 16-bit data. After each eight-bit transfer, the image sensor will give an acknowledge bit. All 16 bits must be written before the register will be updated. After 16 bits are transferred, the register address is automatically incremented so that the next 16 bits are written to the next register. The master stops writing by sending a start or stop bit.

Figure 8: Timing Diagram Showing a Write to Reg0x09 with the Value 0x0284
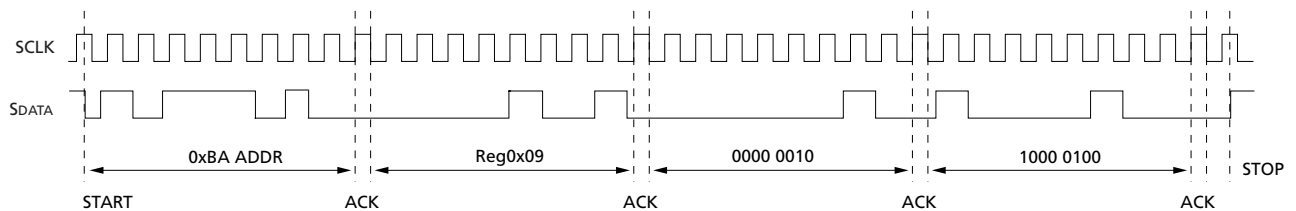
16-Bit Read Sequence

A typical read sequence is shown in Figure 9. First the master has to write the register address, as in a write sequence. Then a start bit and the read address specifies that a read is about to happen from the register. The master then clocks out the register data eight bits at a time. The master sends an acknowledge bit after each eight-bit transfer. The register address should be incremented after every 16 bits is transferred. The data transfer is stopped when the master sends a no-acknowledge bit.

Figure 9: Timing Diagram Showing a Read from Reg0x09; Returned Value 0x0284
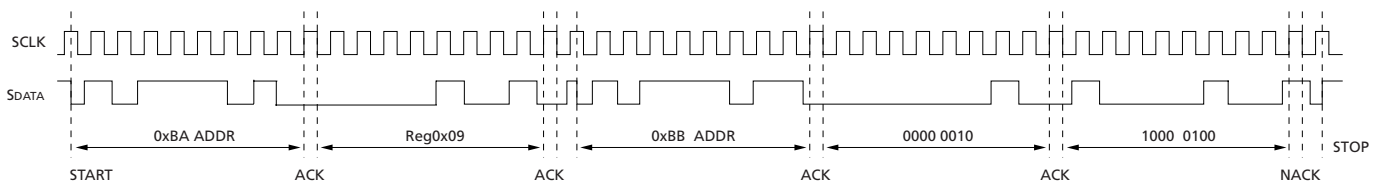
Registers

Register Map
Table 6: Register List and Default Values

Register # (Hex)	Description	Data Format (Binary)	Default Value (Hex)
0x00	Chip Version	1000 0100 0001 0001	0x8431
0x01	Row Start	0000 0ddd dddd dddd	0x000C
0x02	Column Start	0000 0ddd dddd dddd	0x0014
0x03	Row Size (Window Height)	0000 0ddd dddd dddd	0x03FF
0x04	Col Size (Window Width)	0000 0ddd dddd dddd	0x04FF
0x05	Horizontal Blanking	0000 0ddd dddd dddd	0x0009
0x06	Vertical Blanking	0000 0ddd dddd dddd	0x0019
0x07	Output Control	0000 0000 0d00 00dd	0x0002
0x09	Shutter Width	00dd dddd dddd dddd	0x0419
0x0B	Restart	0000 0000 0000 000d	0x0000
0x0C	Shutter Delay	0000 0ddd dddd dddd	0x0000
0x0D	Reset	0000 0000 0000 000d	0x0000
0x1E	Read Options 1	1000 dddd 00dd dd00	0x8000
0x20	Read Options 2	dd01 0dd1 d00d d10d	0x1104
0x2B	Even Row, Even Column	0000 0000 0ddd dddd	0x0008
0x2C	Odd Row, Even Column	0000 0000 0ddd dddd	0x0008
0x2D	Even Row, Odd Column	0000 0000 0ddd dddd	0x0008
0x2E	Odd Row, Odd Column	0000 0000 0ddd dddd	0x0008
0x35	Global Gain	0000 0000 0ddd dddd	0x0008
0x5F	Cal Threshold	dddd dddd d0dd dddd	0x0904
0x60	Even Row, Even Column	0000 000d dddd dddd	0x0000
0x61	Odd Row, Odd Column	0000 000d dddd dddd	0x0000
0x62	Cal Ctrl	d00d d100 1001 1ddd	0x0498
0x63	Even Row, Odd Column	0000 000d dddd dddd	0x0000
0x64	Odd Row, Even Column	0000 000d dddd dddd	0x0000
0xF1	Chip Enable	0000 0000 0000 00dd	0x0001

Note: 1 = always 1
0 = always 0
d = programmable

Table 7:   Register Description

Register	Bit	Description
Chip ID		
0x00	15:0	This register is read-only and gives the chip identification number: 0x8431.
Window Control		
These registers control the size of the window.		
0x01	10:0	First row to be read out—default = 0x000C (12).
0x02	10:0	First column to be read out—default = 0x0014 (20). Register value must be an even number.
0x03	10:0	Window height (number of rows - 1)—default = 0x03FF (1023). Minimum value for 0x03 = 0x0002.
0x04	10:0	Window width (number of columns - 1)—default = 0x04FF (1279). Register value must be an odd number. Minimum value for 0x04 = 0x0003.
Blanking Control		
These registers control the blanking time in a row (called column fill-in or horizontal blanking) and between frames (vertical blanking). Horizontal blanking is specified in terms of pixel clocks. Vertical blanking is specified in terms of row readout times. The actual imager timing can be calculated using Table 4, "Frame Timing," on page 10.		
0x05	10:0	Horizontal Blanking—default = 0x0009 (9 pixels).
0x06	10:0	Vertical Blanking—default = 0x0019 (25 rows).
Output Control		
This register controls various features of the output format for the sensor.		
0x07	0	Synchronize changes (copied to Reg0xF1, bit1). 0 = normal operation. Update changes to registers that affect image brightness (integration time, integration delay, gain, horizontal blanking and vertical blanking, window size, row/column skip or row mirror) at the next frame boundary. The "frame boundary" is 8 row_times before the rising edge of FRAME_VALID. (If "Show Dark Rows" is set, it will be coincident with the rising edge of FRAME_VALID.) 1 = do not update any changes to these settings until this bit is returned to "0."
	1	Chip Enable (copied to Reg0xF1, bit0). 1 = normal operation. 0 = stop sensor readout. When this is returned to "1," sensor readout restarts at the starting row in a new frame. The digital power consumption can then also be reduced to less than 5uA by turning off the master clock.
	2	Reserved—default is 0; set to zero at all times.
	3	Reserved—default is 0; set to zero at all times.
	6	Use Test Data. When set, a test pattern will be output instead of the sampled image from the sensor array. The value sent to the D_{OUT}[9:0] pins will alternate between the Test Data register (Reg0x32) in even columns and the inverse of the Test Data register for odd columns. The output "image" will have the same width, height, and frame rate as it would otherwise have. No digital processing (gain or offset) is applied to the data. When clear (the default), sampled pixel values are output normally.

Table 7: Register Description (continued)

Register	Bit	Description
Pixel Integration Control		

These registers (along with the window sizing and blanking registers) control the integration time for the pixels.

The actual total integration time (^{t}INT) is:

^{t}INT = Reg0x09 x row time - overhead time - reset delay, where:

Row time = ((Reg0x04 + 1) + 244 + Reg0x05 - 19) pixel clock periods

Overhead time = 180 pixel clock periods

Reset delay = 4 x Reg0x0C pixel clock periods

If the value in Reg0x0C exceeds (row time - 548)/4 pixel clock cycles, the row time will be extended by (4 x Reg0x0C - (row time - 548)) pixel clock cycles.

In this expression, the row time term, Reg0x09 x ((number of columns) + 244 + horizontal blanking register - 19), corresponds to the number of rows integrated. The overhead time (180 pixel clocks) is the overhead time between the READ cycle and the RESET cycle, and the final term is the effect of the reset delay.

Typically, the value of Reg0x09 is limited to the number of rows per frame (which includes vertical blanking rows) such that the frame rate is not affected by the integration time. If Reg0x09 is increased beyond the total number of rows per frame, the MT9M001 will add additional blanking rows as needed. A second constraint is that ^{t}INT must be adjusted to avoid banding in the image from light flicker. Under 60Hz flicker, this means ^{t}INT must be a multiple of 1/120 of a second. Under 50Hz flicker, ^{t}INT must be a multiple of 1/100 of a second.

Register	Bit	Description
0x09	13:0	Number of rows of integration—default = 0x0419 (1049).
0x0C	10:0	Shutter delay—default = 0x0000 (0). This is the number of master clocks times four that the timing and control logic waits before asserting the reset for a given row.
Frame Restart		
0x0B	0	Setting bit 0 to "1" of Reg0x0B will cause the sensor to abandon the readout of the current frame and restart from the first row. This register automatically resets itself to 0x0000 after the frame restart. The first frame after this event is considered to be a "bad frame" (see description for Reg0x20, bit0).
Reset		
0x0D	0	This register is used to reset the sensor to its default, power-up state. To put the MT9M001 in reset mode first write a "1" into bit 0 of this register, then write a "0" into bit 0 to resume operation.

Table 7: Register Description (continued)

Register	Bit	Description
Read Mode 1		
In read mode 1, this register is used to control many aspects of the readout of the sensor.		
0x1E	0	Reserved—default is 0; set to zero at all times.
	1	Reserved—default is 0; set to zero at all times.
	2	Column Skip 4—default is 0 (disable). 1 = enable.
	3	Row Skip 4—default is 0 (disable). 1 = enable.
	4	Column Skip 8—default is 0 (disable). 1 = enable.
	5	Row Skip 8—default is 0 (disable). 1 = enable.
	6	Reserved—default is 0; do not change.
	7	Reserved—default is 0; do not change.
	8	Snapshot Mode—default is 0 (continuous mode). 1 = enable (wait for TRIGGER; TRIGGER can come from outside signal (TRIGGER pin on the sensor) or from serial interface register restart, i.e. programming a "1" to bit 0 of Reg0x0B.
	9	STROBE Enable—default is 0 (no STROBE signal). 1 = enable STROBE (signal output from the sensor during the time all rows are integrating. See STROBE width for more information).
	10	STROBE Width—default is 0 (STROBE signal width at minimum length, 1 row of integration time, prior to line valid going HIGH). 1 = extend STROBE width (STROBE signal width extends to entire time all rows are integrating).
	11	Strobe Override—default is 0 (STROBE signal created by digital logic). 1 = override STROBE signal (STROBE signal is set HIGH when this bit is set, LOW when this bit is set LOW. It is assumed that STROBE enable is set to "0" if STROBE override is being used).
	12	Reserved—default is 0; do not change.
	13	Reserved—default is 0; do not change.
	14	Reserved—default is 0; do not change.
	15	Reserved—default is 1; do not change.
Gain Settings		

The gain is individually controllable for each of the four groups of pixels that lie in odd rows and columns, even rows and columns, odd rows and even columns, and even rows and odd columns. This is shown in the register chart.
 	
Formula for gain setting:
Gain $\leq$ 8
       Gain = (bit[6] + 1) x (bit[5-0] x 0.125)
Gain > 8 (bit[6] = 1 and bit[5] = 1)
       Gain = 8.0 + bit[2-0]
 	
Since bit[6] of the gain registers are multiplicative factors for the gain settings, there are alternative ways of achieving certain gains. Some settings offer superior noise performance to others, despite the same overall gain. The following lists the recommended gain settings:
 	
   <u>Gain</u>   <u>Increments</u>   <u>Recommended Settings</u>
1.000 to 4.000   0.125   0x08 to 0x20
4.25 to 8.00   0.25   0x51 to 0x60
9.0 to 15.0 1.0 0x61 to 0x67		

0x2B	6:0	Even row, even column—default = 0x08 (8) = 1x gain.
0x2C	6:0	Odd row, even column—default = 0x08 (8) = 1x gain.

Table 7: Register Description (continued)

Register	Bit	Description
0x2D	6:0	Even row, odd column—default = 0x08 (8) = 1x gain.
0x2E	6:0	Odd row, odd column—default = 0x08 (8) = 1x gain.
0x35	6:0	Global gain—default = 0x08 (8) = 1x gain. This register can be used to set all four gains at once.
Test Data		
0x32	11:2	Test Data. The value used to produce a test pattern in "Use Test Data" mode (Reg0x07 bit 6).
Read Mode 2 This register is used to control many aspects of the readout of the sensor.		
0x20	0	No bad frames—1 = output all frames (including bad frames). 0 (default) = only output good frames. A bad frame is defined as the first frame following a change to: window size or position, horizontal blanking, row or column skip, or mirroring.
	1	Reserved—default is 0; do not change.
	2	Reserved—default is 1; set to "1" at all times.
	3	Column skip—1= read out two columns, and then skip two columns (for example, col 0, col 1, col 4, col 5…). 0 = normal readout (default).
	4	Row skip—1 = read out two rows, and then skip two rows (for example, row 0, row 1, row 4, row 5…). 0 = normal readout (default).
	5	Reserved—default is 0; do not change.
	6	Reserved—default is 0; set to zero at all times.
	7	Flip Row—1 = readout starting 1 row later (alternate color pair). 0 (default) = normal readout.
	8	Reserved—default is 1; set to "1" at all times.
	9	1 = "Continuous" LINE_VALID (continue producing LINE_VALID during vertical blanking). 0 = normal LINE_VALID (default, no LINE_VALID during vertical blanking).
	10	1 = LINE_VALID = "Continuous" LINE_VALID XOR FRAME_VALID. 0 = LINE_VALID determined by bit 9.
	11	Reserved—default is 0; do not change.
	12	Reserved—default is 1; do not change.
	13	Reserved—default is 0; do not change.
	14	Reserved—default is 0; do not change.
	15	Mirror Row—1 = read out from bottom to top (upside down). 0 (default) = normal readout (top to bottom).
Test Data		
0x32	11:2	Test Data. The value used to produce a test pattern in "Use Test Data" mode (Reg0x07 bit 6).
Black Level Calibration These registers are used in the black level calibration. Their functionality is described in detail in the next section.		

Table 7:   Register Description (continued)

Register	Bit	Description
0x5F	5:0	Thres_lo—Lower threshold for black level in ADC LSBs—default = 000100.
	7	1 = override automatic Thres_hi and Thres_lo adjust (Thres_hi always = bits 14:8; Thres_lo always = bits 5:0). Default = 0 = Automatic Thres_hi and Thres_lo adjustment.
	14:8	Thres_hi—Maximum allowed black level in ADC LSBs (default = Thres_lo + 5). Black level maximum is set to this value when bit 7 = 1; black level maximum is reset to this value after every black level average restart if bit 15 = 1 and bit 7 = 0.
	15	No gain dependence. 1 = Thres_lo is set by the programmed value of bits 5:0, Thres_hi is reset to the programmed value (bits 14:8) after every black level average restart. 0 = Thres_lo and Thres_hi are set automatically, as described above.
0x60	8:0	Even row, even column—analog offset correction value for even row, even column, bits 0:7 sets magnitude, bit 8 set sign. 0 = positive; 1 = negative. two's complement, if bit 8 = 1, Offset = bits [0:7] - 256.
0x61	8:0	Odd row, odd column—analog offset correction value for odd row, odd column, bits 0:7 sets magnitude, bit 8 set sign. 0 = positive; 1 = negative. two's complement, if bit 8 = 1, Offset = bits [0:7] - 256.
0x62	0	Manual override of black level correction. 1 = override automatic black level correction with programmed values. 0 = normal operation (default).
	2:1	Force/disable black level calibration. 00 = apply black level calibration during ADC operation only (default). 10 = apply black level calibration continuously. X1= disable black level correction (Offset Correction Voltage = 0.0V). (In this case, no black level correction is possible).
	4:3	Reserved—default is 1; do not change.
	6:5	Reserved—default is 0; do not change.
	7	Reserved—default is 1; do not change.
	9:8	Reserved—default is 0; do not change.
	10	Reserved—default is 1; do not change.
	11	1 = do not reset the upper threshold after a black level recalculation sweep. 0 = reset the upper threshold after a black level recalculation sweep (default).
	12	1 = start a new running digitally filtered average for the black level (this is internally reset to "0" immediately), and do a rapid sweep to find the new starting point. 0 = normal operation (default).
	14:3	Reserved—default is 0; set to zero at all times.
	15	1 = do not perform the rapid black level sweep on new gain settings. 0 = normal operation.
0x63	8:0	Even row, odd column—analog offset correction value for even row, odd column, bits 0:7 sets magnitude, bit 8 set sign. 0 = positive; 1 = negative. two's complement, if bit 8 = 1, Offset = bits [0:7] - 256.
0x64	8:0	Odd row, even column—analog offset correction value for odd row, even column, bits 0:7 sets magnitude, bit 8 set sign. 0 = positive; 1 = negative. two's complement, if bit 8 = 1, Offset = bits [0:7] - 256.

Table 7:   Register Description (continued)

Register	Bit	Description
Chip Enable and Two-Wire Serial Interface Write Synchronize.		
0xF1	0	Mirrors the functionality of Reg0x07 bit1 (Chip Enable). 1 = normal operation. 0 = stop sensor readout; when this is returned to "1," sensor readout restarts at the starting row in a new frame.

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Feature Description

Signal Path

The MT9M001 signal path consists of two stages, a programmable gain stage and a programmable analog offset stage.

Programmable Gain Stage

A total programmable gain of 15 is available and can be calculated using the following formula:

Gain 1 to 8:   Gain = (bit[6] + 1) x (bit[5:0] x 0.125)

For gain higher than eight, the user would need to set bit[6:5] = 11 and use the lower 3 LSB's bit[2:0] to set the higher gain values. The formula for obtaining gain greater than eight is as follows:

Total gain = 8 + bit[2:0]

For example, for total gain = 12, the value to program is bit[6–0] = 1100100.

The maximum total gain = 15, i.e. bit[6:0] = 1100111.

The gain circuitry in the MT9M001 is designed to offer signal gains from one to 15. The minimum gain of one corresponds to the lowest setting where the pixel signal is guaranteed to saturate the ADC under all specified operating conditions. Any reduction of the gain below this value may cause the sensor to saturate at ADC output values less than the maximum, under certain conditions. It is recommended that this guideline be followed at all times.

Since bit[6] of the gain registers are multiplicative factors for the gain settings, there are alternative ways of achieving certain gains. Some settings offer superior noise performance to others, despite the same overall gain. Recommended gain settings are listed in Table 8.

Figure 10: Signal Path
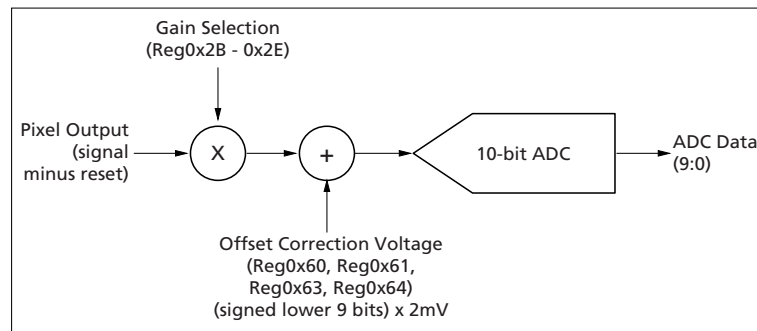
Table 8:   Recommended Gain Settings at 48 MHz

Nominal Gain	Increments	Recommended Settings
1 to 4.000	0.125	0x08 to 0x20
4.25 to 8.00	0.25	0x51 to 0x60
9 to 15	1.0	0x61 to 0x67

Programmable Analog Offset Stage

The programmable analog offset stage corrects for analog offset that might be present in the analog signal. The user would need to program register 0x62 appropriately to enable the analog offset correction.

The lower eight bits (bit[7:0]) determines the absolute value of the analog offset to be corrected and bit[8] determines the sign of the correction. When bit[8] is "1", the sign of the correction is negative and vice versa. The analog value of the correction relative to the analog gain stage can be determined from the following formula:

Analog offset (bit[8] = 0) = bit[7:0] x 2mV

Analog offset (bit[8] = 1) = - (bit[7:0] x 2mV)

Column and Row Mirror Image

By setting bit 14 of Reg0x20, the readout order of the columns will be reversed, as shown in Figure 11.

Figure 11: Readout of Six Columns in Normal and Column Mirror Output Mode
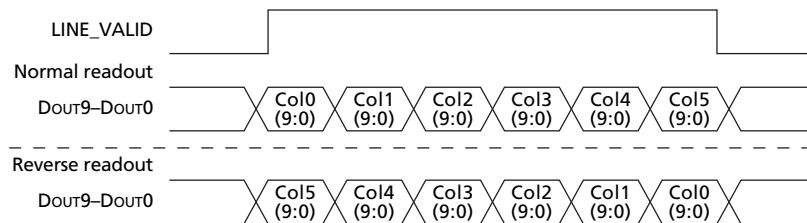
By setting bits 15 of Reg0x20 the readout order of the rows will be reversed, as shown in Figure 12.

Figure 12: Readout of Six Rows in Normal and Row Mirror Output Mode
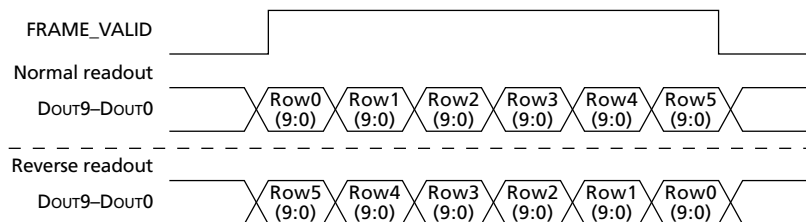
Column and Row Skip

By setting bit 3 of Reg0x20, only half of the columns set will be read out. An example is shown in Figure 13. Only columns with bit 1 equal to "0" will be read out (xxxxxxx0x). The row skip works in the same way and will only read out rows with bit 1 equal to "0." Row skip mode is enabled by setting bit 4 of Reg0x20. For both row and column skips, the number of rows or columns read out will be half of what is set in Reg0x03 or Reg0x04, respectively.

Figure 13: Readout of Eight Pixels in Normal and Column Skip Output Mode
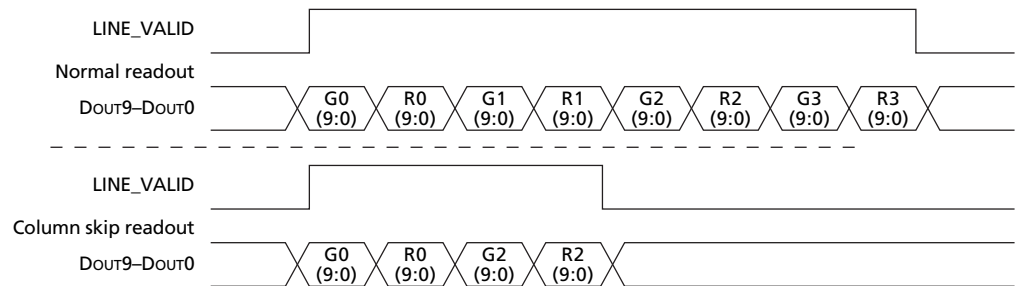
Black Level Calibration

The MT9M001 has automatic black level calibration on-chip which can be overridden by the user, as described below and shown in Figure 14.

The automatic black level calibration measures the average value of 256 pixels from two dark rows of the chip for each of the four colors. The pixels are averaged as if they were light-sensitive and passed through the appropriate color gain. This average is then digitally filtered over many frames.

For each color, the new filtered average is compared to a minimum acceptable level (to screen for too low a black level) and a maximum acceptable level. If the average is lower than the minimum acceptable level, the offset correction voltage for that color is increased by one offset LSB (offset LSBs do not match ADC LSBs; typically, one offset LSB is approximately 2mV). If it is above the maximum level, the level is decreased by 1 LSB (2mV). The upper threshold is automatically adjusted upwards whenever an upward shift in the black level from below the minimum results in a new black level above the maximum. This prevents black level oscillation from below the minimum to above the maximum. The lower threshold is increased with the maximum gain setting according to the formula described under Reg0x5F. This prevents clipping of the black level.

Whenever the gain or any of the readout timing registers is changed (shutter width, vertical blanking, number of rows or columns, or the shutter delay) or if the black level recalculation bit, reset bit or restart bit is set, the running digitally filtered average is reset to the first average of the dark pixels. The digital filtering over many frames is then restarted. Whenever the gain or the readout timing registers are changed, the upper threshold is restored to its default value.

After changes to the sensor configuration, large shifts in the black level calibration can result. To quickly adapt to this shift, a rapid sweep of the black level during the dark-row readout is performed on the first frame after certain changes to the sensor registers. Any changes to the registers listed above will cause this recalculation. The data from this sweep allows the sensor to choose an accurate new starting point for the running average. This procedure can be disabled as described under Reg0x5F.

Figure 14: Black Level Calibration Flow Chart
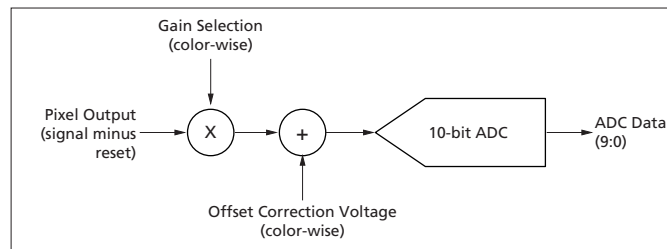
Registers

Table 9:   Black Level Registers

Register	bit	Description
Reg0x5F This register controls the operation of the black level calibration thresholds.		
	15	No gain dependence. 1 = Thres_lo is set by the programmed value of bits 5:0, Thres_hi is reset to the programmed value (bits 14:8) after every black level average restart. 0 = Thres_lo and Thres_hi are set automatically as described below.
	14:8	Thres_hi—maximum allowed black level in ADC LSBs (default = Thres_lo + 5). Black level maximum is set to this value when bit 7 = 1, black level maximum is reset to this value after every black level average restart if bit 15 = 1 and bit 7 = 0.
	7	1 = override automatic Thres_hi and Thres_lo adjust (Thres_hi always = bits 14:8, Thres_lo always = bits 5:0). 0 = automatic Thres_hi and Thres_lo adjustment.
	5:0	Thres_lo—Lower threshold for black level in ADC LSBs. Under default automatic operation (bit 7 = 0, bit 15 = 0), Thres_lo = $RegGain_{max}/4$ x ($RegGain_{max}$, bit 6 +1) x ($RegGain_{max}$, bit 7 +1), where $RegGain_{max}$ is the maximum of the four independent gain register settings. Whenever a jump in the calibration causes the black level data to change from below Thres_lo to above Thres_hi, Thres_hi is adjusted according to the following: If new black level < 64: Thres_hi = Thres_lo + 2 + (2 x Delta), where Delta = new black level - Thres_lo If new black level > 63 and < 119: Thres_hi = new black level + 4 If new black level > 119: Thres_hi = 123 After any recalculation of the black level and average restart, Thres_hi is reset to either Thres_lo + 5 (automatic, default mode), Thres_hi (bit 7 = 1). Reg0x62, bit 11 will override this.
Reg0x62 This register is used to control the automatic black level calibration circuitry.		
	15	1 = do not perform the rapid black level sweep on new gain settings. 0 = normal operation.
	14	Reserved—default is 0; do not change.
	13	Reserved—default is 0; do not change.
	12	1 = start a new running digitally filtered average for the black level (this is internally reset to "0" immediately), and do a rapid sweep to find the new starting point.
	11	1 = do not reset the upper threshold after a black level recalculation sweep. 0 = reset the upper threshold after a black level recalculation sweep (default).
	10:3	Reserved—default is 1; do not change.
	2:1	Force/disable black level calibration. 00 = apply black level calibration during ADC operation only (default). 10 = apply black level calibration continuously. X1 = disable black level correction (Offset Correction Voltage = Skew Voltage = 0.0V). (In this case, no black level correction is possible).
	0	Manual override of black level correction. 1 = override automatic black level correction with programmed values. 0 = normal operation (default).

Registers

Table 9:   Black Level Registers (continued)

Register	bit	Description
Reg0x60, Reg0x61, Reg0x63, Reg0x64		These registers contain the 9-bit signed black level calibration values. In normal operation, these values are calculated at the beginning of each frame. However, if Reg0x62, bit 0 is set to "1," these registers can be written to, overriding the automatic black level calculation. This feature can be used in conjunction with readout of the black rows (Reg0x20, bit 11) if the user would like to use an external black level calibration circuit. The offset correction voltage is generated according to the following formula: Offset Correction Voltage = (9-bit signed calibration value, -256 to 255) x (2mV x Enable bit) two's complement, if bit 8 = 1, Offset = bits [0:7] - 256 ADC input voltage = Pixel Output Voltage x Analog Gain - Offset Correction Voltage

Still Image Capture with External Synchronization

In continuous mode video image capture, the TRIGGER signal should be held LOW or "0." To capture a still image, the sensor must first be put into snapshot mode by programming a "1" in register 0x1E, bit 8. In snapshot mode, the sensor waits for a TRIGGER signal (FRAME_VALID, LINE_VALID signals are LOW, pixel clock signal continues). When the TRIGGER signal is received (active HIGH), one frame is read out (a TRIGGER signal can also be achieved by programming a restart—for example, program a "1" to bit 0 of Reg0x0B). The reset, readout timing for that frame will be the same as for a continuous frame with similar register settings; the only difference is that only one frame is read out. General timing for the snapshot mode is shown in Figure 15.

Figure 15: General Timing for Snapshot Mode
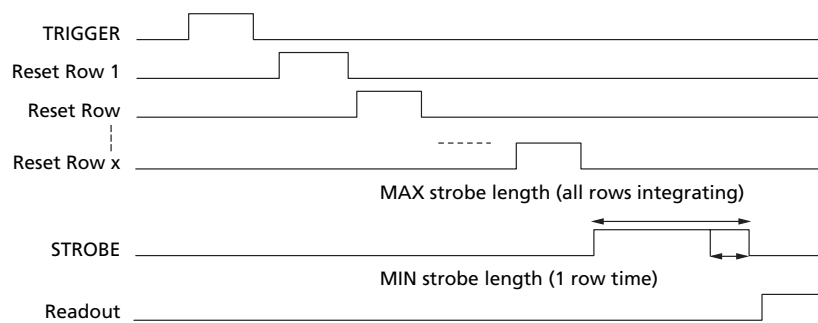
LINE_VALID Signal

By setting bit 9 and 10 of Reg0x20 the line valid signal can get three different output formats. The formats are shown when reading out four rows and two vertical blanking rows (Figure 16). In the last format, the LINE_VALID signal is the XOR between the continuously LINE_VALID signal and the FRAME_VALID signal.

Figure 16: Different LINE_VALID Formats
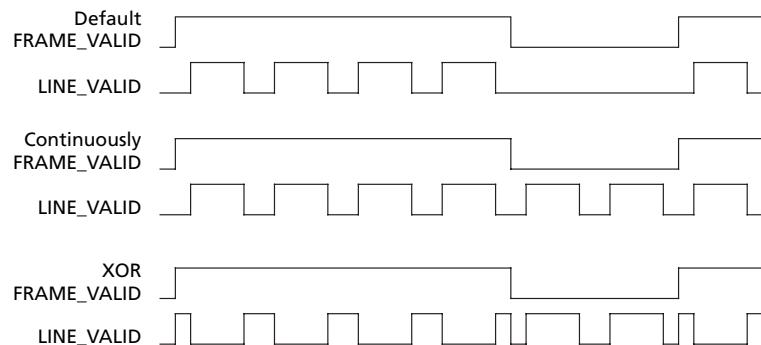
Electrical Specifications

Data Output and Propagation Delays

By default, the MT9M001 launches pixel data, FRAME_VALID and LINE_VALID with the rising edge of PIXCLK. The expectation is that the user captures DOUT[7:0], FRAME_VALID and LINE_VALID using the falling edge of PIXCLK.

Figure 17: Data Output Timing Diagram

Note: Frame_Valid leads Line_Valid by 242 PIXCLKs.

Note: Frame_Valid trails Line_Valid (1+ Reg0x05-19) PIXCLKS.
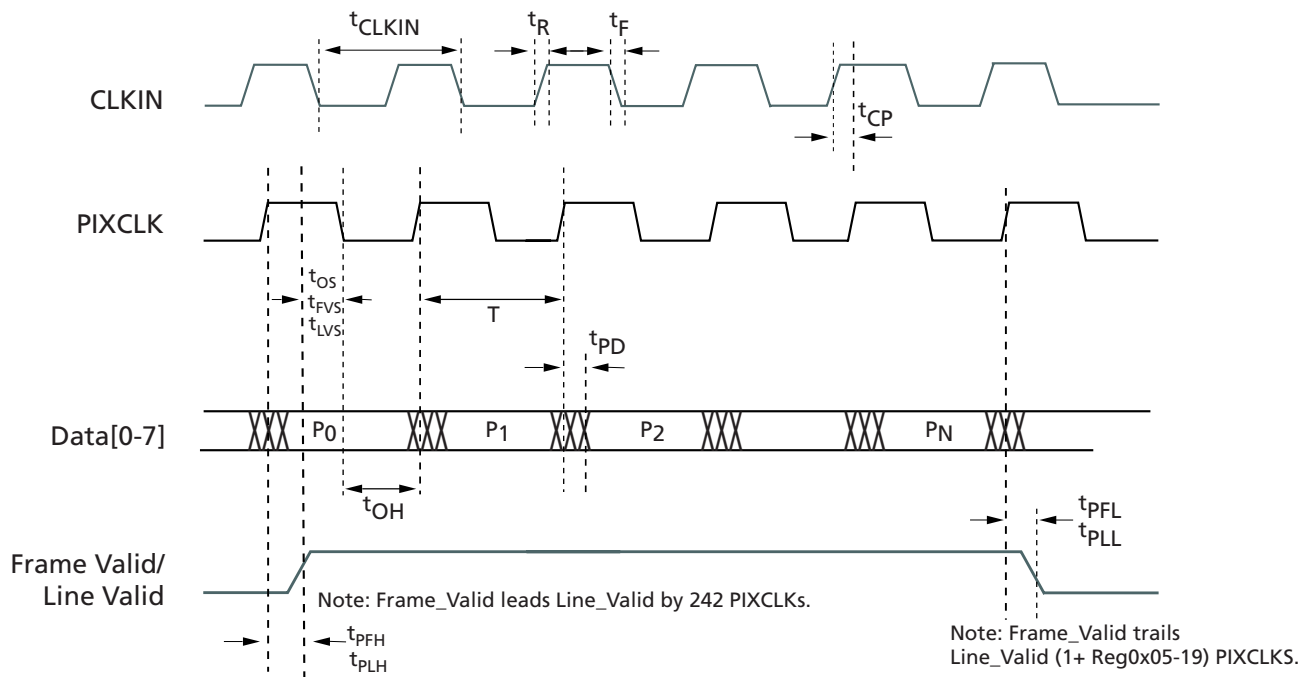
Table 10: DC Electrical Characteristics

(DC Setup Conditions: ^{f}CLKIN = 48 MHz, V_{DD} = 3.3V, V_{AA} = 3.3V, VAAPIX = 3.3V, T_A = 25°C)

Symbol	Definition	Condition	Min	Typ	Max	Units
V_{DD}	Core digital voltage		3	3.3	3.6	V
V_{AA}	Analog voltage		3	3.3	3.6	V
VAAPIX	Pixel supply voltage		3	3.3	3.6	V
V_{IH}	Input high voltage		V_{PWR} - 0.3		V_{PWR} + 0.3	V
V_{IL}	Input low voltage		-0.3		0.8	V
I_{IN}	Input leakage current	No Pull-up Resistor; V_{IN} = V_{DD} or D_{GND}	-15		15	µA
V_{OH}	Output high voltage		V_{PWR} - 0.2		—	V
V_{OL}	Output low voltage				0.2	V
I_{OZ}	Tri-state output leakage current		—		15	µA
I_{DD}	Digital operating current		—	20	24	mA
I_{AA}	Analog operating current		—	85	110	mA

Table 10: DC Electrical Characteristics (continued)

(DC Setup Conditions: ^{f}CLKIN = 48 MHz, V$_{DD}$ = 3.3V, V$_{AA}$ = 3.3V, VAAPIX = 3.3V, T$_A$ = 25°C)

Symbol	Definition	Condition	Min	Typ	Max	Units
I$_{AAPIX}$	Pixel supply current		—	5	10	mA
I$_{STDBYD}$	Digital standby current	STDBY = V$_{DD}$, CLKIN = 0 MHz	—	9	20	mA
I$_{STDBYD}$ w/CLK	Digital standby current	STDBY = V$_{DD}$, CLKIN = 48 MHz	—	55	125	µA
I$_{STDBYDA}$	Analog standby current	STDBY = V$_{DD}$	—	80	100	µA

Table 11: AC Electrical Characteristics

(AC Setup Conditions: ^{f}CLKIN= 48 MHz, V$_{DD}$ = 3.3V, V$_{AA}$ = 3.3V, VAAPIX = 3.3V, Output Load = 30pF, T$_A$ = 25°C))

Symbol	Definition	Condition	Min	Typ	Max	Unit
^{f}CLKIIN	Input clock frequency		1	—	48	MHz
^{t}CLKIN	Input clock period		1000	—	20.83	ns
T	PIXCLK period		1000	—	20.83	ns
^{t}R	Input clock rise time			4		V/ns
^{t}F	Input clock fall time		—	4		V/ns
	Clock duty cycle		45	50	55	%
^{t}CP	CLKIN to PIXCLK propagation delay		—	10	—	ns
^{t}PD	PIXCLK to data valid		—	—	1	ns
^{t}PFH	PIXCLK to FV high		—	—	7	ns
^{t}PLH	PIXCLK to LV high		—	—	7	ns
^{t}PFL	PIXCLK to FV low		—	—	13	ns
^{t}PLL	PIXCLK to LV low		—	—	13	ns
^{t}OS	Setup time for data before falling edge of PIXCLK		T/2 -1	T/2	T/2 +1	ns
^{t}OH	Hold time for data after falling edge of PIXCLK		T/2 -1	T/2	T/2 +1	ns
^{t}FVS	Setup time for FV before falling edge of PIXCLK		2	3	—	ns
^{t}LVS	Setup time for LV before falling edge of PIXCLK		2	3	—	ns
C$_{LOAD}$	Load capacitance				30	pF

Table 12: Absolute Maximum Ratings

Symbol	Parameter	Rating		Unit
		MIN	MAX	
T$_{OP}$	Operating temperature	0	70	°C
T$_{STG}$[1]	Storage temperature	–40	125	°C

Note: [1]Stresses greater than those listed may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

Two-wire Serial Bus Timing

The two-wire serial bus operation requires certain minimum master clock cycles between transitions. These are specified in the following diagrams in master clock cycles.

Figure 18:   Serial Host Interface Start Condition Timing
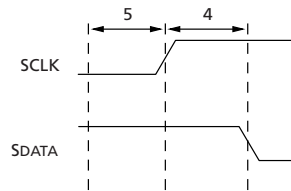
Figure 19:   Serial Host Interface Stop Condition Timing
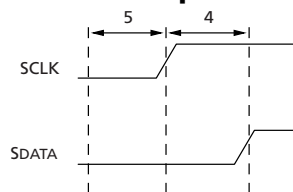
Note: All timing are in units of master clock cycle.

Figure 20:   Serial Host Interface Data Timing for Write
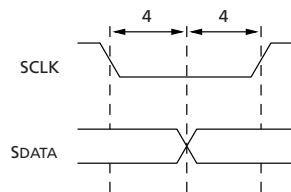
Note: SDATA is driven by an off-chip transmitter.

Figure 21:   Serial Host Interface Data Timing for Read
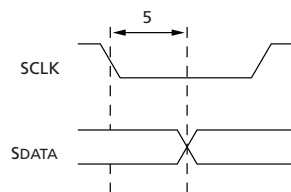
Note: SDATA is pulled LOW by the sensor, or allowed to be pulled HIGH by a pull-up resistor off-chip.

Figure 22: Acknowledge Signal Timing After an 8-Bit Write to the Sensor
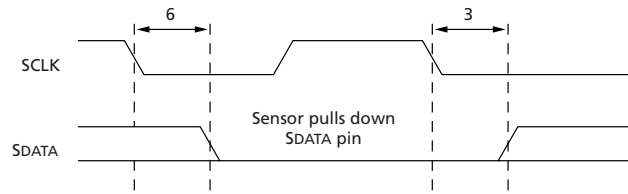
Figure 23: Acknowledge Signal Timing After an 8-Bit Read from the Sensor
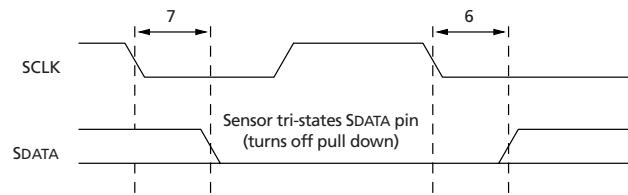
Note: After a read, the master receiver must pull down SDATA to acknowledge receipt of data bits. When read sequence is complete, the master must generate a no acknowledge by leaving SDATA to float HIGH. On the following cycle, a start or stop bit may be used.

Quantum Efficiency

Figure 24: Quantum Efficiency—Monochrome
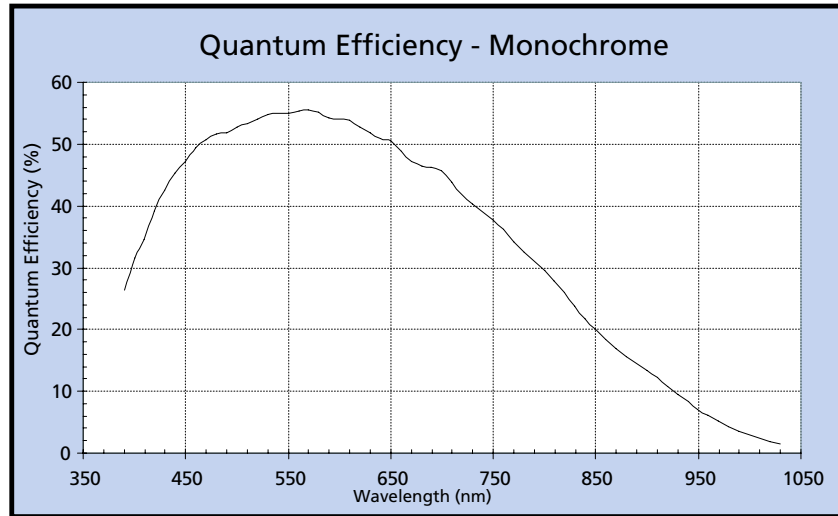
Image Center Offset and Orientation

Figure 25: Image Center Offset
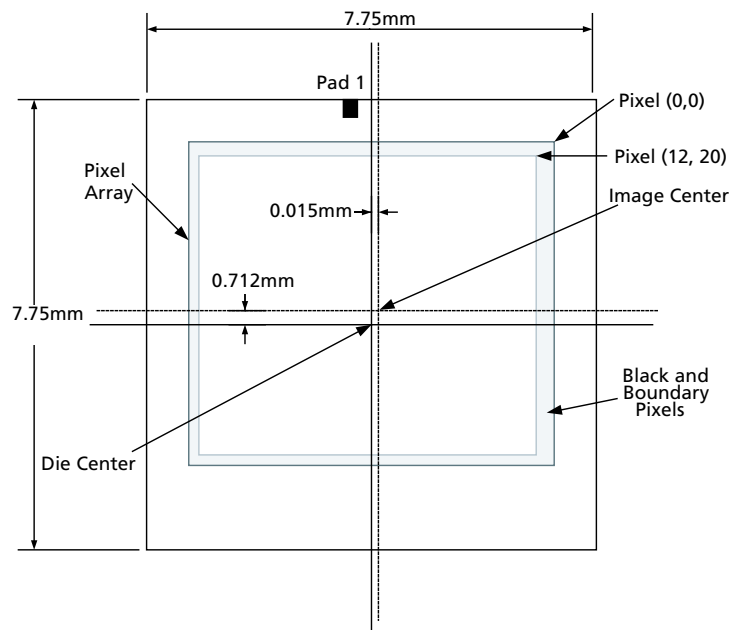
Table 13:   Optical Area Dimensions

Optical Area	Pixel	X-Dimension	Y-dimension
SXGA	Center of pixel (20, 12)	3,340.70µm	3,372.45µm
	Center of Pixel (1299, 1035)	-3,315.2µm	-1,952.35µm
Chip Size, mm	(including Seal Ring)	7.75mm	7.75mm

Notes: 1. X and Y coordinates referenced to center of die.
2. Die center = package center.
3. Image center offset from package center (x = 0.015mm, y = 0.712mm).

Figure 26: Optical Orientation

Figure 27: 48-pin CLCC Package Outline Drawing

SUBSTRATE MATERIAL: ALUMINA CERAMIC
LID MATERIAL: BOROSILICATE GLASS 0.55 THICKNESS

LEAD FINISH: GOLD PLATING, 20 MICRO INCHES MINIMUM THICKNESS

MAXIMUM ROTATION OF OPTICAL AREA RELATIVE TO PACKAGE EDGES [B] AND [C] : 1°
MAXIMUM TILT OF OPTICAL AREA RELATIVE TO SEATING PLANE [A] : 50 MICRONS
MAXIMUM TILT OF OPTICAL AREA RELATIVE TO TOP OF COVER [D] : 50 MICRONS
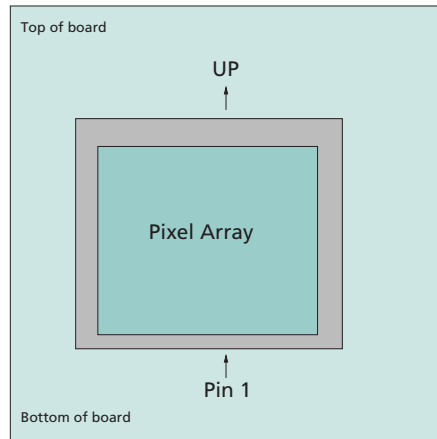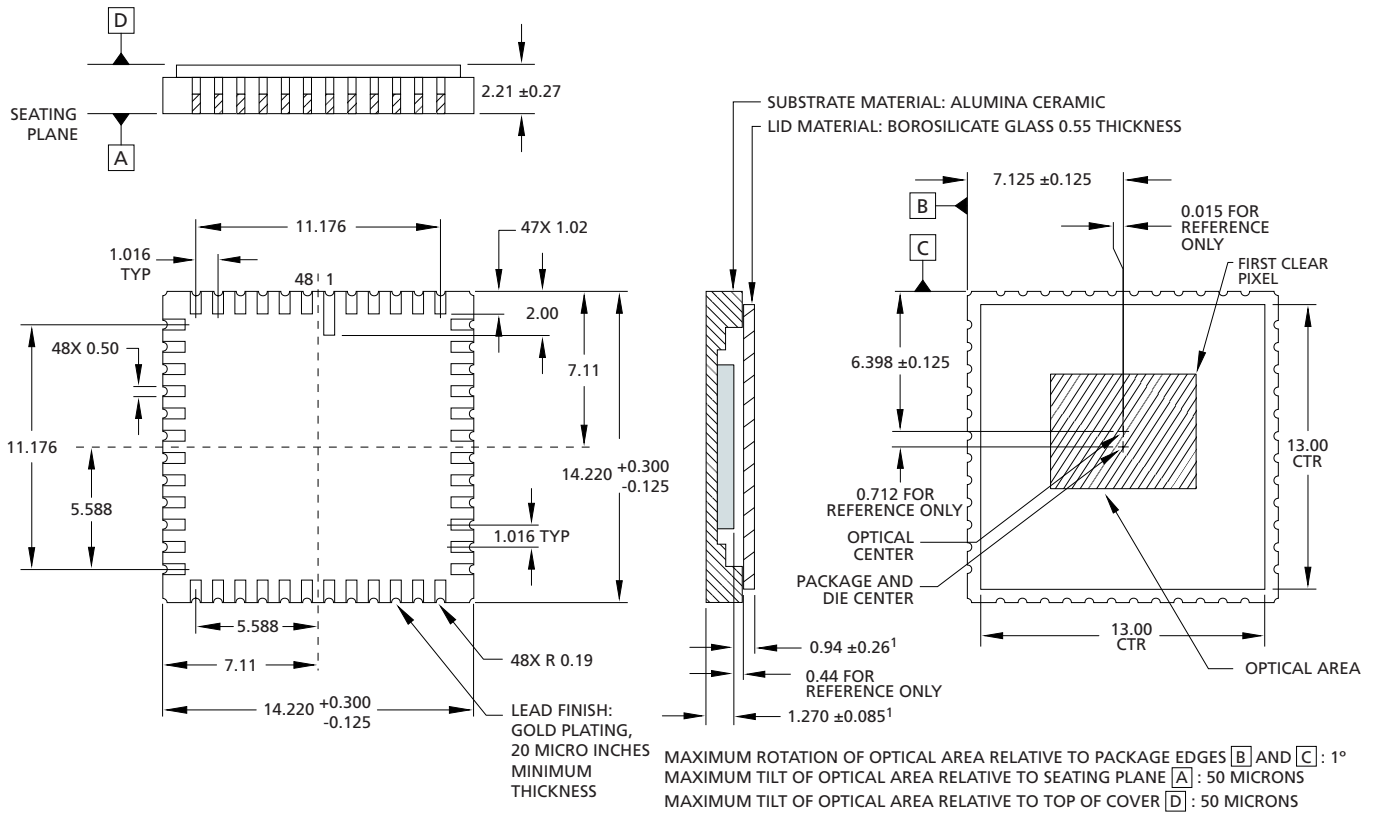
NOTE: 1. THESE DIMENSIONS ARE NON ACCUMULATIVE

Note: All dimensions in millimeters.

Revision History

- Updated Table 2, "Available Part Numbers," on page 1

- Updated "Data Output and Propagation Delays" on page 28
- UpdatedTable 11, "AC Electrical Characteristics," on page 29

- Updated Table 1, "Key Performance Parameters," on page 1
- Update Table 2, "Available Part Numbers," on page 1
- Updated Figure 4: "Pixel Pattern Detail (Top Right Corner)," on page 7

- Remove color information
- Updated Table 1, "Key Performance Parameters," on page 1
- Updated Table 6, "Register List and Default Values," on page 14
- Updated Table 7, "Register Description," on page 15
- Updated Figure 12, Readout of Six Rows in Normal and Row Mirror Output Mode, on page 22
- Deleted Figure 13, Readout of Eight Pixels in Normal and Column Skip Output Mode, on page 23
- Updated Table 11, "AC Electrical Characteristics," on page 29
- Updated Figure 25, Image Center Offset, on page 32
- Updated Figure 27, 48-pin CLCC Package Outline Drawing, on page 34

- Page 1, remove PRELIMINARY disclaimer
- Page 1, add Key Performance Parameters table, add APPLICATIONS
- Page 2, add Table of Contents
- Page 6, update Pin Description table
- Page 11, update Serial Bus Description
- Page 12, update Timing Diagram Showing a Read from Reg0x09; Returned Value 0x0284 figure
- Page 13, update Register List and Default Values table
- Page 14, update Register Description Table (add Test Data-Reg0x32[11:2], update Output Control-Reg0x07[6]
- Page 28, update AC and DC Electrical Characteristics table
- Page 29, add Figure 17, Data Output Timing Diagram, and Absolute Maximum Ratings, Table 11
- Page 30, update Propagation Delay for Frame_Valid and Line_Valid Signals (Data Output and Propagation Delays
- Page 32, delete Quantum Efficiency figure (Color)
- Page 33, update Figure 27, 48-pin CLCC Package Outline Drawing

- Initial Release of document

THORLABS

Thorlabs Digital Camera
Quick Start Guide

Table of Contents

Chapter 1 Description

1.1.   Introduction

This booklet is a Quick Start Guide to the installation of Thorlabs Compact and Scientific-Grade cameras, and it is meant to be a companion to the camera user guides in the Program Files\Thorlabs\Scientific Imaging\Documentation folder that will be installed with your software. This Quick Start Guide is intended to provide basic information regarding the initial set-up and installation of your camera.

It is highly recommended that you familiarize yourself with the detailed information contained in the documentation folder associated with your specific camera model and Thorlabs Software once you have completed this installation.

1500_Series_Digital_Camera_User_Guide

Scientific_Series_Digital_Camera_User_Guide

Compact_Scientific_Series_Digital_Camera_User_Guide

TSI_Application_Programming_Interface_Guide

ThorCam_Software_User_Guide

DCx_User_and_SDK_Manual

1.2.   Receiving and Unpacking

Your camera was thoroughly tested and carefully packed at the factory. Once the camera shipment is accepted for delivery, the carrier assumes full responsibility for its safe arrival. Should you receive your shipment with any damage—concealed or apparent—please contact the carrier at once. The carrier will instruct you on how to initiate a damage claim. If a visual inspection reveals damage upon receipt, it must be noted on the freight bill or express receipt and the notation signed by the carrier's agent. Failure to do so can result in the carrier refusing to honor the claim.

To return your camera to TSI for service, you must first contact your local Thorlabs office or distributor and request a Return Material Authorization (RMA). Returns will not be accepted without an RMA. See chapter titled "Warranty Information" for details.

Chapter 2 Safety

2.1.   Precautions

⚠️   ATTENTION USERS   ⚠️

This attention symbol indicates that additional information is available in these user guides.

Please read the instruction manual for the appropriate model device carefully before operating your Digital Video Camera. All statements regarding safety and technical specifications are published in that document and will only apply when the unit is operated correctly.

Refer to this Quick Start Guide or User Guide whenever the following symbols are encountered on the Digital Video Camera and Power Supply:

This equipment is intended for laboratory use only and is not certified for medical applications, including but not limited to, life support situations.

⚠️ **Check the supply voltage of the system BEFORE plugging in the power supply. Make sure the included power cord is the correct type for the service you are connecting to AND connected to a properly grounded power outlet (100 – 240 VAC; 50 – 60 Hz).**

Transportation and delivery may cause the Digital Video Camera to be warm or cool upon receipt. Please wait for the device to reach room temperature before attempting to operate.

There are NO user accessible fuses in this Digital Video Camera or the included External Power Supply.

⚠️ **Do not open the Digital Video Camera or the External Power Supply. Doing so is dangerous and could result in damage to the unit or death to the user.**

Please contact Thorlabs' Technical Support at techsupport@thorlabs.com and a member of our team will be happy to assist you with any questions you may have regarding this product.

2.2.   Before installation

🛑 **STOP** Before proceeding with the installation of hardware or software, please identify whether your camera interface is Camera Link, Gigabit Ethernet (GigE), or USB 3.0. Please note the significant difference in installation steps for the three types of cameras.

Chapter 3   Setup & installation

3.1. Know Your Camera Family!

Scientific Cameras and **Compact Scientific Cameras** have a black and red aluminum case. Both Scientific Camera families have their own drivers (Camera Link, Gigabit Ethernet, USB 3.0) and SDK.

Figure 1   Scientific and Compact Scientific Cameras

DCC- or DCU- (also referred to as DCx) Compact USB Cameras are small with either a black/stainless steel or grey plastic case, depending on the model. The DCx Camera family has its own USB drivers and SDK.

Figure 2   DCU/DCC cameras

3.2.   USB Camera Installation

If you purchased a DCx or Compact Scientific USB camera, the only connection required is with the supplied USB cable.

1. **Run the software installer** – follow the steps outlined in the next section, including driver installation.

2. Connect the USB cable* to the appropriate USB port.

3. Wait for windows to recognize the camera

4. Run ThorCam application software

* We recommend using only the USB3 cable that was shipped with the camera.

3.3.   GigE Camera Installation:

If you purchased a Gigabit Ethernet camera, an Intel PCI/PCIe adapter card is provided for use on desktop computer systems. Although the system will work with other adapters (including laptop GigE adapters), it is recommended that this card be used for optimal performance on all desktop installations.

1. **Power down the computer.**

2. Taking necessary precautions, **install the Intel PCI/PCIe GigE adapter**.

3. Turn on the computer and accept Windows driver recommendations for the newly installed hardware

4. **Run the software installer** – follow the steps outlined in the next section, including driver installation.

5. Connect camera per section 3.5, then power on camera and run ThorCam application software.

3.4.   Camera Link Installation:

If you purchased a Camera Link camera, an EDT PCIe interface card is provided. Other Camera Link interface cards are not supported.

1. **Run the Software Installer** - follow the steps outlined in the next section, including driver installation.

2. **Power down the computer**.

3. Taking necessary precautions, **install the EDT PCI/PCIe Camera Link interface card.**

4. Turn on the computer

5. Accept the driver installation recommendations for the newly installed hardware.

6. Connect camera per section 3.7, then power on camera and run ThorCam application software

3.5.   Scientific USB 3.0 Installation:

If you purchased a Scientific or Compact Scientific USB 3.0 camera, an optional USB 3.0 PCIe interface card is available, **USB3-PCIE**, which may provide higher throughput over an integrated USB 3.0 port on your PC. (Other USB interface cards may work, but are not supported)

1. **Run the Software Installer** - follow the steps outlined in the next section, including driver installation.

2. **If installing a PCIe USB3.0 card - Power down the computer**. Taking necessary precautions, install the USB 3.0 PCIe interface card. Turn on the computer.

3. Otherwise, simply connect the camera to a USB3.0 port on the PC.

4. Accept the driver installation recommendations for the newly installed hardware.

5. Power on the camera and run the ThorCam application software.

3.6.   Installing the Software

The Thorlabs camera software runs on **Windows 7, 8.1, and 10 operating systems ONLY.**

3.6.1.   Load the Distribution Disk

A CD or DVD disk can be found with the camera. Load the disk into the CD/DVD drive on the computer you wish to operate the camera and software. The installation software will automatically detect whether your system is 32-bit or 64-bit. Loading and detection could take a minute or two, depending on your drive speed. You may also download the latest version from our website at https://www.thorlabs.com/software_pages/viewsoftwarepage.cfm?code=ThorCam .

3.6.2. Driver Selection

Your camera requires a driver to be installed on your computer. After the welcome screen, acceptance of the license agreement, and entering your user information, you will be presented with a choice of drivers. Select the driver that matches the interface on your camera; USB (2.0 or 3.0), Gigabit Ethernet, or Camera Link. If you have more than one camera and with different interfaces, select all that apply. If you're unsure, select them all.
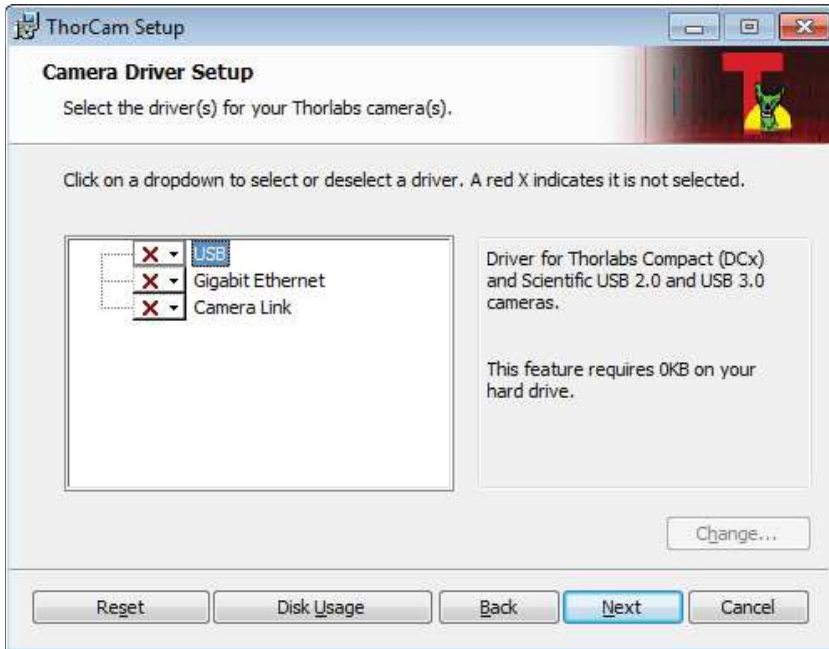
Select a driver for installation by clicking on the dropdown and selecting either of the two choices; "This feature will be installed on local hard drive," or "This feature, and all subfeatures, will be installed on local hard drive." There are no subfeatures, so both choices do the same thing.

If you do not wish to install the driver, select "This feature will not be available"
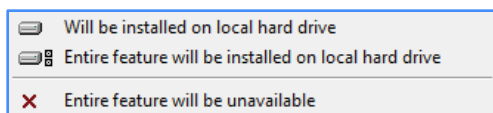
Once a driver is selected, the red X will be replaced with a hard drive icon as shown in the USB selection below.
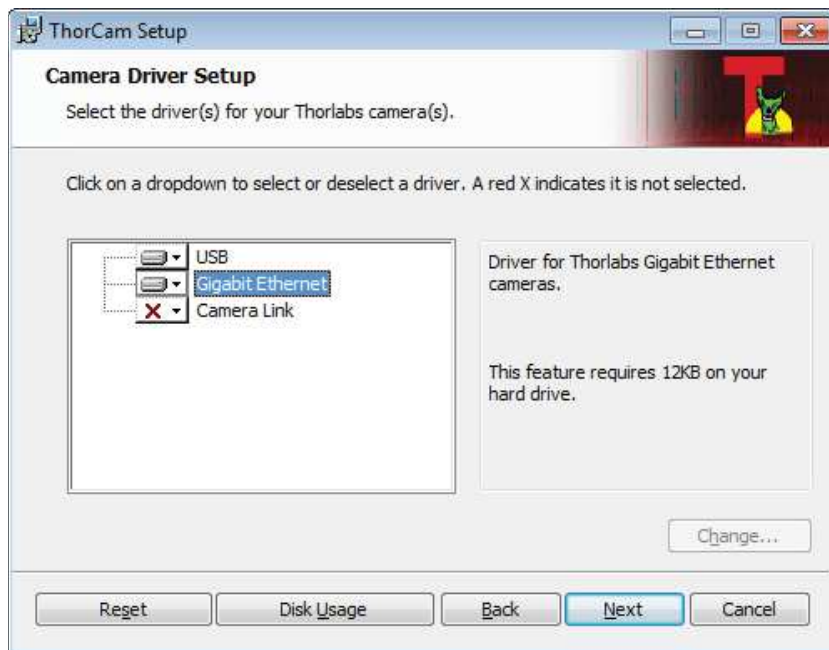
Click Next to proceed with the driver installation. Depending on your PC's configuration and the drivers you selected, you might encounter the additional Windows security dialogs below. Be sure to click install to complete the operation, otherwise the installer will "roll back" and exit.

Camera Link Driver Installation (if selected). Click "Install"
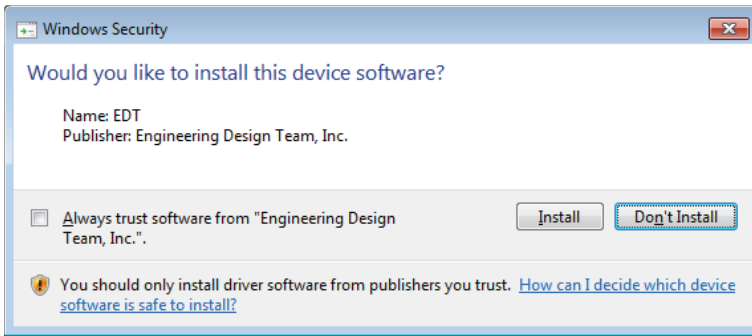
USB Driver Installation (if selected). Click "Install"
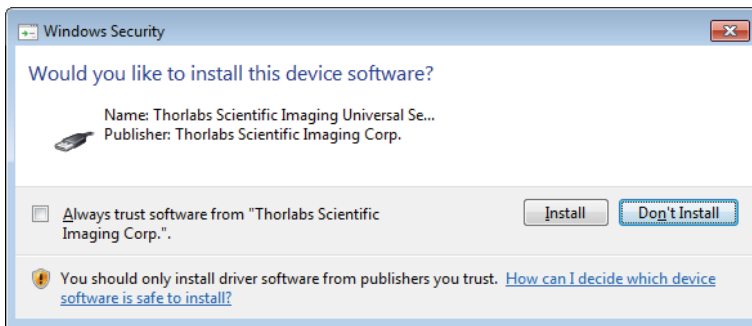
Gigabit Ethernet Driver Installation (if selected). Click "Install"
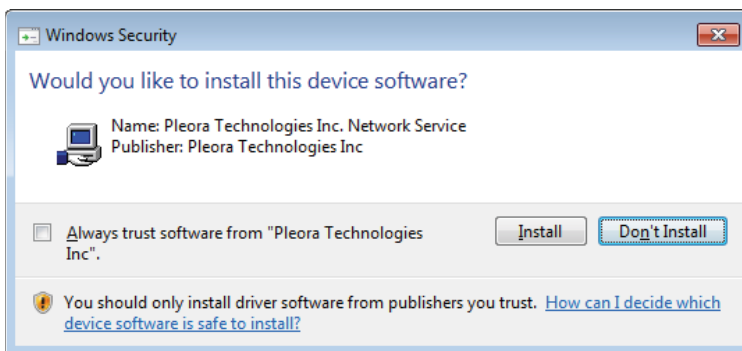
Once setup is complete, you may now proceed to the next section that will describe how to connect and power on your camera. When the camera is connected and powered up, you can navigate to the ThorCam Imaging Software as shown below.

 "Start"→"All Programs"→"Thorlabs" →"Scientific Imaging "→"ThorCam"
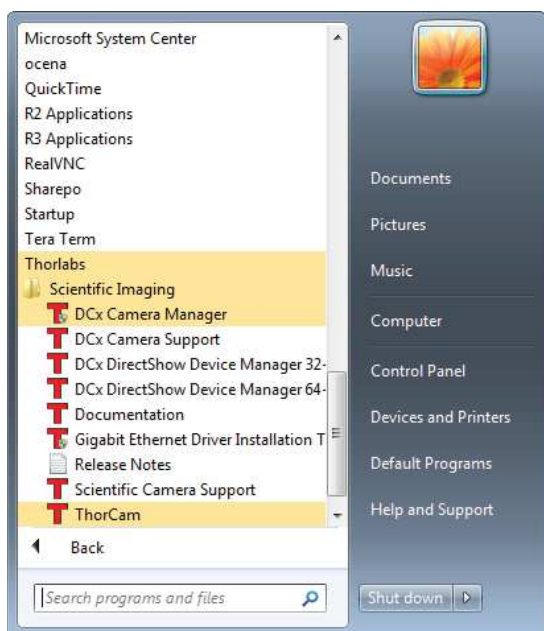
Figure 3 Thorlabs Start Menu Shortcuts

Please refer to the **User Manual** for more information on the additional items installed during this procedure, including configuring the Gigabit Ethernet Driver for best performance.

3.7. Basic Connections

3.7.1. Connections for Camera Link Scientific Camera

Power to camera must be turned off before connecting to computer

CL_0 to Camera Link Port 0 / CL_1 to Camera Link Port 1

Port 0 is default Port. Port 1 used for Multi-Tap operation

For operation with a single Camera Link cable always use port 0.

3.7.2. Connections for a Gigabit Ethernet Scientific Camera

3.7.3.   Connections for a USB 3.0 Scientific Camera

Note: Compact Scientific cameras use the USB 3.0 cable for both data and power.

Chapter 4 Regulatory

As required by the WEEE (Waste Electrical and Electronic Equipment Directive) of the European Community and the corresponding national laws, Thorlabs offers all end users in the EC the possibility to return "end of life" units without incurring disposal charges.

- This offer is valid for Thorlabs electrical and electronic equipment:
- Sold after August 13, 2005
- Marked correspondingly with the crossed out "wheelie bin" logo (see right)
- Sold to a company or institute within the EC
- Currently owned by a company or institute within the EC
- Still complete, not disassembled and not contaminated
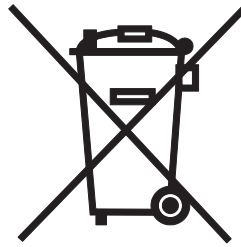
Wheelie Bin Logo

As the WEEE directive applies to self-contained operational electrical and electronic products, this end of life take back service does not refer to other Thorlabs products, such as:

- Pure OEM products, that means assemblies to be built into a unit by the user (e.g. OEM laser driver cards)
- Components
- Mechanics and optics
- Left over parts of units disassembled by the user (PCB's, housings etc.).

If you wish to return a Thorlabs unit for waste recovery, please contact Thorlabs or your nearest dealer for further information.

Waste Treatment is Your Own Responsibility

If you do not return an "end of life" unit to Thorlabs, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

Ecological Background

It is well known that WEEE pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.

The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of life products will thereby avoid negative impacts on the environment.

Chapter 5 Product Care

- Do not store or operate in a damp, closed environment.

- Do not use solvents on or near the equipment.

- Keep away from dust, dirt, and airborne pollutants (including cigarette smoke). The system is not designed for outdoor use. Protect the equipment from rain, snow, and humidity.

- Do not expose to mechanical or thermal extremes. Protect the equipment from rapid variation in temperature.

- Handle all connectors with care. Do not use unnecessary force as this may damage the connectors.

- Clean using a soft, lint free cloth. Use of isopropyl alcohol is permitted, however do not immerse in any liquid or solvent.

- Clean any accessible optical surfaces with an appropriate optics grade tissue or cloth.

5.1.1. Service

Only trained and approved Thorlabs' personnel should service the system. Please contact Thorlabs' Technical Support at techsupport@thorlabs.com and a member of our team will be happy to assist you.

5.1.2. Warranty

Any modification or servicing by unqualified personnel renders the warranty null and void, leaving Thorlabs free of liability. Please refer to your camera User Manual for complete warranty information.

5.1.3. Troubleshooting

Ethernet Connector LED Indications:

1500x-GE Models:

LED Color	If LED is On	If LED is Flashing	If LED is Off
Green	The Link is Operational, but the Camera is Currently not Sending Data	Normal (Indicates that the Camera is Sending Data)	There is no Ethernet Connection
Yellow	Normal Operation	Not Applicable	There is no Ethernet Connection, or The Camera is Plugged into a 10/100 Mbps Network

8051/4070/1501/340 –GE Models:

LED Color	If LED is On	If LED is Flashing	If LED is Off
Green	The Link is Operational, but the Camera is not Sending Data	Normal (Indicates that the Camera is Sending Data)	There is no Ethernet Connection
Green/ Orange	Normal Operation/ or 10/100Mbps	Normal Operation/ or 10/100Mbps	There is no Ethernet Connection

USB 3.0 Rear Panel LED Indications:

Scientific Cameras 8051/4070/1501/340 –USB Models:

LED	If LED is On	If LED is Flashing	If LED is Off
Link	**Blue**: Connected to USB 3.0 Port **Green**: Connected to USB 2.0 Port **Amber**: Camera has internal USB problem	Not Applicable	There is no USB Connection or, Camera is turned off
Status	**Green**: Camera is paused	**Green**: Camera is sending frames	Camera is turned off

Compact Scientific Cameras

LED	If LED is On	If LED is Flashing	If LED is Off
Status	**Blue**: Connected to USB 3.0 Port **Green**: Connected to USB 2.0 Port **Amber**: Camera has internal USB problem	USB port cannot provide sufficient power to the camera	There is no USB Connection providing power to the camera

Chapter 6 Thorlabs Worldwide Contacts

For technical support or sales inquiries, please visit us at www.thorlabs.com/contact for our most up-to-date contact information.

www.thorlabs.com

THORLABS

ThorCam

User Guide

Table of Contents

Chapter 1   Safety

1.1.   Warning Symbol Definitions

Below is a list of warning symbols you may encounter in this manual

          Caution: Risk of Electric Shock

          Caution: Risk of data loss and damage to operating system

1.2.   Precautions

Please read the instruction manual for your ThorCam-compatible instrument carefully before using with ThorCam. All statements regarding safety and technical specifications will only apply when the unit is operated correctly.

1.3.   Accessories and Customization

Although the system is easily adapted for custom interfaces, to achieve the listed specifications this system should only be used with accessories provided by Thorlabs. Any modification or servicing by unqualified personnel renders the warranty null and void, leaving Thorlabs free of liability. Please contact Thorlabs for questions on customization.

Chapter 2   Description

2.1.   Introduction

This manual is a functional overview of the ThorCam software application, and is meant to be a companion to your camera's User Manual.

ThorCam works with the general-purpose DCU- and DCC-series cameras and the high-performance Scientific and Compact Scientific cameras.

ThorCam is installed as part of your camera software installation process. Please follow the instructions in the User Manual or Quick Start Guide that accompanied your camera.

2.1.1.   Optional Items

- Auxiliary I/O Patch cable – The auxiliary connector on the camera allows the user to access optional camera control and internal status signals. Please consult your camera's manual for details.

2.1.2.   Recommended System Requirements

- Operating System: Windows® 7 or 10 (64 Bit)[a]

- Processor (CPU): ≥3.0 GHz Intel Core (i5 or Higher)[b]

- Memory (RAM): ≥8 GB

- Hard Drive: ≥500 GB (SATA) Solid State Drive (SSD)[c]

- Graphics Card: Dedicated Adapter with ≥256 MB RAM[d]

- Motherboard:

  - USB 3.0 (-USB) Cameras: Integrated Intel USB 3.0 Controller

    or One Unused PCIe x1 Slot (for Item # USB3-PCIE)

  - GigE (-GE) Cameras: One Unused PCIe x1 Slot

  - Camera Link (-CL) Cameras: One Unused PCIe x4/x8/x16 Slot

a-   Windows® 8.1 is supported, but not recommended.
b-   Intel Core i3 processors and mobile versions of Intel processors may not satisfy the requirements.
c-   We recommend a solid state drive (SSD) for more reliable streaming to disk during image sequence storage.
d-   On-board/integrated graphics solutions present on Intel Core i5 and i7 processors are also acceptable.

Chapter 3   Using ThorCam

3.1.   Launching the application

To start the camera, launch the ThorCam application. The following splash screen will momentarily appear:
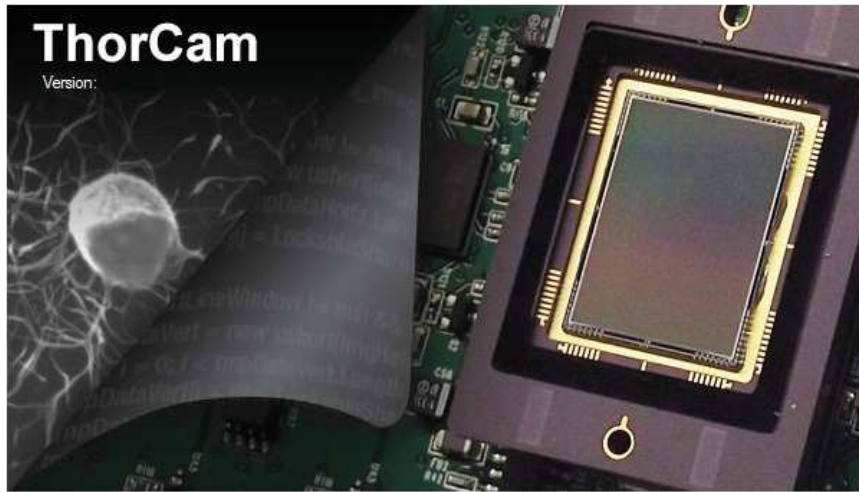
Followed immediately by this window:
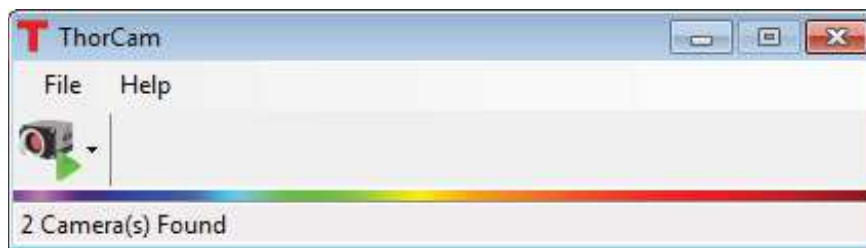
When the camera is recognized, it will appear in the pull-down menu as shown below:
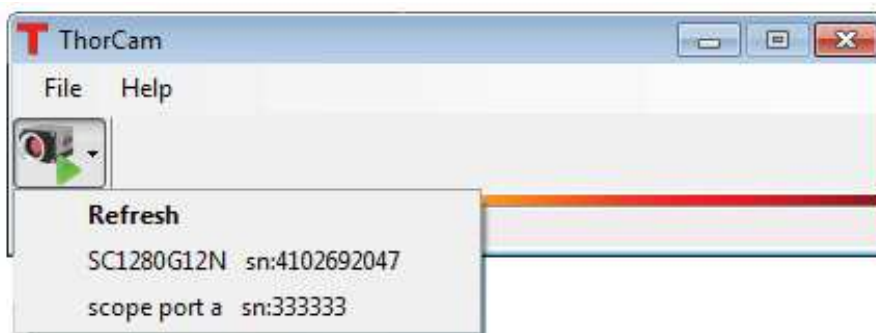
If the camera does not appear, check that the power supply is turned on and the camera is properly connected to the computer. Gigabit Ethernet cameras can take 20-30 seconds to register on the network after power is applied. Select **Refresh** to check for the presence of the camera.

Next, select the camera from the pull-down menu. Any or all cameras can be operated simultaneously after selection from this menu. Each time a camera is selected, the *Live* window for the chosen camera will appear. The window border is color-coded with a random border color to facilitate association of multiple camera Live windows with their settings and analysis windows.

3.2.   The Live Window

The Live window is the main window for the camera and the one in which images are displayed.

There are a few differences between Live window tool icons and functions for the scientific-grade and DCU-series cameras. This was done to maintain a familiar interface for current DCU-series camera owners while tailoring scientific-grade camera functionality to those customers. The scientific-grade Live window is shown below.
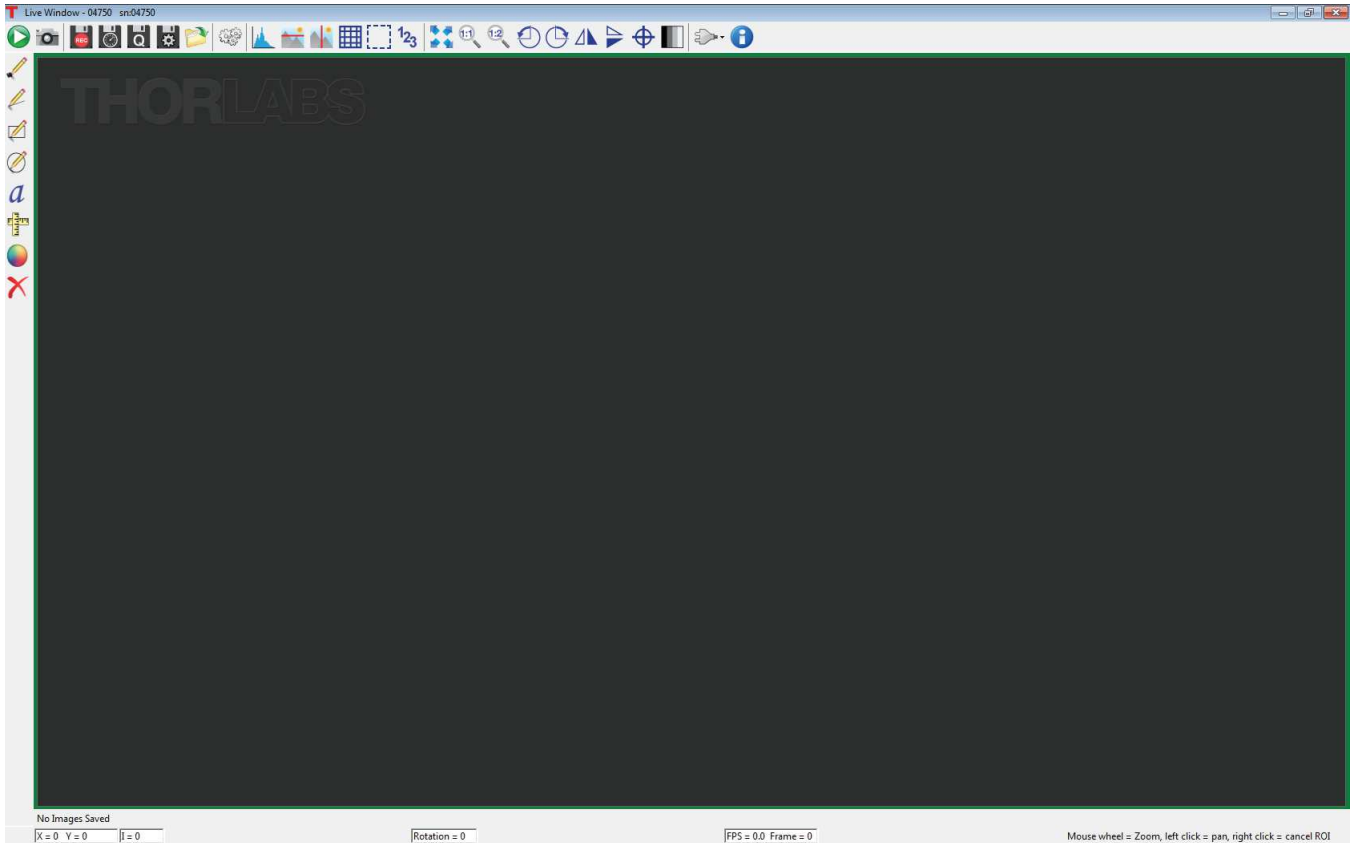
3.3.   Scientific Camera Controls

The following controls are specific to the scientific-grade Live window. The DCU specific controls will be covered separately, followed by the controls that are common to both GUIs.

3.3.1.   Start/Stop Capture

Commences capture according to the camera settings. When clicked, the start capture button changes to the stop capture button.

3.3.2.   Snapshot

Takes a single snapshot from camera with the current camera settings.

3.3.3.   Start/Stop Record

Commences recording of capture to a Motion JPEG AVI or multipage TIFF file. The AVI file is saved as a scaled 24-bit image, while the TIFF is saved a variety of formats (bit depth and grayscale/color depends on camera model). When clicked, the start record button changes to stop record. While recording, **REC** is visible in the upper left corner of the image.

If the "Quick Save" feature has NOT been selected (see below) you will be prompted for a file name and location using the native Windows Save As dialog window, otherwise the recording will immediately start - saving to the parameters set-up in the *Save Configuration Tool*.
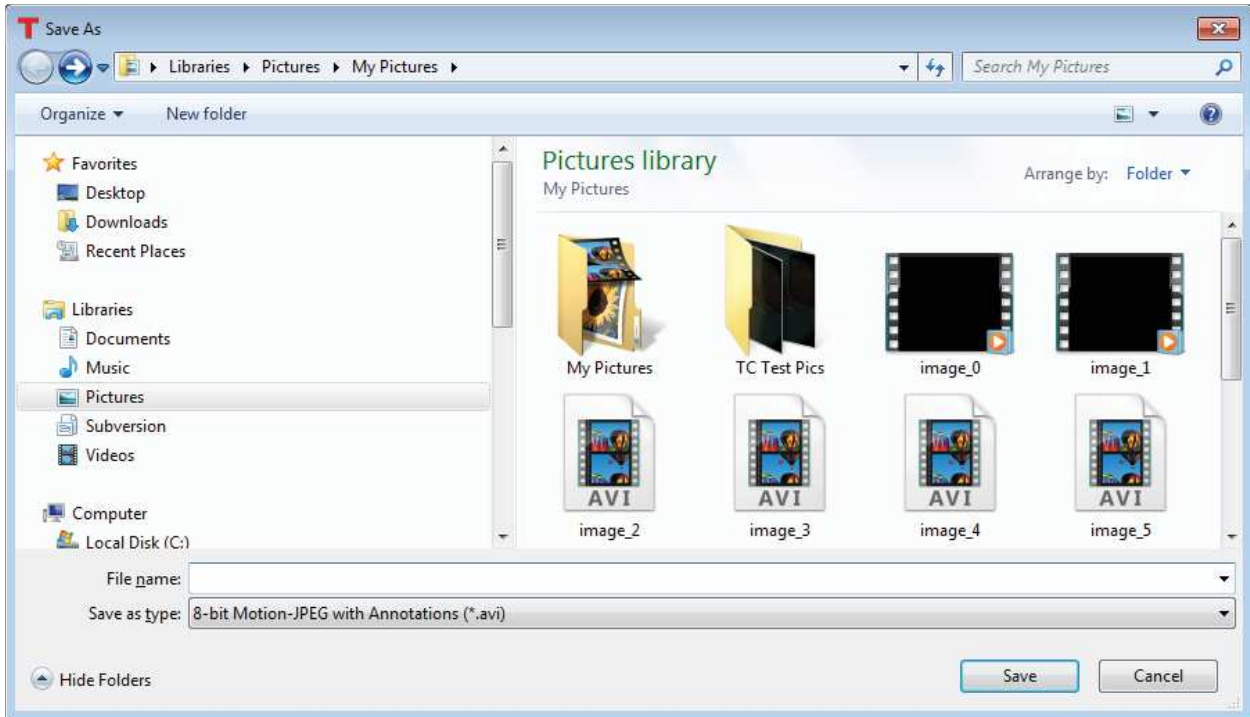
The file type, format, location, and name of the stored image can be viewed or changed in the *Save Configuration* dialog accessed from this icon: [icon]. The Quick Save feature is enabled only when the "**Quick Save**" box is checked. The default path is the Window's Users\Pictures folder with a default image prefix of "image". Using the Configuration set-up you can change the image name (Image Prefix), and browse to any folder you wish to save to, provided you have write-access privileges.

Reliable delivery of frames to a file on a storage device such as a hard drive depends greatly on the performance of the host computer and mass storage device, the use of computing and interface resources due to other devices and programs, and the overall data rate from the camera. Due to the vast number of computer configurations worldwide, Thorlabs cannot guarantee 100% frame delivery to a storage device.

Placing a check in the "**Disable live view while recording**" option decreases the likelihood of dropped frames when recording to disk by disabling the display refresh process.
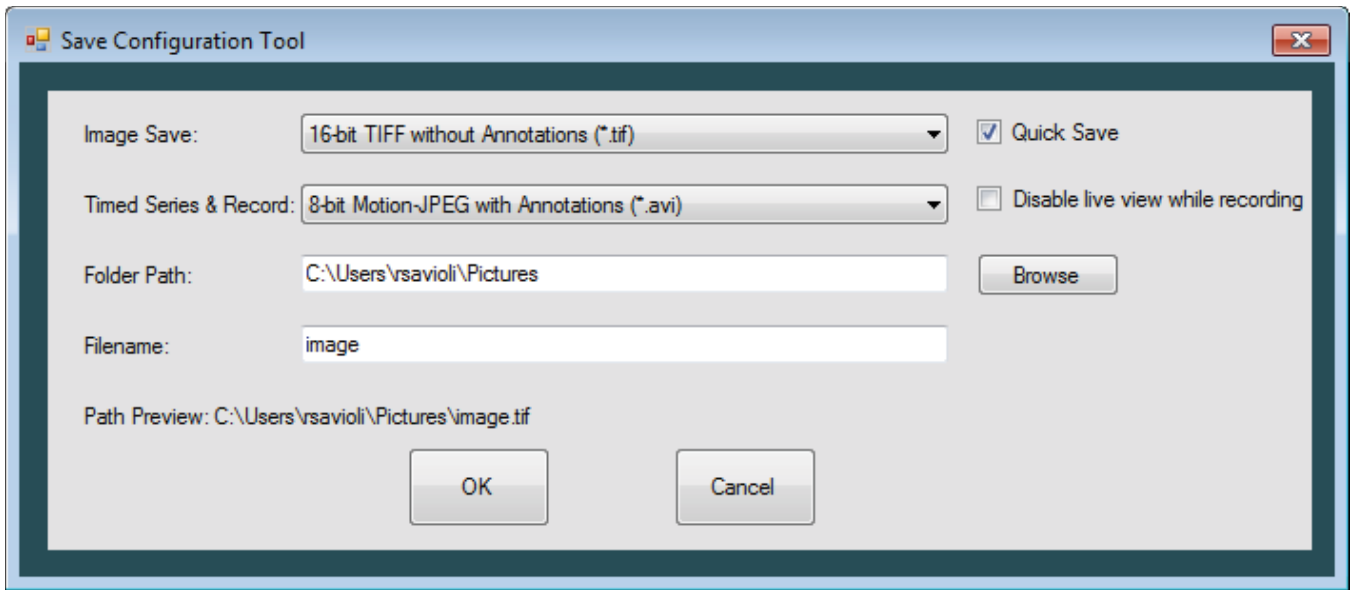
The first recording captured will have a file name consisting of the Image Prefix appended with "_0". As additional recordings are captured and saved they will be automatically appended with a numerical suffix _1, _2, _3 …).

The icon provides a short-cut to the folder in which you have saved your images. Additionally, each time you press the Record icon, the path information will be displayed along the bottom status bar, momentarily highlighted in green to indicate a successful acquisition and save.

Last Recording Saved: C:\Users\rsavioli\Pictures\image_9.avi

Unattended recording can result in excessive use of file storage space and ultimately result in operating system malfunction and/or loss of data.

3.3.4. Rotate 90 Degrees

Rotates the image in the viewing window clockwise and counter-clockwise in 90 degree steps. This feature will apply when saving images and video captures. The current rotation angle is displayed along the bottom of the Live window.

3.3.5. Mirror Flip Horizontal or Vertical

These two icons will mirror the current image from left to right (Horizontal Flip) or from top-to-bottom (Vertical Flip). This feature will apply when saving images and video captures.

3.3.6. ⚙ Camera Settings (Scientific and Compact Scientific Cameras)

The Camera Settings window provides access to camera and display controls. Controls are grouped into dynamic and static settings. Dynamic settings can be adjusted while ThorCam is capturing data and remain active during image acquisition. Static settings require acquisition is stopped before allowing changes to the settings.
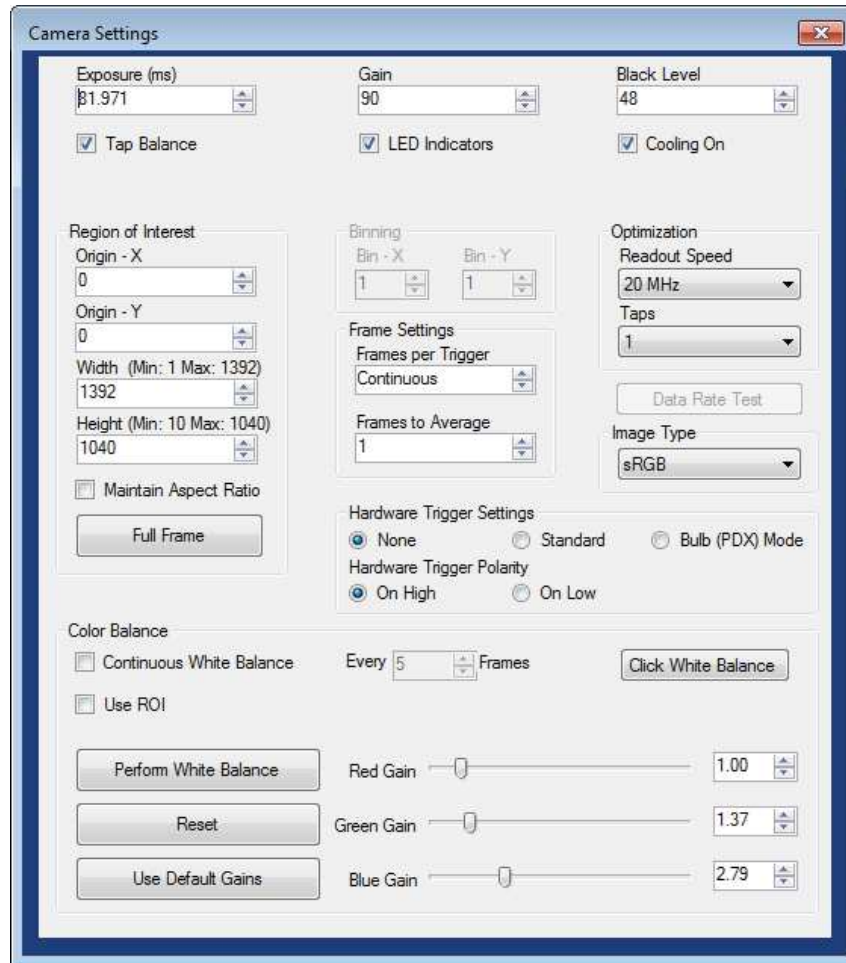
Dynamic Settings:

Dynamic settings are active at all times.

Exposure

Sets the exposure time for all frames to be acquired. Units are in milliseconds.

The camera exposure time is very stable, but the exact exposure accuracy and increment depends on a number of settings including Binning, Region of Interest (ROI), and Readout Speed. Therefore, the actual exposure time of the camera will be the closest possible to the value entered.

Gain

The relative gain applied to the analog signal from the image sensor. Units: 0.036 dB/step.

Black Level

The average image signal from the camera in the absence of light. Increments of 0.25 ADU (analog-to-digital unit).

Tap Balance

For multi-tap cameras operating with two or more taps only. Applies a factory-calibrated equalization to each tap to remove the visible "seam" due to natural differences in the signal level for each CCD tap. Tap balance is meant to provide a visually pleasing image and is not absolute. Under extreme contrast stretching and/or camera settings residual tap-to-tap differences can be observed. This is not a malfunction. The 1501x Series cameras will not display the Tap Balance function since they are single tap cameras.

NIR Boost

The 1501x Series cameras provide a special function called NIR Boost that allows for a slight increase of the spectral response of the camera into the near IR wavelengths. This feature is only visible on the monochrome cameras, and color cameras operating in the Unprocessed Image Type. Refer to the Scientific Camera User's Guide for more information. The check box for NIR Boost is located under the Exposure setting box when available - replacing the Tap Balance option.

LED Indicators

The USB3.0 Series cameras provide a special function to allow the user to control the two LED indicators on the rear panel of the camera. If the box is checked, the LEDs will be turned on. Cycling power to the camera will result in the LEDs, by default, being turned on.

Cooling Mode

For cameras with the thermoelectric cooler option only. Turns on or off the camera thermoelectric cooler.

Image Type
All monochrome cameras default to an Image Type of **Unprocessed**, while color and polarization cameras have additional options. See section 4.3 for more details on polarimetry tools and data visualization.

Binning is only allowed when the Unprocessed Image Type is selected.

Image Type is a static setting requiring the camera to be stopped prior to making a change to it.

Static Settings:

Static settings can only be altered when the camera is not actively acquiring images.

ROI/Bin Settings

Origin-X and **Origin-Y** set the origin, or upper left corner of the Region of Interest (ROI). **Width** and **Height** determine the width and height of the region of interest. The **Full Frame** button resets the Region of Interest to the maximum CCD sensing area indicated next to the Width and Height labels.

Width and **Heigh**t not only sets the size of the data stored in memory and to disk, but it also determines the region that is read from the CCD sensor in the camera. Specifically, only the Height changes the readout area on the CCD. The Width is truncated in software. As a result, Height entries that reduce the vertical size of the region also increase the readout of the chip and vice versa. This increase in readout speed is not directly proportional to ROI vertical size due to overhead in the readout process. ROI does not impact the noise floor.

Bin X

Horizontal binning factor. Horizontal binning is accomplished in software and has no impact on readout rate. Horizontal binning will increase the offset level and noise floor commensurate with the binning factor selected. The offset level increases as the sum of the offset of individual pixels binned. The noise floor standard deviation increases as the square root of the sum of the standard deviation of the pixels binned. The Bin X control is disabled when the camera is acquiring frames.

Bin Y

Vertical binning factor. Vertical binning is done on the CCD chip in the camera and will produce increased frame rates as the binning factor is increased. In general, vertical binning has little effect on offset level or noise floor. The Bin Y control is disabled when the camera is acquiring frames.

Color capable cameras can only operate at 1 x 1 binning when the Image Type is anything except "Unprocessed". Unprocessed Type can bin at the specified maximum bin values of the camera. If the Image Type is changed from Unprocessed to one of the RGB Types, the binning settings are automatically reset to 1 x 1.

Readout Speed

Selectable 20 MHz or 40 MHz. Faster readout speed results in higher achievable frame rates at the cost of slightly higher readout noise in general.

Taps

For cameras with multi-tap readout capabilities only. This control sets the number of taps used to read out the CCD, using more taps will provide faster frame rates.

Data Rate Test

The ***Data Rate Test*** button is only active on USB 3.0 Scientific cameras. Running this test will help determine the maximum Clock and Taps settings that your host computer is capable of operating at. Pressing the button will stop any current acquisitions and open the following window:
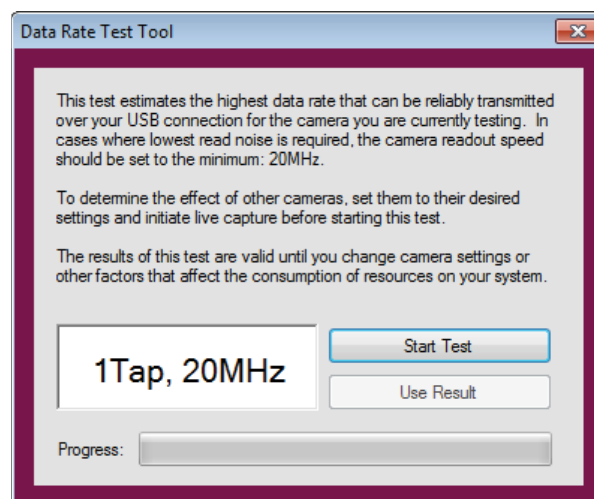
Pressing the ***Start Test*** button will commence the test. The ***Progress*** bar will indicate the status of the test. Once it has completed, the Speed Gauge window will show the maximum capabilities of your USB 3.0 system. You may choose to use the maximum settings by pressing the ***Use Result*** button, or you can simply close the window by clicking on the **X**.

Frames per Trigger

The number of frames captured per software or hardware trigger. Refer to timing diagrams in the camera User's Manual for more detail. A value of "0" (zero) results in continuous streaming.

Frames to Average

The number of frames to average from a sequence, from a minimum of 1 (no averaging) to 32.

Hardware Trigger Settings

Selects the method of triggering the camera. Please see your camera manual for detailed timing diagrams of the exposure modes.

None

Trigger is generated by ThorCam (e.g. pressing the capture button will capture the number of frames in Frames per Trigger setting above.

Standard

Trigger is provided through the camera hardware auxiliary connector. Capture is triggered by the rising or falling edge of the trigger signal according to the HW Trigger Polarity setting, with the exposure value according to the Exposure setting.

Bulb (PDX) mode

Trigger is provided through the camera hardware auxiliary connector. Capture is triggered by the rising or falling edge of the trigger signal according to the HW Trigger Polarity setting, with an exposure dependent on the trigger pulse width.

Hardware Trigger Polarity

This setting controls whether the camera will respond to the Low-to-High transition of the external trigger (On High) or to the High-to-Low transition of the trigger (On Low).

Color White Balance

The Color White Balance settings group is only active on color cameras and consists of a number of dynamic settings - meaning they can be adjusted while the camera is capturing frames.

The check box for **Continuous White Balance** causes the software to automatically make corrections to the white balance parameters. When the box is checked it will enable a settings field allowing you to set how often the balance is adjusted, the range is from 1 frame to 9999 frames:
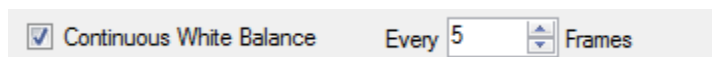
While operating in the Continuous White Balance mode the manual RGB Gain controls are adjusted automatically, and are still active for the user to manually adjust, however, at the automatic adjustment frame the value will be reset by the Continuous White Balance function.

Alternatively you can press the **Perform White Balance** button and the software will perform a one-time calibration of the white balance gains. The RGB Gain controls will be automatically adjusted, and the Gain controls remain active and can be adjusted dynamically.

By checking the **Use ROI** box you can then select the Select Analysis ROI drawing tool to draw a region which to base the white balance adjustment. This can produce better results in images with a small amount of area that is neutral-colored. Simply draw the ROI within the neutral area. After checking the Use ROI box and drawing your desired region, press the **Perform White Balance** button to complete the process.

By pressing the **Click White Balance** button and then clicking on a single point in the image the white balance gain adjustment will be performed as well. This feature evaluates only a few pixels around the chosen point and is useful when there are only very small neutral areas in the image.

Finally, the color balance can be manually adjusted using the three individual *Red*, *Green*, and *Blue* slide controls or numeric input boxes, which can be incremented or decremented using the up/down arrow buttons or by typing in a value directly. The usable range of gain values is 0 to 10.00.

Pressing the *Reset* button will change all three gain settings to "1.0". Pressing the *Use Default Gains* button will change all three gain settings to the default values specific to each camera model.

The Color Balance controls apply to all frames captured AFTER applying the change (including Continuous, Perform White Balance adjustments, Reset, and Defaults). That is, if the camera is stopped and an image is displayed, making adjustments to the White Balance gains will have no effect on that image. Once the camera is started again, or a snapshot is taken, all of the new gains settings will apply.

3.3.7.   Info

Provides information pertaining to the camera, such as the camera name, serial number, model, and various embedded firmware version numbers. All TSI cameras are shipped with the Camera Name the same as the Serial Number (info SN :). The Info window allows the user to change the camera name to any alpha-numeric format of 31 characters or less, including spaces and special characters. NOTE: Once the camera name has been changed you must close the Live window and cycle power to the camera before the change will take effect in ThorCam.
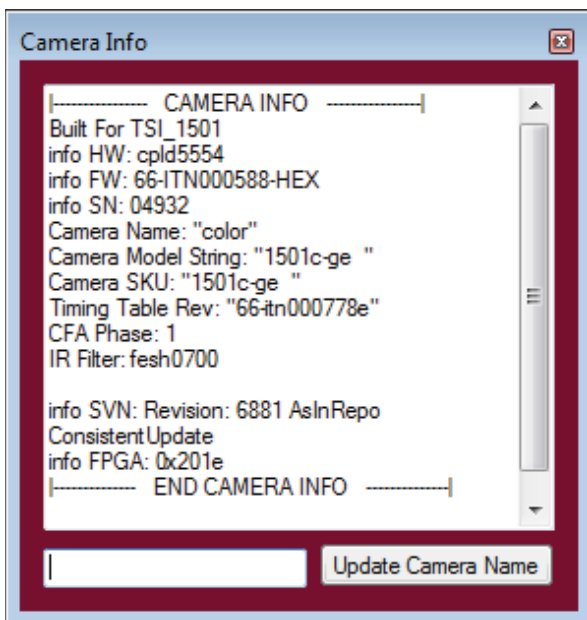
3.3.8. ⚙ Camera Settings (Compact Scientific Cameras)

The Camera Settings window for the Compact Scientific family of cameras provides access to camera and display controls. While being quite similar to the Scientific Camera settings, there are a few differences that are discussed here, otherwise please refer to the Scientific Camera settings descriptions above.
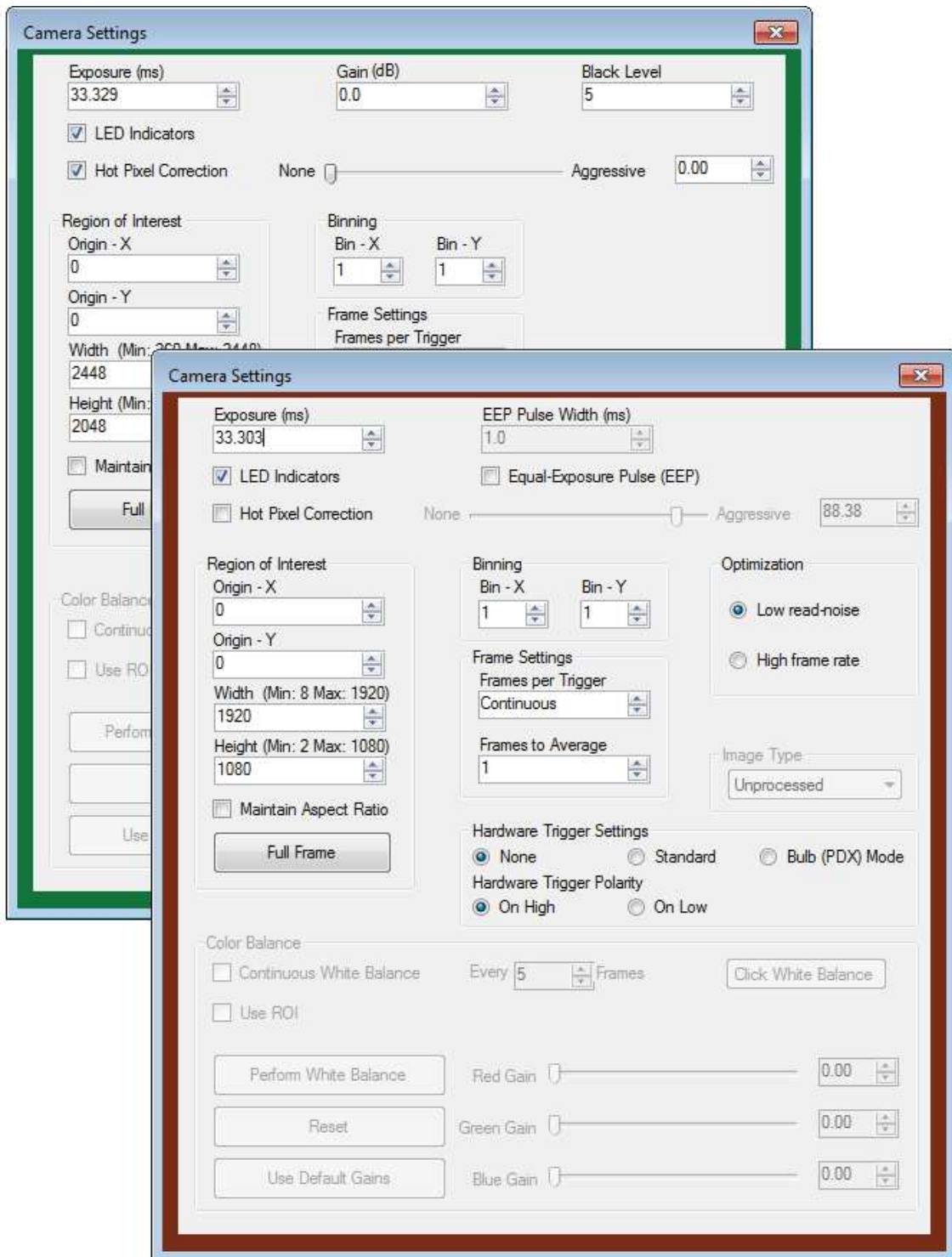
Hot Pixel Correction

Hot Pixel Correction is a function that identifies and corrects pixels that are much brighter than their surrounding pixels. Typically visible as very bright pixels regardless of the scene being imaged, these are unavoidable by-products of the sensor manufacturing process.

By checking this box, Hot Pixel Correction will be activated and the threshold can then be adjusted using the adjacent slider or the numeric input box. The Hot Pixel Correction box can only be checked and unchecked when the camera is stopped. Once it is checked however, the threshold adjustment can be made on a live image.

The threshold adjustment is made by simply adjusting the slider from the far left position (None) to the right (Aggressive). Care must be taken to not correct too aggressively, as this could affect valid pixels, particularly in bright scenes with high pixel values.

A hot pixel is identified by comparing with the mean value of the surrounding 8 pixels out of a 3x3 neighborhood. If the difference between the pixel value and the mean is larger than a specified threshold value, then this pixel is considered a hot pixel and will be replaced with the median value of those pixels in the neighborhood. As the slider is moved towards "Aggressive," the threshold is reduced in a linear fashion. The minimum threshold value, corresponding to the upper limit, has been selected to provide users with the ability to correct hot pixels having a deviation of only a few hundred counts. At this most aggressive value, it is quite likely that image content near the maximum pixel values (full scale) will be altered by the Hot Pixel Correction algorithm.

Optimization
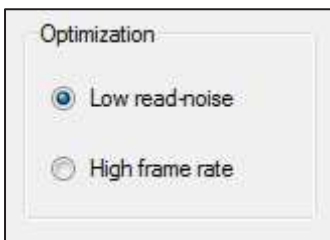
Image optimization can be achieved using the Optimization selections. A choice of "Low read-noise" sets the cameras master clock to a lower frequency, thereby reducing the read-noise. A choice of "High frame rate" increases the master clock, resulting in a higher frame rate. This function is only available on CS2100M-USB Quantalux sCMOS models.

Equal Exposure Pulse
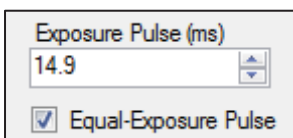
The Equal-Exposure Pulse is an output signal available on the CS2100M-USB Compact Scientific camera's I/O connector (refer to the Camera User Manual for details on this connector). When the Equal-Exposure Pulse (EEP) box is checked, the Strobe_Out signal on the I/O connector is reconfigured to be active only after the sensor's "rolling reset" function has completed. The signal will remain active until the sensor's "rolling readout" function begins. This means that the signal is active only during the time when all of the sensor's pixels are actively integrating.

The Equal-Exposure Pulse can only be produced when the exposure time is greater than the frame period - defined as 1/fps. Exposure time, Optimization rate, and ROI all determine the final fps, so varying combinations of all will determine when the signal can be produced.

When a user checks the Equal-Exposure Pulse (EEP) selection box, all camera settings parameters are greyed out and held in their current state. Based on these parameters AND the value in the EEP Pulse Width (ms) input box, ThorCam calculates the exposure setting required to produce an Equal Exposure pulse of the duration entered into the EEP Pulse Width (ms) input box. This new *total* exposure value will be shown in the greyed out Exposure (ms) box.

The EEP Pulse Width (ms) value is the only parameter that can be changed when the Equal-Exposure Pulse box is checked. In order to make adjustments to other parameters you must first uncheck the Equal-Exposure Pulse box.

The Equal-Exposure Pulse is primarily meant to be used to control a light source that will expose a scene for a precise duration only when all pixels are integrating charge. The result is a more consistent exposure across the entire sensor. The user must keep in mind that the Exposure (ms) setting in the Camera Settings dialog will not be the effective exposure produced from the external light source. The effective exposure will be the value in the EEP Pulse Width (ms) setting.

For example, a CS2100M-USB at full frame ROI, with an Optimization setting of Low read-noise, and the EEP Pulse Width (ms) time in the Setting window set to 10.0mS, will have an effective exposure of 10mS, even though your adjusted Exposure (ms) setting will be 43.3mS.
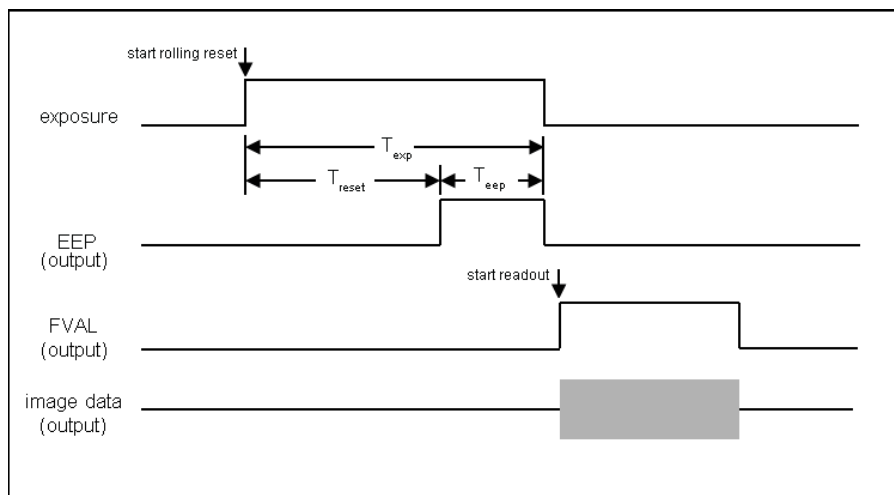
Be aware that the Equal-Exposure Pulse has no bearing on continuously illuminated scenes, and the resulting exposure will be whatever the actual Exposure (ms) time is set to. Please refer to the Compact Camera User Manual for additional timing diagrams and related information.

The minimum EEP Pulse Width is 1 ms, with increments of 0.1 ms thereafter. This function is only available on CS2100 Quantalux sCMOS models.

Gain and Black Level Controls

The Gain control for Compact Scientific cameras accepts values from 0 to 48.0 dB. The Black Level offset control accepts values from 0 to 4095. These functions are not available on CS2100M-USB models.
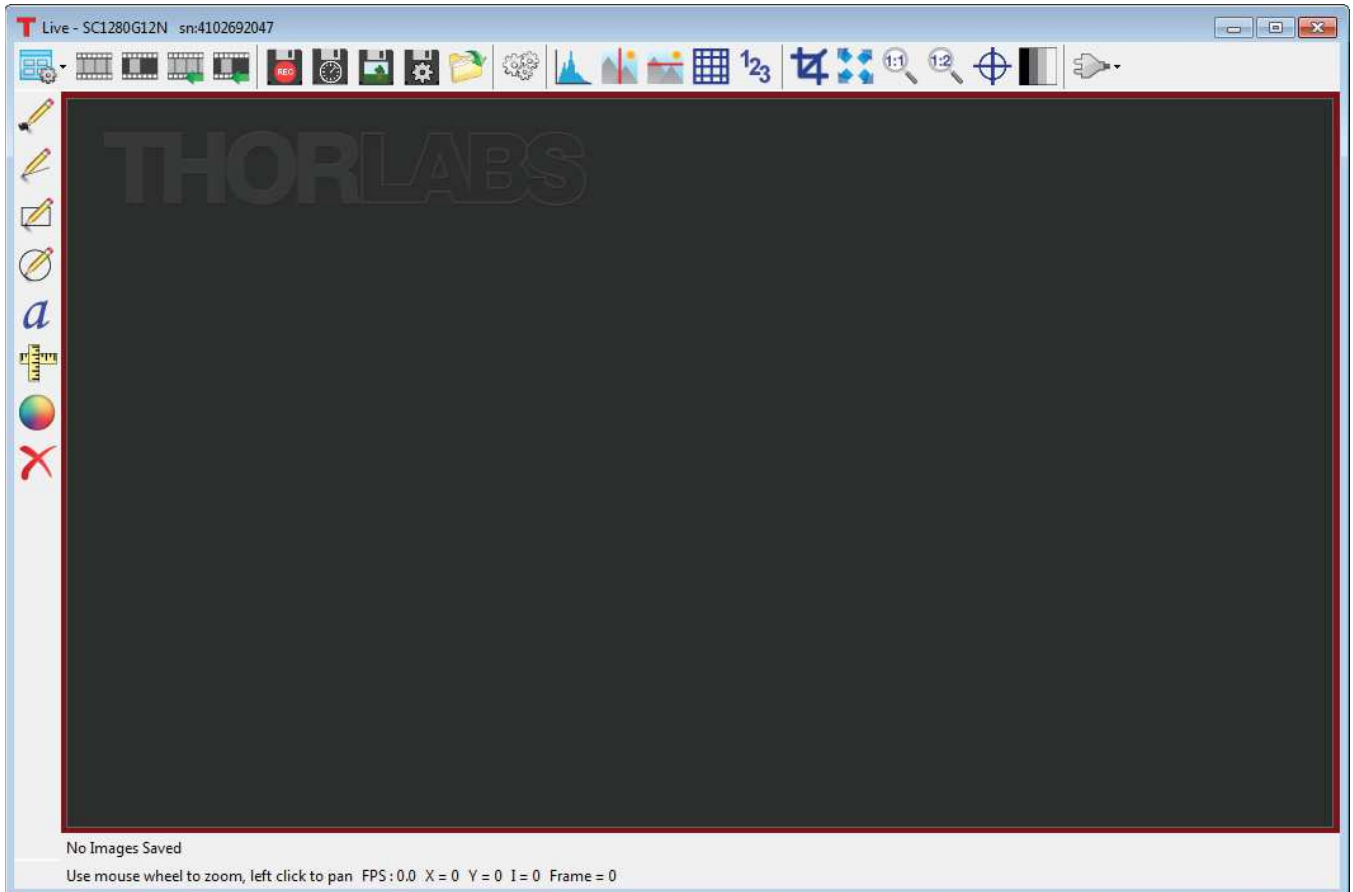
3.4.   DCx-Series Camera Controls

3.4.1.   Load/Save Camera Settings

Specific camera settings can be saved in, and retrieved from a Thorlabs Camera Profile (.tcp) file. This icon allows you to name the file and save it to a suitable folder on the host computer. The file will contain information from the

camera settings dialog only.

3.4.2.   Start Capture

Commences capture according to capture settings. Clicking again stops capture.

3.4.3.   Snapshot

Takes a single-frame capture.

3.4.4.   Start Continuous Trigger

Arms the camera for capture using external hardware trigger. See camera user manual for further information.

3.4.5.   Snapshot Trigger

Arms the camera for single capture using external hardware trigger. See camera user manual for further information.

3.4.6. [REC] Start/Stop Record

Commences recording of capture to a Motion JPEG AVI (in 24-bit RGB mode) or multipage TIFF file (in 10-bit Monochrome mode). The recording dialog box (for both AVI and TIFF) gives you the option of limiting the recording size by setting the maximum number of frames or the maximum file size in MB.

The actual record is commenced in the Record Movie dialog box by pressing the "Record" button. The Record button then changes to a "Stop" button. Press this button to stop the recording.

The Save Path Preview is informational only and shows where the recording will be saved. To change this location press the [gear] icon and you will be redirected to the Save Configuration dialog.
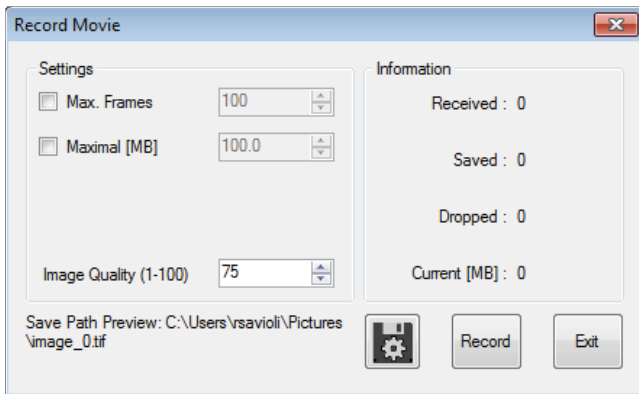
The file type, format, location, and name of the stored image can be viewed or changed in the **Save Configuration** dialog accessed from this icon: [save icon]. The default path is the Window's Users\Pictures folder with a default image prefix of "image". Using the Configuration set-up you can change the image name (Image Prefix), and browse to any folder you wish to save to, provided you have write-access privileges.

The first recording captured will have a file name consisting of the Image Prefix appended with "_0". As additional recordings are captured and saved they will be automatically appended with a numerical suffix _1, _2, _3 …).

The [folder] icon provides a short-cut to the folder in which you have saved your images. Additionally, each time you press the Record icon, the path information will be displayed along the bottom status bar, momentarily highlighted in green to indicate a successful acquisition and save.

Last Image Saved: C:\Users\rsavioli\Pictures\image_7.tif

3.4.7.   ⚙️ Camera Settings (DCx-Series Cameras)

Launches the Camera Settings window to allow control of camera parameters.
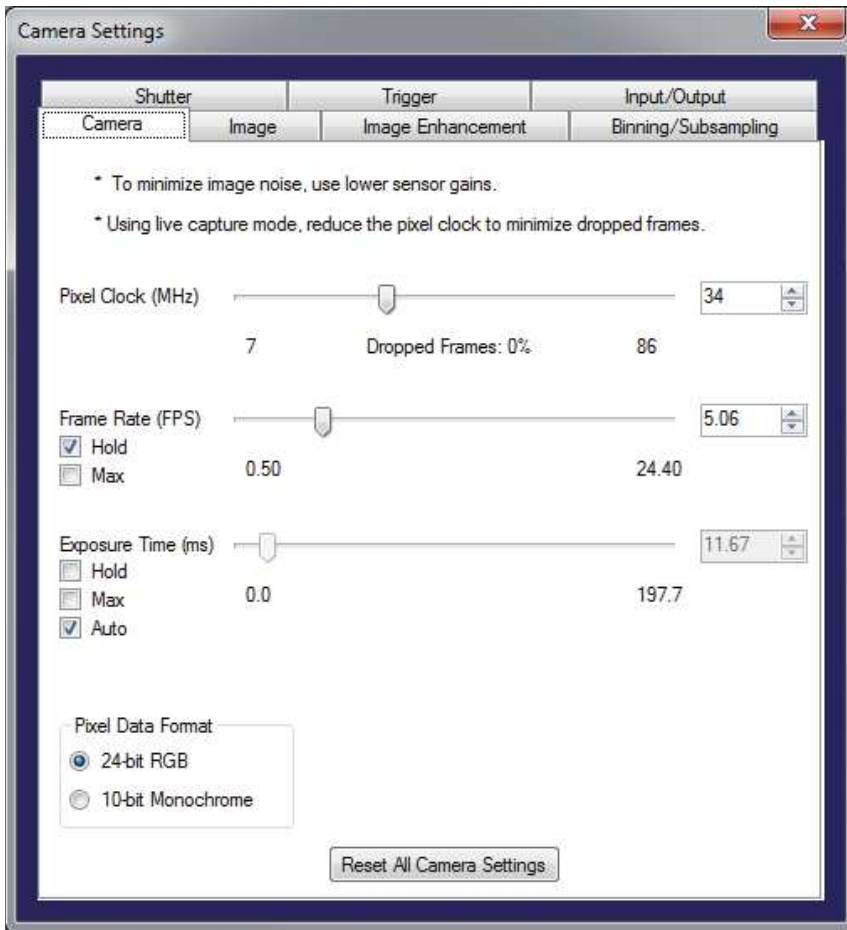
The Camera Tab:

Pixel Clock

The basic parameter for camera timing is the pixel clock. It determines the speed at which the sensor pixels are read out.

We recommend not setting the pixel clock any higher than necessary to achieve the desired frame rate. To find a pixel clock that meets your imaging needs, start capturing images by pressing the 🎞️ Start Capture button. Then, adjust the pixel clock while observing the percentage of dropped frames shown beneath the Pixel Clock slider.

Frame Rate

The possible range of settings for the frame rate depends on the currently selected pixel clock. You can select a lower frame rate without changing the pixel clock. To set a higher frame rate, however, the pixel clock might need to be increased.

Exposure Time

The exposure time depends on the currently selected frame rate and is preset to its reciprocal value. A shorter exposure time can be set without changing the frame rate. A longer exposure time will reduce frame rate.

Note: The increments for setting the exposure time depend on the sensor's current timing settings (pixel clock, frame rate). The exposure time values are rounded down to the nearest valid value, if required. For this reason, the actual exposure time can deviate slightly from the exposure time you have selected.

Pixel Data Format

Some DCx cameras provide a user-selectable choice in image pixel format between 24-bit RGB, 24-bit Monochrome, and 10-bit Monochrome. The choice of pixel data format affects how the images will be saved, the scale of the raw data seen in the analysis windows, etc.

The Image Tab:

Gain

To increase image brightness, the signal can be amplified by an analog gain before the digitizing process. The results of analog signal processing are usually better than the results of digital post-processing.

Depending on the sensor type, a global gain value for all pixels (master gain) or a separate gain value for each color (RGB gain) can be set.

Note: Signal gain will also result in a noise gain. High gain settings are therefore not recommended.

Offset

This sets the black level for the camera. The black level is the signal level acquired when there is no light falling on the sensor.

Auto White Balance

Different light sources can have different spectra, sometimes characterized as "color temperature" which can result in color casts in the captured images. Sources with low color temperatures (e.g. incandescent lamps), the white point is offset towards a red hue. Sources with high color temperatures (e.g. cool-white fluorescent lamps), the white content is offset towards a blue hue.

The white balance control feature uses the RGB gain settings of the camera to correct the white level. This is achieved by adjusting the gain controls within the 0-100 % range until the red or blue channel matches the average brightness of the green channel. In order to manually influence the color rendering, you can adjust the setpoint values for the red and blue channels relative to the green channel by using an offset value.

Gamma

Applies a digital gamma correction in software which applies a gamma characteristic to the image. Sensor gamma applies additional gamma correction in hardware if the camera model supports it.

The Image Enhancement Tab:

Edge Enhancement

This function enables/disables a software edge-enhancement filter. This function results in a higher computer CPU load.

Color Saturation

Adjusts the color saturation in software. In the U channel, this information results from the difference between the blue level and Y (luminance), in the V channel from the difference between the red level and Y.

Sensor Hot Pixel Correction

During the manufacture of our cameras, all sensors that will be used in DCx Cameras are checked for hot pixels. In the process, images are taken with a darkened sensor and long exposure times. Pixels with a brightness higher than a specific value are classified as hot pixels. Hot Pixel Correction suppresses these pixel values.

Area of Interest (AOI)

Using this function, you can set the size and position of an area of interest (AOI) within an image. In this case, only data included in this AOI will be read out and transferred to the computer. The smaller partial image enables the camera to use a higher frame rate. Note: Area of interest is sometimes called region of interest (ROI).

The Binning/Subsampling Tab:

Binning

Binning is a function that averages or adds multiple sensor pixels to obtain a single value. This reduces the amount of data to be transferred and enables higher camera frame rates. The captured image has a lower resolution but still the same field of view compared to the full-resolution image. This mode can be used as a fast preview mode for high-resolution cameras.

Subsampling

Subsampling is a technique that skips multiple sensor pixels when reading out image data. This reduces the amount of data to be transferred and enables higher camera frame rates. The captured image has a lower resolution but still the same field of view compared to the full-resolution image. This mode can be used as a fast preview mode for high-resolution cameras.

The Shutter Tab:

Global Shutter

On a global shutter sensor, all pixel rows are reset and then exposed simultaneously. At the end of the exposure, all rows are simultaneously moved to a darkened area of the sensor. The pixels are then read out row by row.

Exposing all pixels simultaneously has the advantage that fast-moving objects can be captured without geometric distortions. Sensors that use the global shutter system are more complex in design than rolling shutter sensors.

All CCD sensors as well as some CMOS sensors use the global shutter method.

Rolling Shutter

With the rolling shutter method, the pixel rows are reset and exposed one row after another. At the end of the exposure, the lines are read out sequentially. As this results in a time delay between the exposure of the first and the last sensor rows, captured images of moving objects are distorted.

To counteract this effect, the DCx Camera software provides a global flash window where you set the time by which flash activation is delayed. You can also specify the flash duration. This allows implementing a global flash functionality which exposes all rows of a rolling shutter sensor simultaneously.

Rolling Shutter with Global Start

Some rolling shutter sensors also provide a global start mode, which starts exposure of all rows simultaneously. For best results, use a flash for this mode. No light is allowed to fall on the sensor outside the flash period because otherwise the image brightness will be distributed unevenly.

Log Mode

Log mode is a special mode in some camera models that defines a threshold at which the linear response of the camera switches over to a logarithmic response.

The Trigger Tab:

Trigger

In trigger mode, the camera is on standby until it receives an electrical input signal telling it to start acquisition. The Trigger settings tab allows you to set the delay time between the trigger and start of acquisition, whether the trigger is a rising or falling edge, and how long the camera should wait for a trigger signal before timing out.

The Input/Output Tab:

The input/output tab allows you to setup hardware input/output signals with camera. Not all cameras support all features.

3.5.   Common Control and Analysis Tools

3.5.1.   Pan/Zoom

To pan the image, left click and hold the left mouse button. Drag to pan around the image.

To zoom, use the mouse wheel to zoom in and out. This applies to both the DCU-series and scientific-grade Live windows.

3.5.2.   ⏲ Timed Series

Launches Timed Series control window to set up recording of a time lapse.
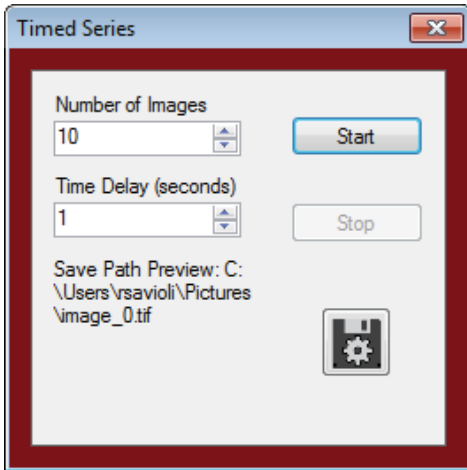
Set the Number of Images and the Time Delay, then press the **Start** button. If the "Quick Save" feature has NOT been selected (see below) you will be prompted for a file name and location using the native Windows Explorer window, otherwise the timed series will immediately start - saving to the parameters set-up in the **Save Configuration Tool**.
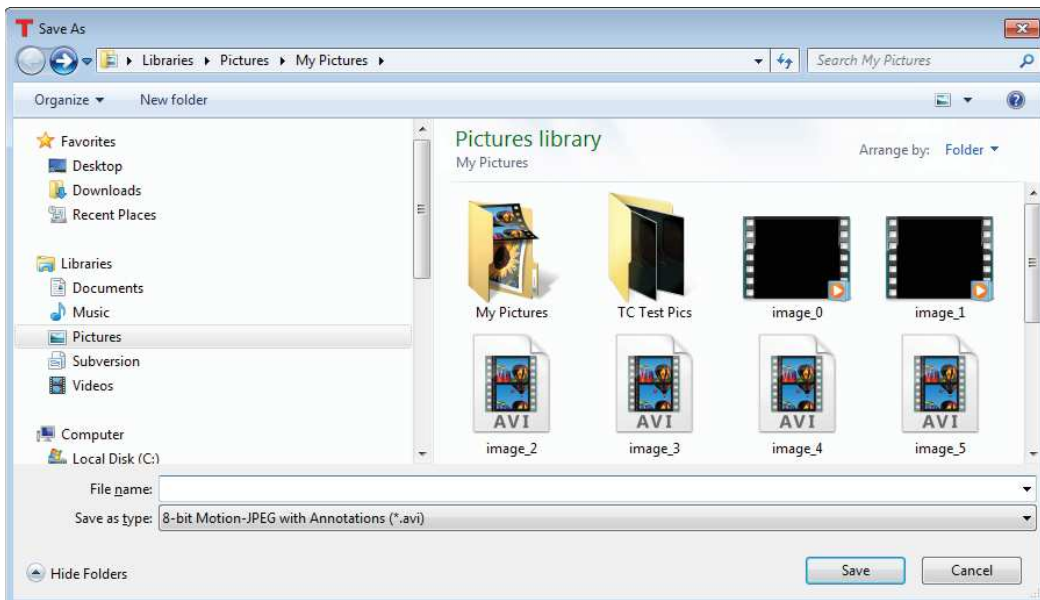
The Save Path Preview is informational only and shows where the recording will be saved. To change this location press the icon and you will be redirected to the Save Configuration dialog (See Section 3.5.4.).

The icon provides a short-cut to the folder in which you have saved your images. Additionally, each time you press the Quick Save icon, the path information will be displayed along the bottom status bar, momentarily highlighted in green to indicate a successful acquisition and save.

Last Image Saved: C:\Users\rsavioli\Pictures\image_7.tif

3.5.3. Save Image

Pressing this floppy disk icon saves the current image to file. Users can select a variety of file formats. This feature can be selected to capture a static image (camera is stopped) or capture a snapshot of a live video image without pausing the acquisition.

If the "Quick Save" feature has NOT been selected (See Section 3.5.4.) you will be prompted for a file name and location using the native Windows Explorer window…
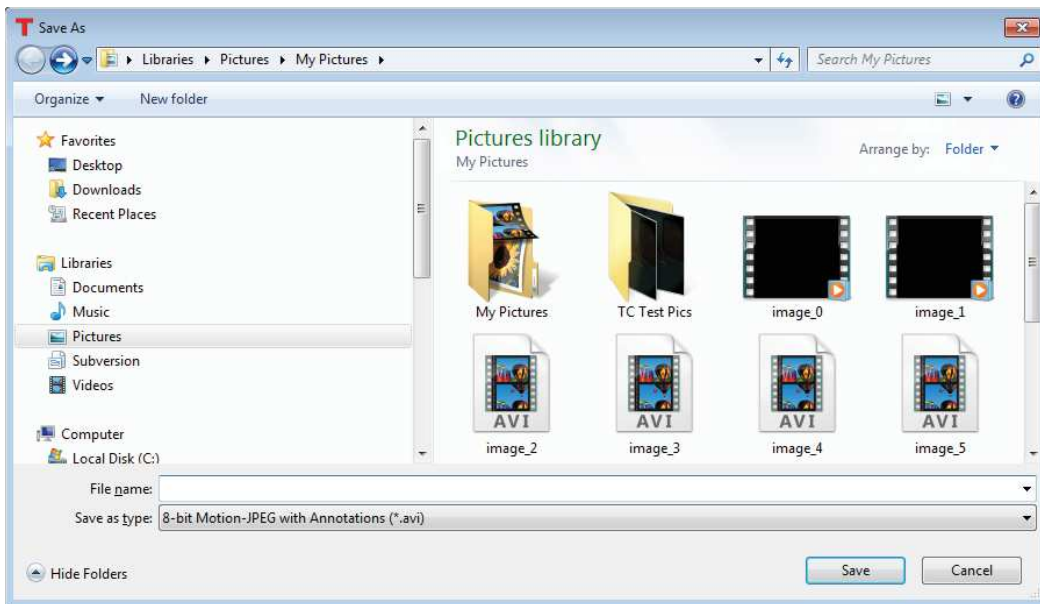
… Otherwise a single frame acquisition will start - saving to the parameters set-up in the ***Save Configuration Tool*** (See Section 3.5.4.).

The icon provides a short-cut to the folder in which you have saved your images. Additionally, each time you press the Save Image icon , the path information will be displayed along the bottom status bar, momentarily highlighted in green to indicate a successful acquisition and save.

Last Image Saved: C:\Users\rsavioli\Pictures\image_2.jpg

The Quick Save feature does not work in Record mode or Timed-series capture mode.

When a TIFF file is opened by ThorCam the relevant bits per pixel parameter is read from a custom tag in order to properly display the image. Other metadata stored within custom tags in the TIFF file include various camera settings.

Annotations and display settings are not saved in TIFF images. Use PNG or JPEG formats if annotation is to be saved.

⚠️

Caution: Not all imaging programs preserve custom TIFF tags. Thorlabs metadata might not be preserved if the ThorCam TIFF file is processed and saved by a third-party program.

**PNG** and **JPEG** formats are provided in order to save an image as displayed. Both display rendering (contrast) and annotations are preserved. **PNG** or *Portable Network Graphics* file format converts the image in 8 bits/pixel/color uncompressed. This results in larger images but with no loss of quality relative to the image as it is displayed in the Live window. **JPEG** format also saves the image in 8 bits/pixel/color, but the image is JPEG-compressed. This will create much smaller files. Use JPEG for casual documentation or email.

3.5.4.   💾 Image Save Configuration Tool

The file type, format, location, and name of a stored image can be viewed or changed in the *Save Configuration* dialog. The default path is the Window's Users\Pictures folder with a default image prefix of "image". Using the Configuration set-up you can change the image name (Image Prefix), and browse to any folder you wish to save to, provided you have write-access privileges. The parameter fields are only active when the **Quick Save** box is checked.
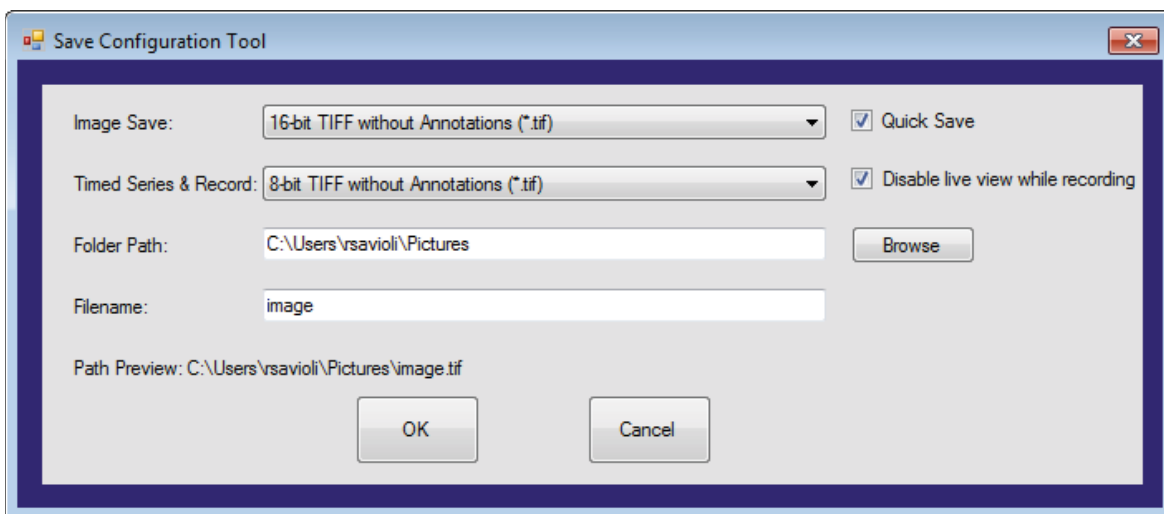
The first image or recording captured will have a file name consisting of the Image Prefix appended with "_0". As additional images or recordings are captured and saved they will be automatically appended with a numerical suffix _1, _2, _3 …).

The save path displayed in the path preview can be the actual location an image or recording is to be saved to, but the file name is not guaranteed. It is possible that another image or recording of the same name has been previously saved to the same path displayed in the path preview. When this happens the existing file will not be overwritten and ThorCam will save the new image or recording using the naming scheme previously outlined. The actual file name will be displayed on the status bar of the Live window.

Leaving the Quick Save box checked allows you to capture images using the Save Image Icon ![icon] without having to browse to a location to save each image.

By checking the **Disable live view while recording** box you can disable the live image while a recording is being made. This will reduce the instances of dropped frames while recording. This feature is available for all Timed Series & Record choices except "8-bit Motion-JPEG with Annotations (*avi)".

Note: Images with > 8 bits/pixel are often not properly rendered in imaging programs such as Microsoft photo viewer. To properly display them you should open them in the ThorCam viewer (see 3.7) or a capable imaging application such as ImageJ or IrfanView.

3.5.5.   Browse Saved Images

The Browse Saved Images icon provides a shortcut to your current location for saving Recordings, Time Series, and Quick Save Images.

3.5.6.   Histogram

Displays the histogram of the captured image values. If an analysis ROI is defined, the histogram uses that ROI.

TSI Scientific Cameras:

Close inspection of histogram values can be accomplished left-clicking on the graph and swiping left or right while holding the left mouse button down. Pressing ***Reset*** or right-clicking on mouse reverts back to the full histogram range. The histogram can also be viewed in a log-linear fashion by selecting the Logarithmic scaling button.

The histogram can be displayed as a bar graph by clicking this icon ![icon], or as a line graph by clicking this icon ![icon] . Hovering you mouse over the Histogram will allow you to inspect individual bins for their respective R, G, B, or Unprocessed values. Use the ***Linear sRGB Image Type*** for more consistent RGB bin values. For color images each of the R, G, B waveforms can be turned on or off using the corresponding check box.

The histogram data can be saved to a text file using the Save Data button, and imported into a spreadsheet as a comma delimited file for further evaluation.
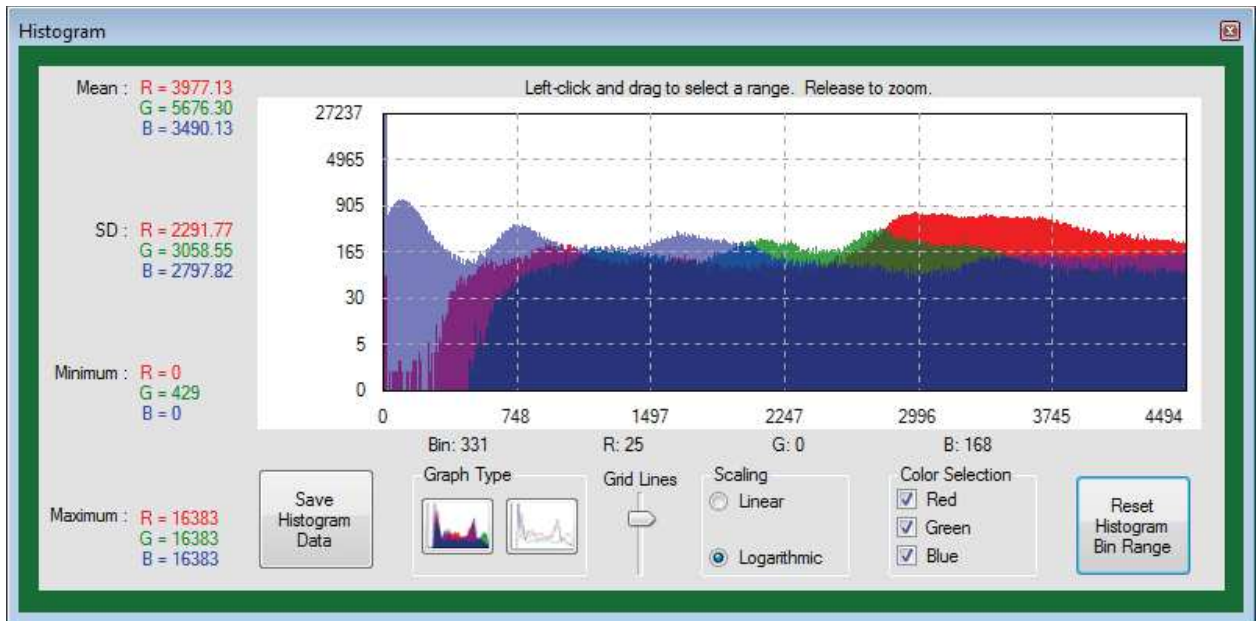
Bar Histogram
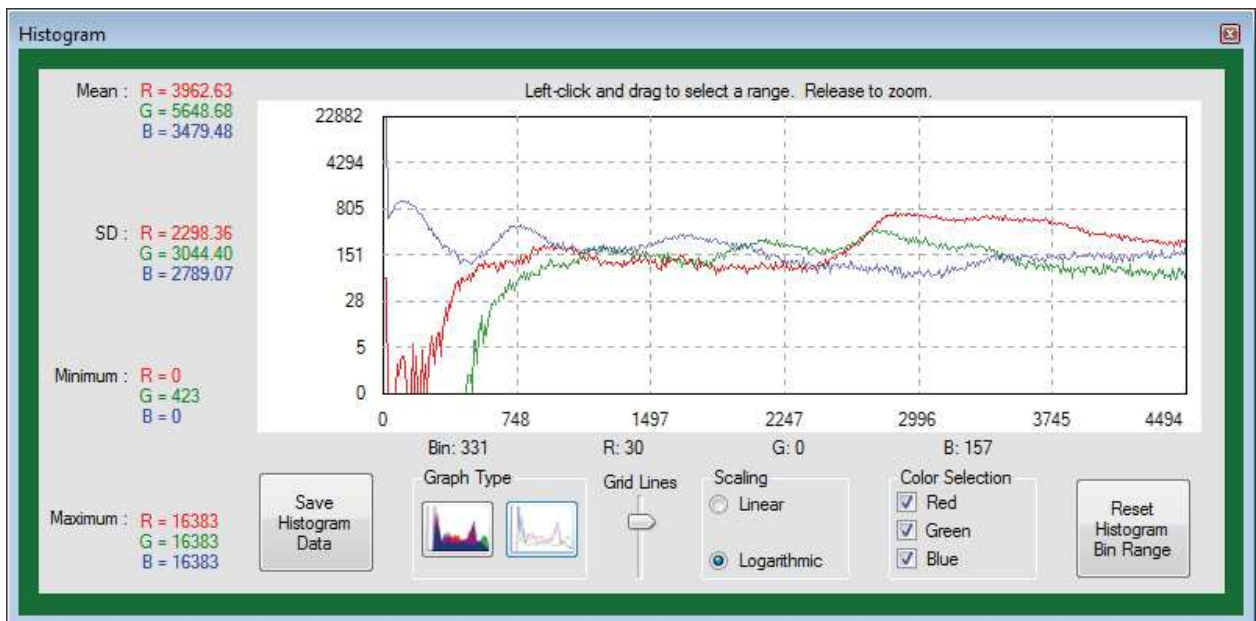
Line Histogram
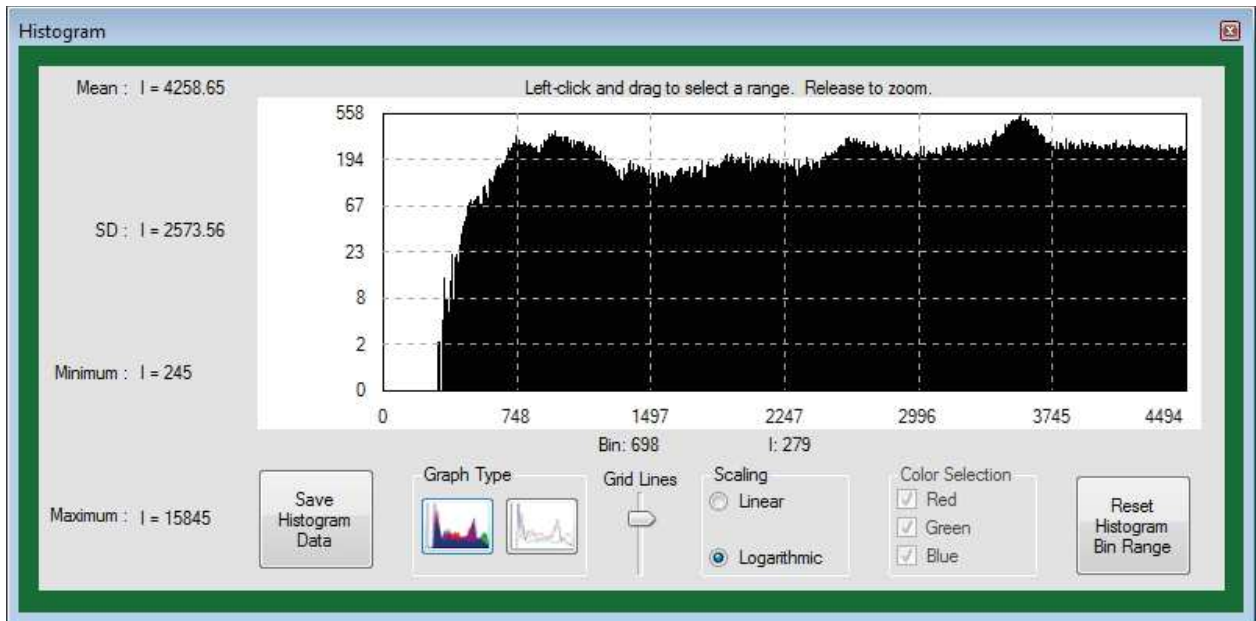
Monochrome Bar Histogram

DCx-Series Cameras:

The histogram for the DCx-Series cameras is shown below and contains very few of the features provided for our scientific cameras. Color cameras can display all or none of the R, G, B waveforms, along with the average value of each.
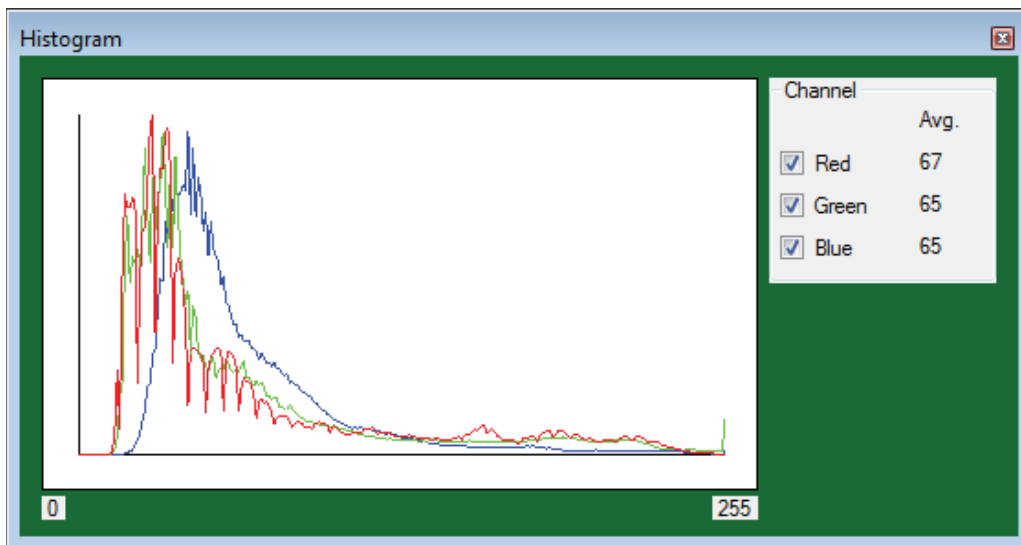
DCx-Series Histogram

A note about histograms: Due to the method that the histogram values are calculated, in conjunction with the various color balancing gains applied to the digital data received from the camera, there may be certain conditions that result in a histogram having the appearance of missing data bits. This is not an indication of poor image processing from the camera and only a side-effect of the complexities of the graphical representation of the data.

3.5.7. ⛰ Horizontal Line Profile

Draws a horizontal line across the image and displays the values of the pixels along the line in a separate window. The position of the line can be moved by left-clicking anywhere in the image. With your cursor anywhere within the profile graph, a set of cross-hairs appear allowing you to measure the intensity of specific pixels. For color cameras, individual R, G, B plots can be viewed or turned-off by checking the appropriate box. Clicking on the Horizontal Line Profile icon a second time removes the line and window.
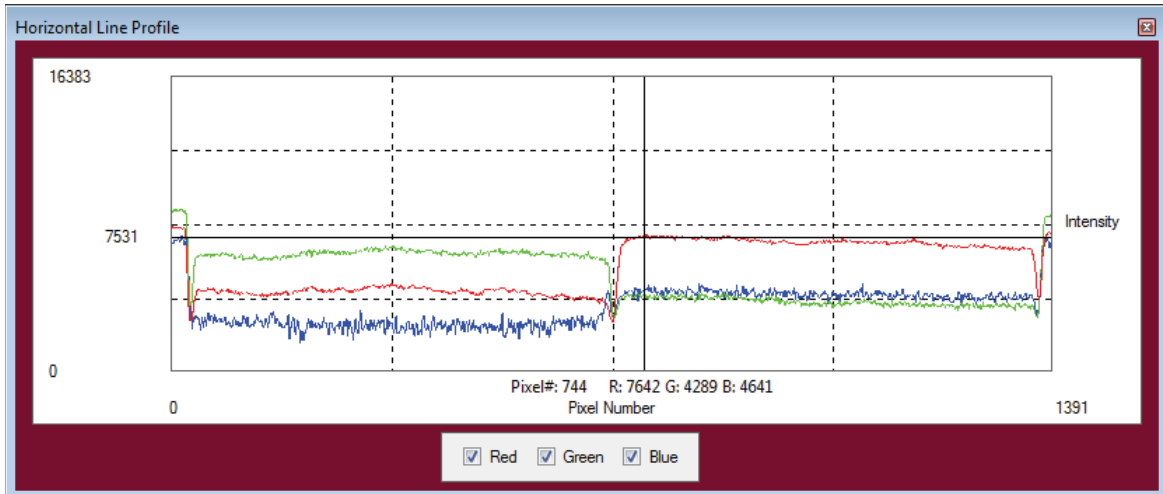
3.5.8. ⛰ Vertical Line Profile

Draws a vertical line across the image and displays the values of the pixels along the line in a separate window. The position of the line can be moved by left-clicking anywhere in the image. Other functionality is the same as the Horizontal Line Profile. Clicking on the Vertical Line Profile icon a second time removes the line and window.

3.5.9. ▦ Pixel Peeker

Shows the user the value of the pixel that the mouse is currently over (gray box in center), as well as pixel values in the surrounding neighborhood. This window is resizable to allow viewing of a smaller/larger neighborhood.

3.5.10. ▱ ✂ Analysis ROI

Allows a rectangular region to be drawn in the image for analysis such as histogram, mean, and standard deviation, and auto-scaling of the image display. Right-click to de-select. Note: The DCU-series cameras crop the visible area when an ROI is selected. Right clicking un-crops.

3.5.11. ¹₂₃ Tally Counter

Launches a tally counter window that allows counting and marking objects in the image. Hold the shift key and left-click to count/mark. Releasing shift key pauses counting and resumes normal dragging and zooming to allow interactivity with the image in between counting.

3.5.12. ⬈⬋, 🔍¹:¹, 🔍¹:² Image Resize: Fit to Window, Display 1:1, Display 1:2

Fits image to window, maps each display pixel to each camera pixel, maps each display pixel to every 2 camera pixels.

3.5.13. ⊕ Reticle

Places a reticle cross-hair target in center of image for visual reference.

3.5.14.　　▉ Display Settings
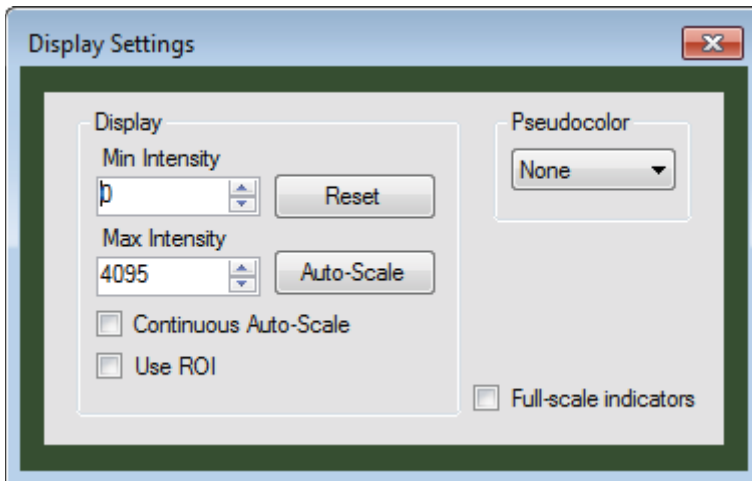
The ***Min Intensity*** and ***Max Intensity*** controls set the contrast of the image. Pixel values equal to or less than the Min intensity level are set to a display value of 0, or black. Pixel values greater than or equal to the Max Intensity level are set to a display value 255 or white. Pixel values in between are mapped to the display linearly from 0 to 255.

The ***Reset*** button resets the Min Intensity and Max Intensity to their default values based on the camera's native bits/pixel.

The ***Auto-Scale*** sets the Min Intensity and Max Intensity according to the image data captured at the time the button is clicked. Auto-Scale ignores extreme outlying values so that the values are not influenced by one or a small number of pixels.

Continuous Auto-scale performs Auto-scale on each frame as they are rendered.

Use ROI works in conjunction with the Analysis ROI tool (See 3.5.10). Draw a box around the specific area of the image that you wish to have the Auto-scale values calculated from.

Pseudocolor provides a means of visualizing subtle intensity differences in a greyscale image. Selecting one of the seventeen options from the drop down menu will colorize a monochrome image by substituting a unique color for each intensity level.　See Section 4.2. – Appendix B for details.

Full-scale indicators changes the brightest (top 1% of full-scale) and darkest (bottom 1% of full-scale) pixels to red and blue respectively for images from the polarization sensitive camera CS505MUP only.

3.5.15.　　⚡ Plug-ins

Identifies and launches plug-in windows if plug-ins are installed. See 4.1 – Appendix A for details.

3.6. Common Annotation functions

Image annotation functions are accessed from the toolbar on the left side of the Live window. The user can select whether or not to save annotations in the Save As or Quick Save dialogs. Not all formats support annotation.

3.6.1. Draw Freehand, Line, Rectangle, Circle

Clicking on any one enters the annotation mode for that graphical element. Multiple graphical objects can be drawn in succession, and annotation mode persists until either right-click or icon is clicked again to disable. Deletion of each graphical item is done in order using successive clicks of the Undo Last Annotation icon.

3.6.2. Draw Text

Clicking on the Draw Text icon enters annotation mode for text. Next click on the desired location for the text, which will bring up the text annotation box. Enter text and select font size. Click OK to place text. Multiple text objects can be placed in succession, and text annotation persists until either right-click the Draw Text icon is clicked again to disable.

3.6.3. Measure

Enters measurement mode. Click on image location to begin measurement. Drag to draw line. Release to end measurement. Result is displayed in units of pixels. Multiple measurements can be made in succession, and measurement mode persists until either right-click or Measurement icon is clicked again. Use Undo Last Annotation to delete.

3.6.4. Choose Annotation Color

Launches a color-picker window for annotations. Color choice does not affect prior annotation.

3.6.5. Undo Last Annotation

Deletes the last annotation in the image. Successive clicks will delete multiple annotations in reverse order.

3.7. Reading save images

Saved images can be viewed in ThorCam by loading them using the File->Load Image command in the main ThorCam window:
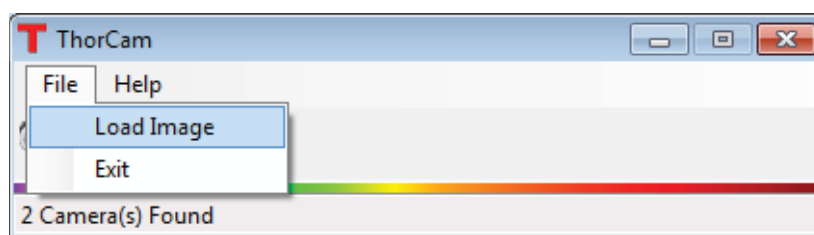
3.7.1. Multi-Page TIFF sequence Playback Controls

Sequences from scientific-grade cameras are stored in multi-page TIFF format in order to preserve the high-precision, unaltered image data. A multi-page TIFF file is a single file that contains multiple images. ThorCam will read back the multi-page TIFF files it generates during the Record or Timed Series modes and provides a set of simple controls to play the sequence, step forward or backward one frame at a time, or advance to the beginning or end of the sequence using the control buttons shown above.

3.7.2.   Analysis of saved images

ThorCam offers the same analysis/annotation functionality for loaded images that it has for live images.
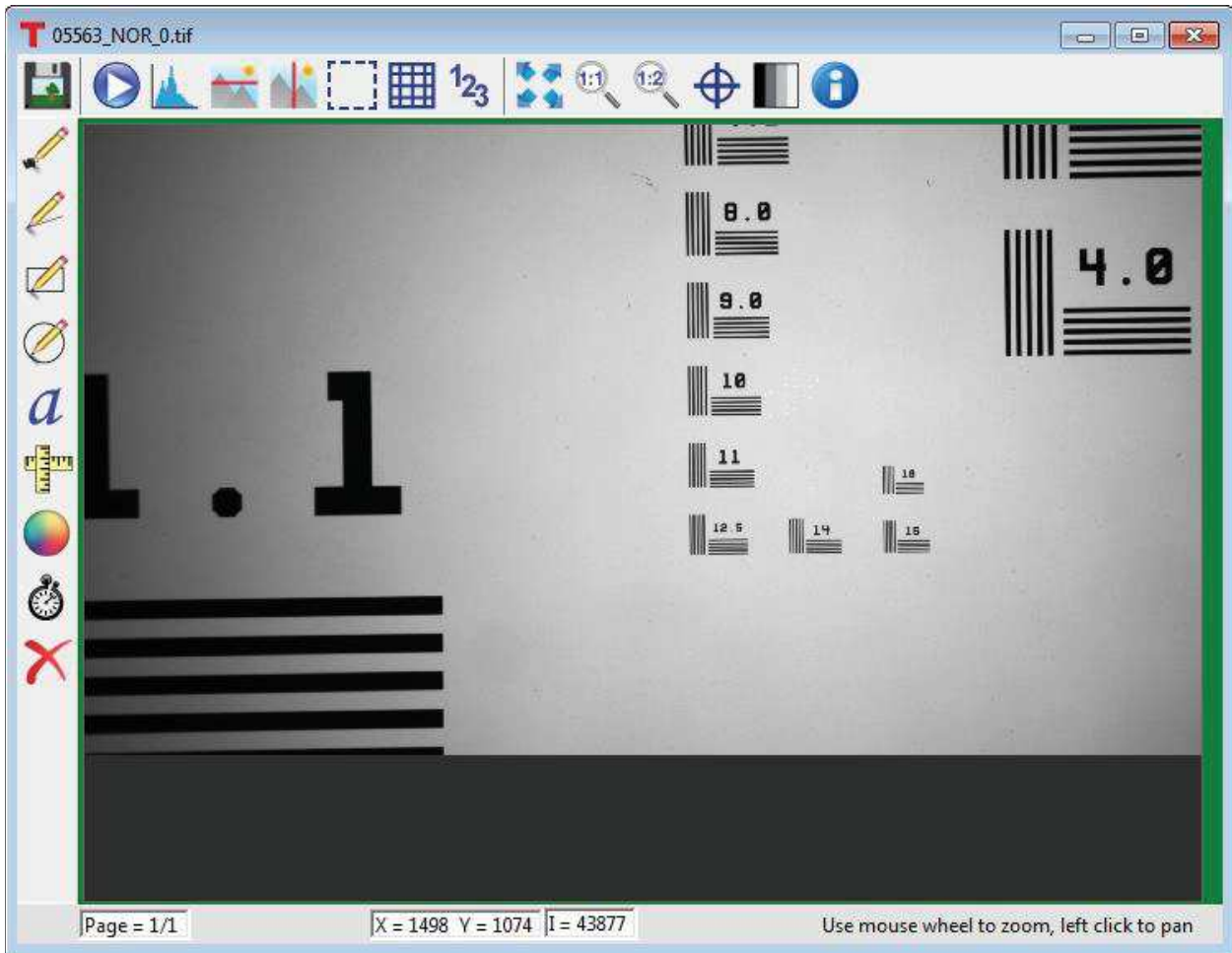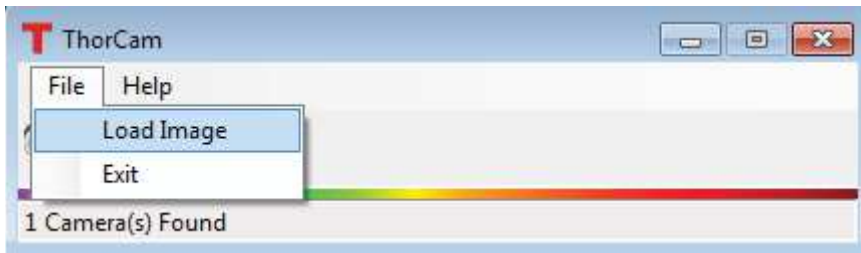
Chapter 4   Appendix

4.1.   Appendix A: Plug-ins

Plug-ins are small, application specific programs provided with ThorCam that allow a user to perform specialized tasks that are not provided in the main ThorCam application. They are accessed by clicking on the Plug-in icon along the top row of function icons. There is currently a limited number of Plug-ins that come standard with the ThorCam installation. More may be added as the need arises.

The TSI Overlay Plug-in

The TSI Overlay Plug-in is used in conjunction with the Thorlabs Scientific Imaging Two Camera Adapter 2SCM1-DC. The 2SCM1-DC is a two-way camera microscope mount which can be used in a variety of ways to simultaneously image the output of a microscope split by a dichroic mirror or a plate beam splitter to two cameras. The TSI Overlay Plug-in provides a number of controls to aid in visualizing the outputs of both cameras. This plug-in only works with TSI Scientific Cameras.

Set-up

Prior to working in the TSI Overlay Plug-in, you must first focus and align the cameras you intend to use. Refer to the ***2SCM1-DC Two Camera Mount User Guide*** for details on mounting your cameras. Open the ThorCam Software. A small window will pop up telling you how many cameras you have connected. It should register two available cameras; if they are not both showing up, hit the refresh button. Make a note of the serial number associated with each of the two cameras and their respective positions on the 2SCM1-DC (Refer to ***3.3.7*** for information on renaming each camera with a more descriptive identifier). The transmitted image is being captured by the camera mounted to the CXY2 while the reflected image is captured by the camera mounted to the LCP02R. Either camera can be used as the Background image, but it is most common to use the transmitted image as the Background Image. From the GUI for the desired background image, open the Two Camera Overlay from the plug-in tab at the top of the window. Click on each of the two available cameras to open their image view windows. Hit the "Play" button in the upper left corner of each window to start live image capture. Depending on the light level used for excitation and the filter/mirror configuration used for your application, the exposure time and contrast levels may need to be adjusted on each camera to capture the desired image. ***Note: setting too long of an exposure time will greatly decrease the frame rate capture of the camera and make the output image choppy in real-time during alignment and adjustment.***

Now you will adjust each camera individually to properly focus the image onto the image sensor. This is accomplished by making slight adjustments to the depth that the ER1 cage rods are inserted into the CXY2 and the LCP02R. Start with the cameras flush against their respective mounts (e.g. with the ER1 cage rods fully inserted). Apply a light amount of pressure to the cage rods with the set screws, just enough that there is a slight resistance to changing the inserted rod depth. By using the embedded line profile tool in the toolbar of the ThorCam Software (see ***3.5.7***) in conjunction with visual inspection of the output image on the screen you can fine tune the focus of each camera's output image. Bring the image into focus by incrementally sliding the camera away from its mount. When the image is in focus, the peaks of the line profile histogram will be at their tallest and narrowest readings, meaning the greatest amplitude and smallest variance. At this point the output image should appear in its crispest form on the screen. Once this is done for both cameras, tighten the cage rods; you are now ready to align the transmitted and reflected images in overlay.

Alignment

In order to align the transmitted and reflected images you will use the TSI Overlay Plug-in. Click on the "Plug-In" button on the toolbar of the transmitted image window and click on "Two Camera Overlay." When this is done a "TSI Overlay Plug-In" window will open. Choose the second camera from the drop-down list and click on "Start." Depending on how the reflected image is flipped, you will need to click on either the "Flip Horizontal" or "Flip Vertical" box of the reflected image to orient the two images in the same manner on the screen. Now, using the X & Y plane adjustment knobs on the CXY2 and the rotation adjustment knob on the LCP02R, you can position the two images so that they are perfectly overlaid.
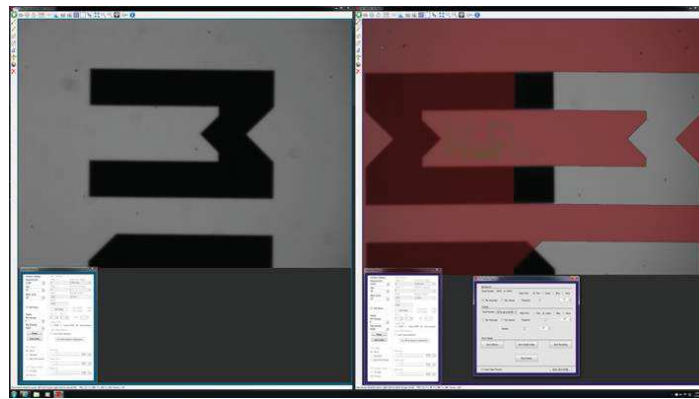
(L) Original Background Image; (R) False colored background image with reflected image overlaid

Operation

The main window of the TSI Overlay Plug-in is used to initiate Overlays, Single Image Saves and Recordings from two TSI cameras.
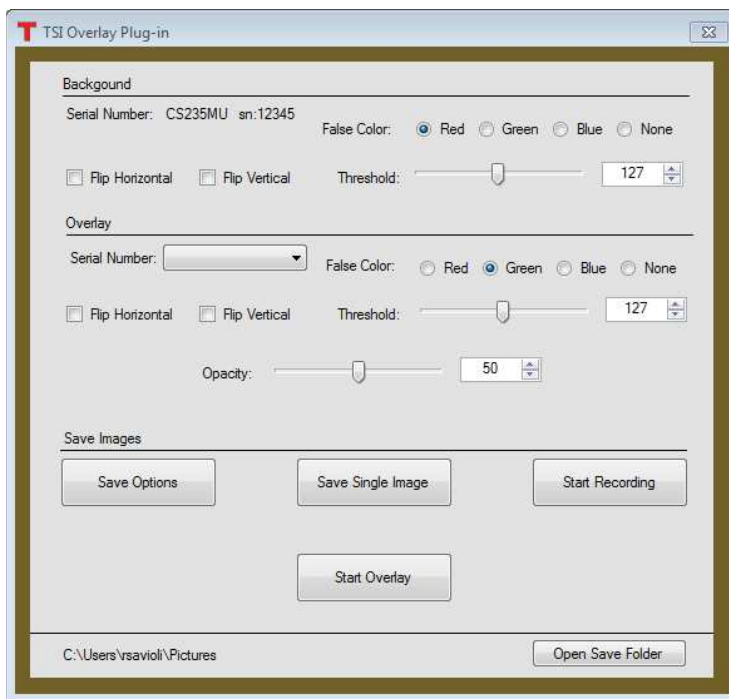
From the ThorCam main menu window (see section ***3.1***) select the two cameras you will be working with from the drop down selection. You will now have two instances of the imaging GUI open - one for each camera. Determine which camera will be used for the Background image and open the TSI Overlay Plug-in from that camera's GUI. The name and serial number of the other camera will now be listed in the Overlay section of the plug-in screen.

The main window of the TSI Overlay Plug-in is used to initiate Overlays, Single Image Saves and Recordings from two TSI cameras.

An overlay session is initiated by clicking the Start Overlay button. During an overlay session the image data from a secondary camera will be projected over the image data from the background camera. The image data presented to you during an overlay session can be false colored in order to highlight desired image features. This false coloring will be applied to pixels which have intensity values greater than the threshold set for the selected color channel. For example, if you set the threshold to 127 and select red for

the false color, then any pixel with an intensity value greater than 127 will be false colored to red while all other pixels in the image will be fully transparent. By selecting different false colors and setting the proper thresholds for the images delivered from the background and secondary cameras, different image features can be highlighted for the purpose of differentiation and inspection. This becomes especially useful when using multiple light sources and a dichroic mirror for fluorescence imaging. By selecting the "None" option for false coloring you will simply be overlaying the reflected image on the transmitted image. This is useful when aligning the two images. Two image sources are always required for an overlay session. In addition to setting the intensity threshold for the false colored pixels, the opacity of false colored pixels can be adjusted with the "Opacity" slide bar on the Overlay Plug-in window.

You may also elect the flip the false colored pixels along the X or Y axis to align the information you are seeing to accommodate your needs. The actual image from the background camera is not flipped and only the image from the background camera is displayed in the Live Window hosting your overlay session.

The opacity of false-colored pixels from the background camera and the secondary camera is adjusted with the Opacity slide bar.

At any time you can elect to save individual images or recordings from the background and secondary cameras. An image is saved in its original form from the image source, meaning no false coloring is applied to pixels in saved images. You can configure how images are saved using the TSI Save Configuration Tool for the TSI Overlay Plug-in. To use the TSI Save Configuration Tool click the "Save Options" button on the TSI Overlay Plug-in Main Window.
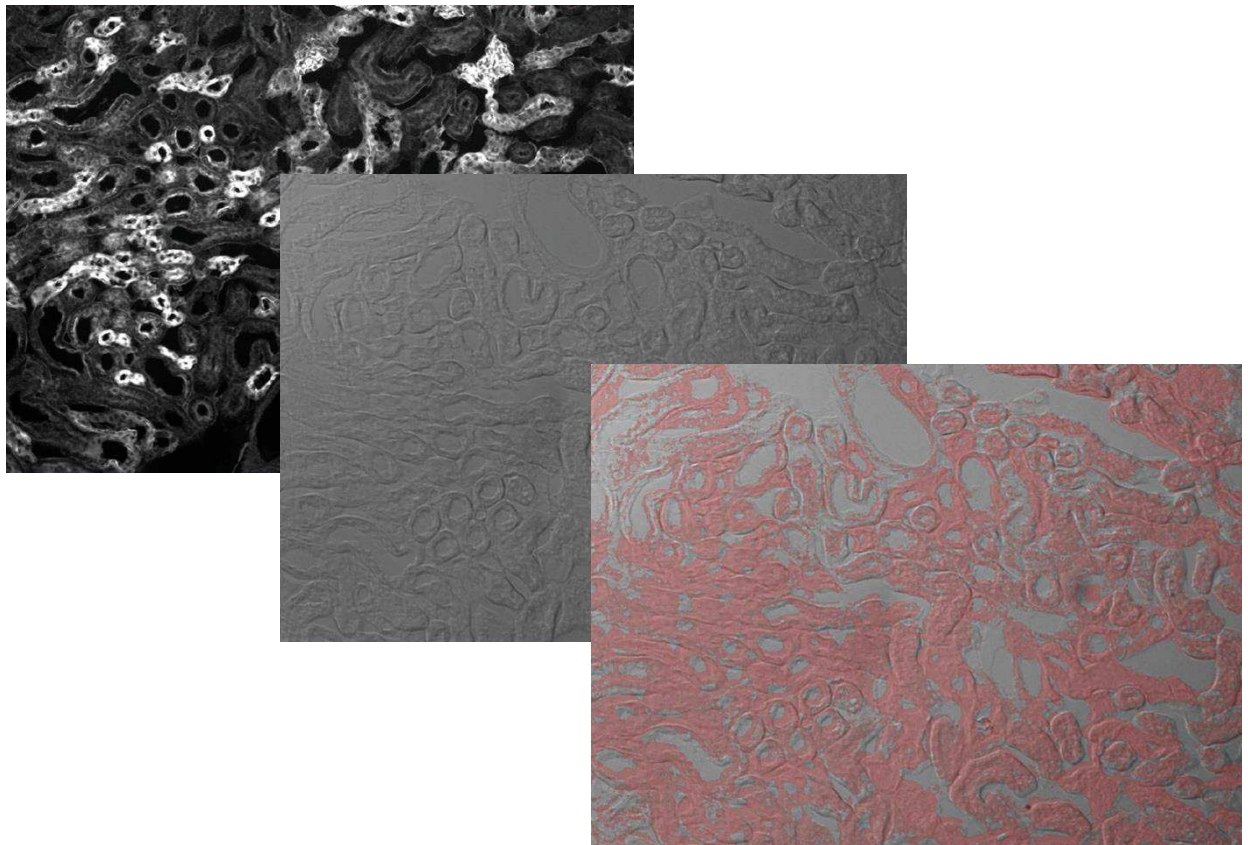
Live two-channel composite image generated with the ThorCam Overlay Plug-In. The image shows Fluorescence (Pink) and DIC (Grayscale) images of a mouse kidney.

TSI Overlay Plug-in Save Configuration Tool:
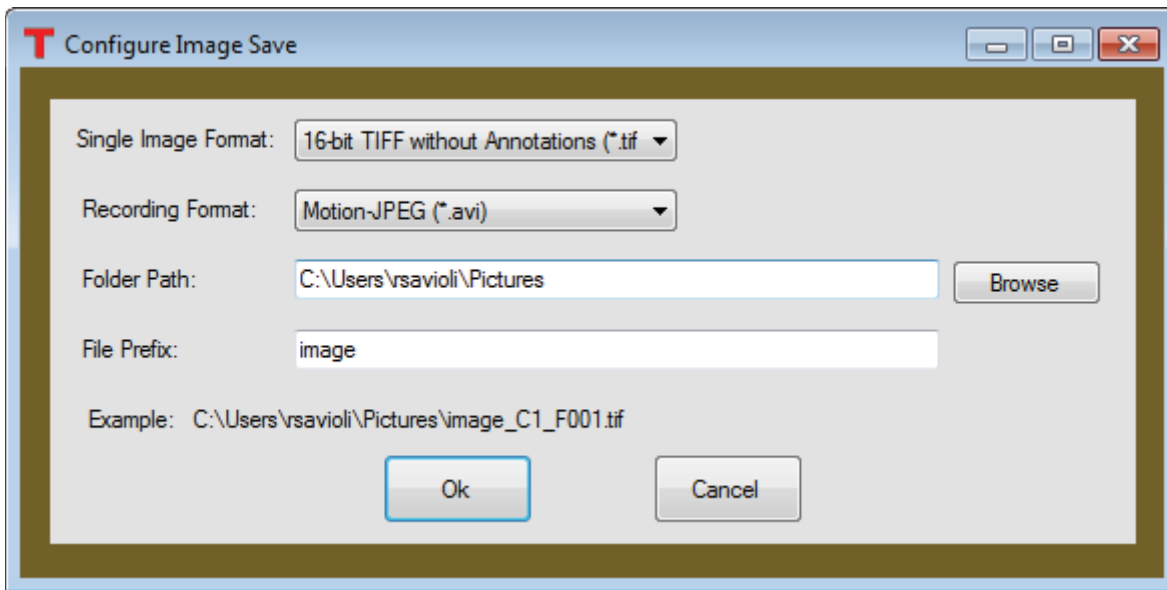
The TSI Save Configuration Tool is used to configure how individual images and recordings are saved when using the TSI Overlay Plug-in. You may configure the saving of both individual images and recordings.

To configure how individual images are saved' select an option from the Single Image Format drop-down box. You will notice that annotations are supported when saving images to the PNG or JPG format, however, only 8 bits per color channel is supported when using these image formats. If you require greater fidelity in your images then it is suggested that you use the 16-bit TIFF image format.

To configure how recordings are saved, select an option from the Recording Format drop-down box. Annotations are not supported for recordings. If you require smaller files when recording then it is suggested that you select the Motion-JPEG format and save your recording to an AVI file. If you require greater image fidelity then it is suggested you select the Multipage TIF format and save your recording to a TIFF file. Be aware the Motion-JPEG format uses 8 bits per pixel and are compressed using lossy JPEG compression, while the Multipage TIF format uses 16 bits per pixel and are not compressed, resulting in substantially larger files.

You may select where your images are saved by directly entering a valid path to your desired save folder or by clicking the Browse button and navigating to it. Be aware that you must have write permission at the selected save location.

You may define a file prefix for the artifacts you wish to save. This prefix can be any valid file name. If the filename is already in use at your save location then ThorCam will attempt to generate an unused filename automatically using your requested prefix as a base. ThorCam will append a numeric suffix to your prefix when attempting to generate an unused filename for you. For example if "myFile.tif" already exists at your save location then "myFile_1.tif" will be generated and then "myFIle_2.tif" until an unused filename is discovered or it is determined that it is not possible to generate a unique filename automatically for you.

The TSI Overlay Plug-in will always append a suffix to your filename's prefix using the following convention:

Suffix = _C[Camera number]_F[Frame Number]_Z000.[File Extension]
Ex. _C1_F0001_Z000.tif

Filename = prefix + suffix
Ex.
Prefix = myImage
Suffix = _C1_F0001_Z000.tif
Filename = myImage_C1_F0001_Z000.tif

This convention is used to make it easier for you to identify from which camera a saved image originated and which frame number associates two images from two cameras. Be aware the frame number used is always that from the background camera. The,"_Z000," portion of the suffix is reserved for future use by Thorlabs.

As you select image formats, save locations, and the prefixes for filenames, you will see a preview of the filename generated for you. The actual name of your file is not knowable until the moment your data is stored, because frame numbers are not constant and there is no way to pre-determine whether a filename is already in use at your selected location. The preview is provided to help you understand where your images will be saved and how they will be named, but it cannot tell you absolutely what a saved image will be named at any given moment.

4.2.   Appendix B: Pseudocolor

In the Display Settings menu option you will find the Pseudocolor selections. Pseudocolor provides a means of visualizing subtle intensity differences in a greyscale image. Selecting one of the options from the drop down menu will colorize a monochrome image by substituting a unique color for each intensity level. A few examples are shown below.
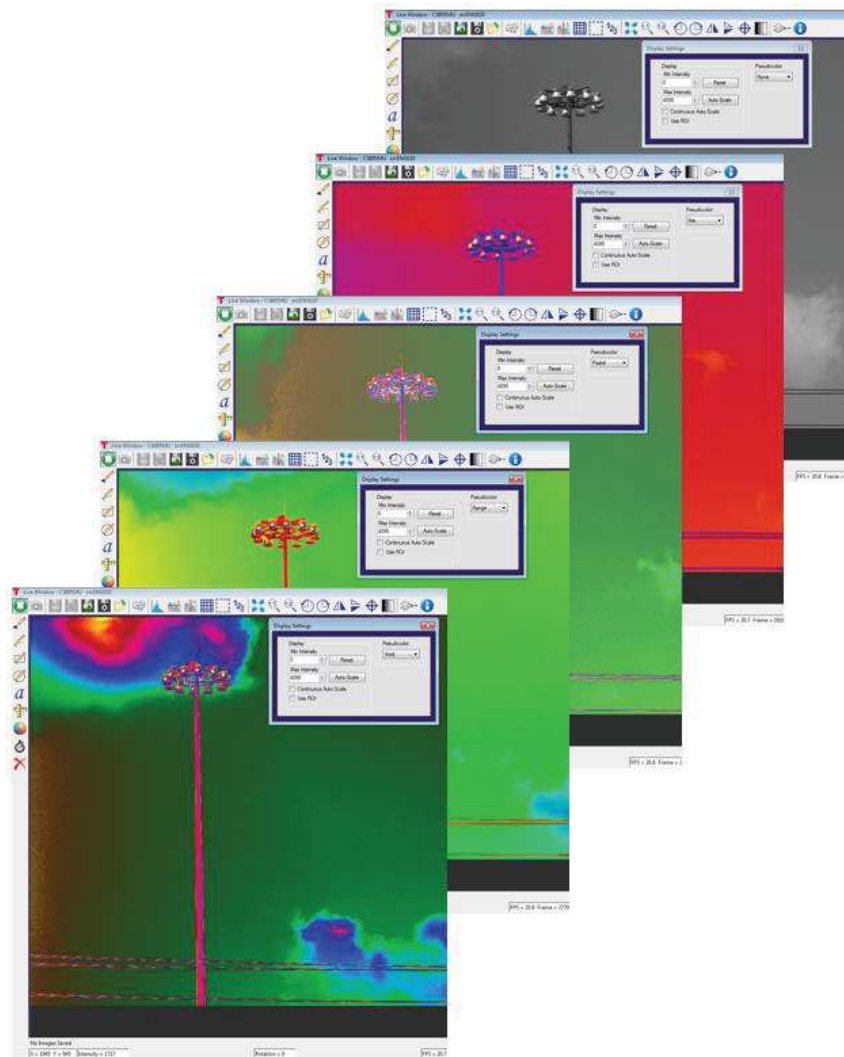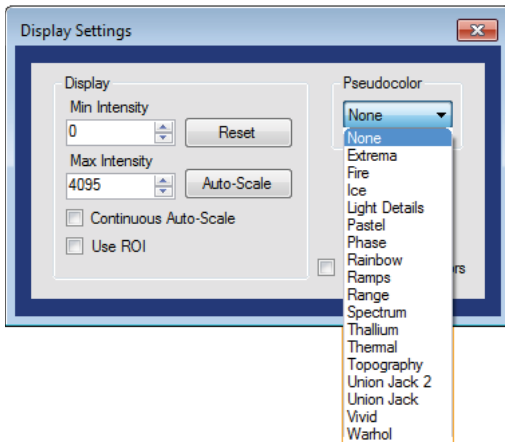
There is a folder in the ThorCam installation folder that is for Pseudocolor look-up tables (LUTs). The typical path is **C:\Program Files\Thorlabs\Scientific Imaging\ThorCam\LUTs**. New and custom LUTs can be added to this folder, as long as they are in the correct format, and will automatically be added to the Pseudocolor drop down menu. There is a readme file in the same LUTs folder that explains how to do this.

A Pseudocolor look-up table is a table of red, green, and blue values from 0-255 that correspond to the grey intensity value.

To add a new LUT simply save the LUT file into the ThorCam installation LUT folder and restart ThorCam.
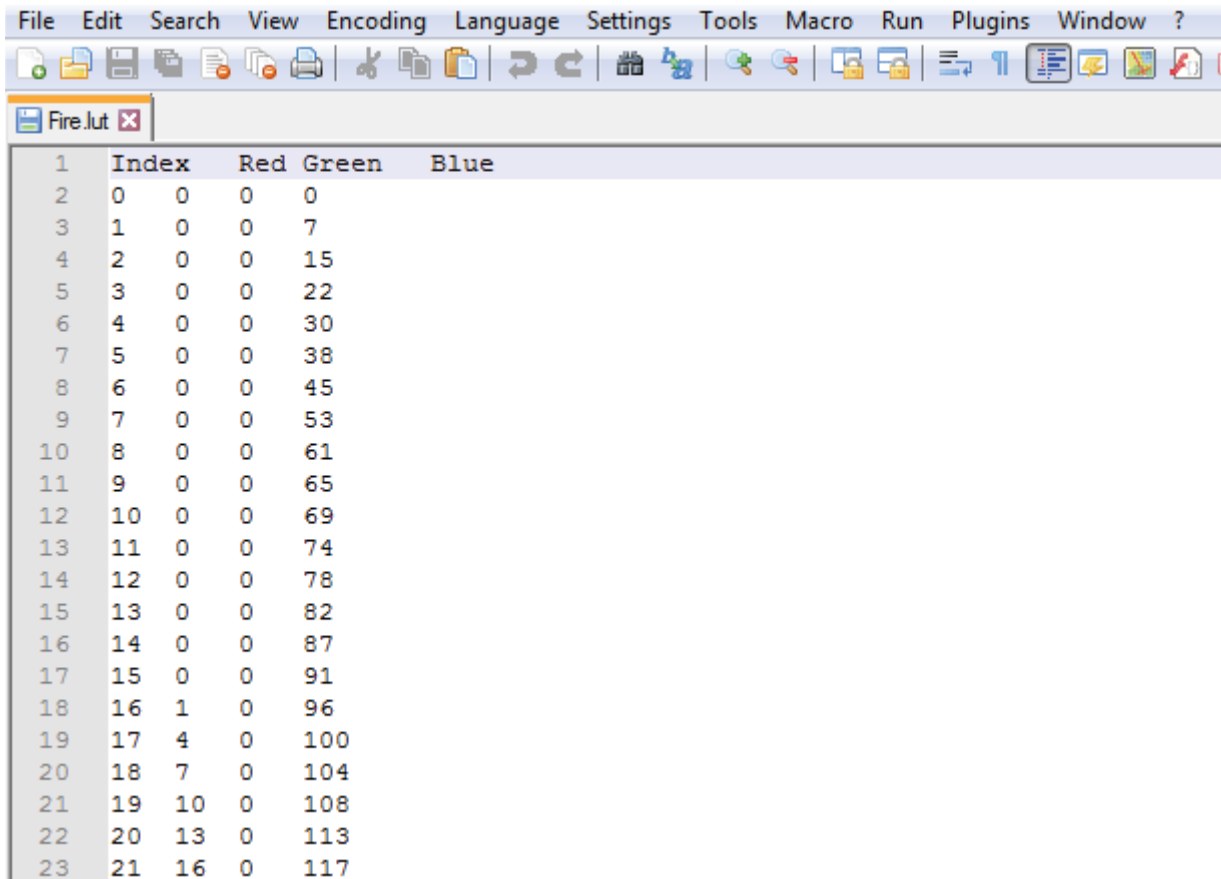
Each LUT should have the file extension ".lut" in order to be recognized and used.

LUTs will also have to be in the correct format. The installed LUTs show formats which are acceptable:

> The format should have each row of the file including the **index**, **red**, **green**, then **blue** values (integers from 0-255) in that order.
> Any text/characters other than numbers will be ignored.

More LUTs can be downloaded from ImageJ at https://imagej.nih.gov/ij/download/luts/ or a custom created LUT can be added to this folder.

Existing LUTs can be edited using a text editor such as Notepad++, an example is shown below.

| File | Edit | Search | View | Encoding | Language | Settings | Tools | Macro | Run | Plugins | Window | ? |

Fire.lut

Index	Red	Green	Blue
0	0	0	0
1	0	0	7
2	0	0	15
3	0	0	22
4	0	0	30
5	0	0	38
6	0	0	45
7	0	0	53
8	0	0	61
9	0	0	65
10	0	0	69
11	0	0	74
12	0	0	78
13	0	0	82
14	0	0	87
15	0	0	91
16	1	0	96
17	4	0	100
18	7	0	104
19	10	0	108
20	13	0	113
21	16	0	117

4.3.   Appendix C: Polarization Tools

4.3.1.   Selection and display of Polarization Parameters

ThorCam provides a number of useful analytic and visualization tools for use with our CS505MUP polarization camera. In the Camera Settings dialog window is a selection field for five *Image Types*; Intensity, DoLP, Azimuth, QuadView, and Unprocessed.

- Intensity: Total optical power in percent and Stokes parameter S_0: $\text{Intensity} = S_0, 0 \leq \text{Intensity} \leq 100$

- DoLP: Degree of linear polarization in percent: $\text{DoLP} = \frac{\sqrt{S_1{}^2 + S_2{}^2}}{S_0}, 0 \leq \text{DoLP} \leq 100$

- Azimuth: $\vartheta = \frac{1}{2} \arctan\left(\frac{s_2}{s_1}\right)$, $-90° \leq \text{Azimuth} \leq 90°$
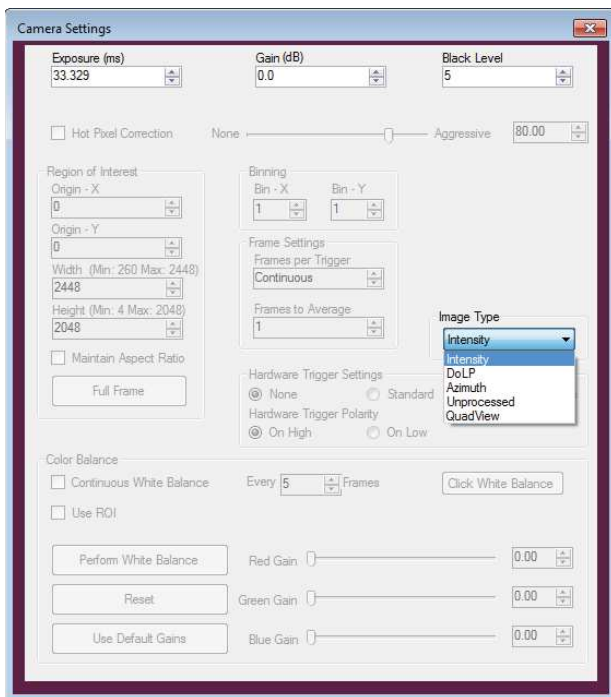

Each Image Type will affect how the image is rendered as well as how the Histogram and the Pixel Peak tools will be presented, resulting in each tool representing the appropriate unit of measure for the Image Type selected.

Selecting the QuadView Image Type from the drop down menu will produce a four-quadrant image which displays the raw 0, -45, 90, and 45 degree polarization azimuth angles detected by the image sensor. The image data is the same as Unprocessed but reorganized from the raw mosaic to a 4 quadrant image. The four quadrants will be preserved when saving the QuadView image to the various formats available (TIFF, JPEG, PNG, BMP).

The image below illustrates surface reflection as a function of the detector polarization with QuadView. Visualization is further enhanced using the Pseudocolor function in the Display Settings.
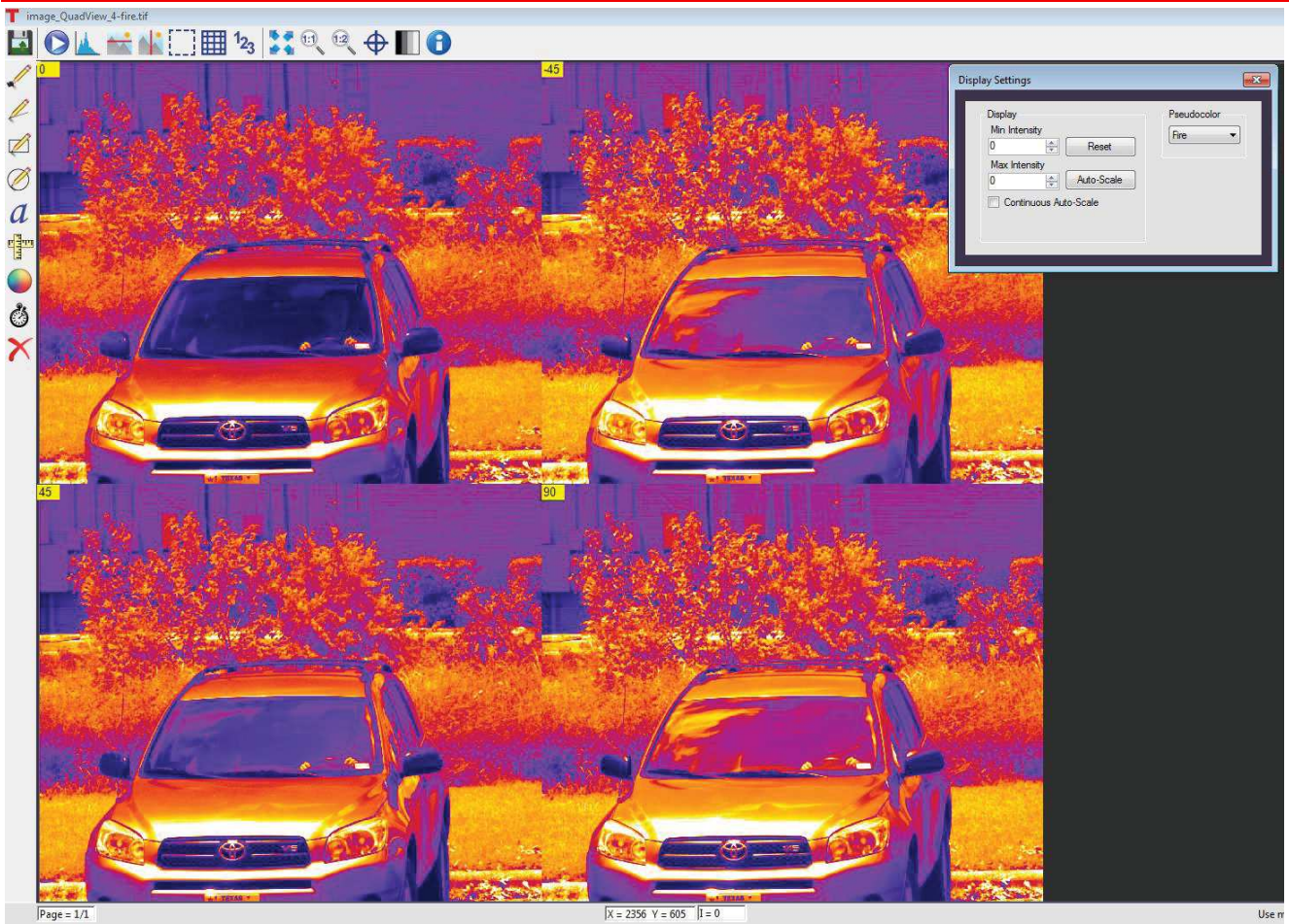
When saving QuadView images, selecting any file type option "with Annotations" will save the azimuth identifiers in the upper left corner of each quadrant.

4.3.2.   Expression of Polarization Parameter Numerical Values

The polarization image data for all data types is internally represented as integers for optimal performance and to reduce complexity of the processing data path from the camera to the polarization processing module through the ThorCam application to display and data files.

All data reporting windows (including pixel peek, histogram, and line profiles) as well as the toolstrip and display settings window will display the pixel values scaled to one of the specific ranges indicated above, depending on the selected polarization image type.

ThorCam converts the integer polarization parameter value for each pixel from to the appropriate floating point value with the following expression:

```
polarization_parameter = pixel_integer_value * (max_parameter_value / (2^bit_depth-1)) + min_parameter_value)
```

Where:

    polarization_parameter is the chosen parameter, expressed in the proper
    units, based on the Image Type; e.g. Azimuth in units of degrees from -90°
    to 90°

    bit_depth equals the number of bits per pixel that the camera delivers; e.g.
    12 for the CS505MUP)

```
pixel_integer_value is the integer value for a given pixel delivered from the
camera processing software
max_parameter_value: the maximum value for the polarization parameter
expressed in the proper units minus the min_parameter_value;
e.g. 90-(-90) = 180

min_parameter_value: the minimum value for the polarization parameter
expressed in the proper units; e.g. -90

e.g. pixel_integer_value = 4000 for an Azimuth image on the CS505MUP:
polarization_parameter = 4000 * (180 / (4096 – 1)) + -90 ≈ 85.82°
```

Polarization TIFF image data are saved to the file as integers, and a custom TIFF tag is created, TSI_POLARIZATION_IMAGE_TYPE, that contains the Image Type (Azimuth, Intensity, or DoLP). The saved filename will also include a suffix indicating the Image Type.

When such an image is loaded into the ThorCam image viewer (see 3.7) it will be displayed in the appropriate units using the same expression above. This feature only applies to images saved as 16-bit TIFF without Annotations, or 8-bit TIFF without Annotations, in all other cases the current displayed image is saved as-rendered, without the custom TIFF tag. See 3.5.4

If an 8-bit or 16-bit TIFF polarization image without annotations is read into a program other than ThorCam, the custom TIFF tag will not be recognized, and any data conversion to the floating point polarization values and units will need to be performed on the integer data using the expression above.

Chapter 5   Thorlabs Worldwide Contacts

For technical support or sales inquiries, please visit us at **www.thorlabs.com/contact** for our most up-to-date contact information.