Hardware Triggering and Pseudo-Global Shutter Triggering in CMOS Cameras

Dr Louis Keal – Version A3, 10-12-2020

In this document, the different modes and options to use Teledyne Photometrics CMOS cameras to control or be controlled by external hardware are explained. Why and how to use the cameras in Pseudo-Global Shutter modes is explained, and timing and frame rate tables in these modes are given. Additionally, the final section explains how to configure multiple cameras for simultaneous acquisition through hardware triggering.

Contents

Introduction to Hardware Triggering

Hardware triggering allows for high-speed, high precision interfacing and control between different components of a microscope or other optical system, without the need for software intervention.

To understand the triggering of CMOS cameras, it is first necessary to understand the behavior of the rolling shutter of CMOS cameras. This is introduced in the figure below, which also introduces the Timing Diagrams used throughout this document.

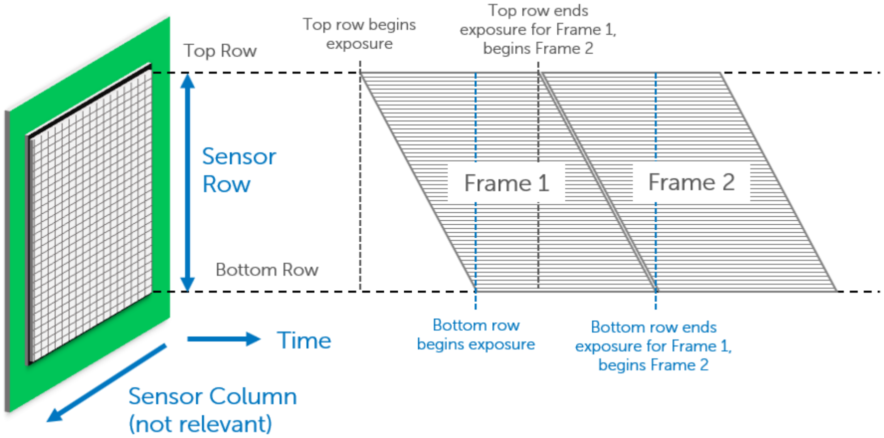


Figure 1: Introduction to Timing Diagrams. The camera sensor is shown on the left, with rolling shutter architecture meaning that exposure does not begin for the entire sensor at the same time, but exposure and readout move from the top to the bottom of the sensor. The time dimension is shown from left to right, with which rows are reading out indicated on the vertical axis. In overlap mode, there is some overlap in time between neighboring frames as shown.

Further, there are two important concepts to understand for the timing of rolling shutter cameras: the Exposure Time, and the Frame Time. These are introduced in Figure 2. The Frame time is the time taken for the rolling shutter to move down the sensor. This is easily found by $1 \, / \, Camera\ Frame\ Rate$, or is determined by the number of row of your camera or region of interest, multiplied by the readout time per line (the 'line time').

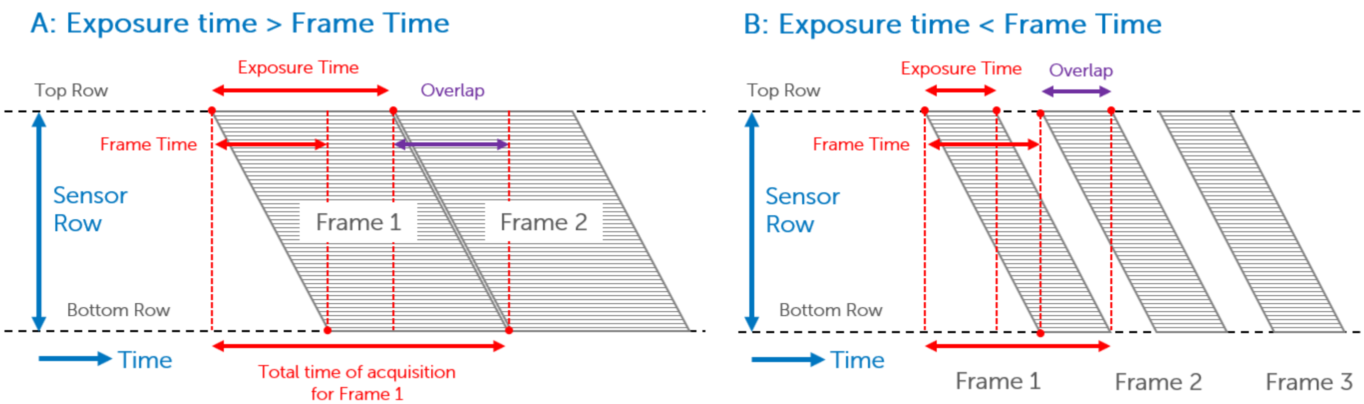


Figure 2: Introduction to Frame Time and Exposure Time. A: Camera behavior when exposure time is greater than Frame Time. B: Camera behavior when exposure time is less than Frame Time.

Available Trigger Signals & Modes

Expose Out Triggers

Expose Out triggers are triggers that go from 0V to 5V dependent upon the active exposure of the camera. There are different behaviors possible due to the rolling shutter operation of CMOS cameras.

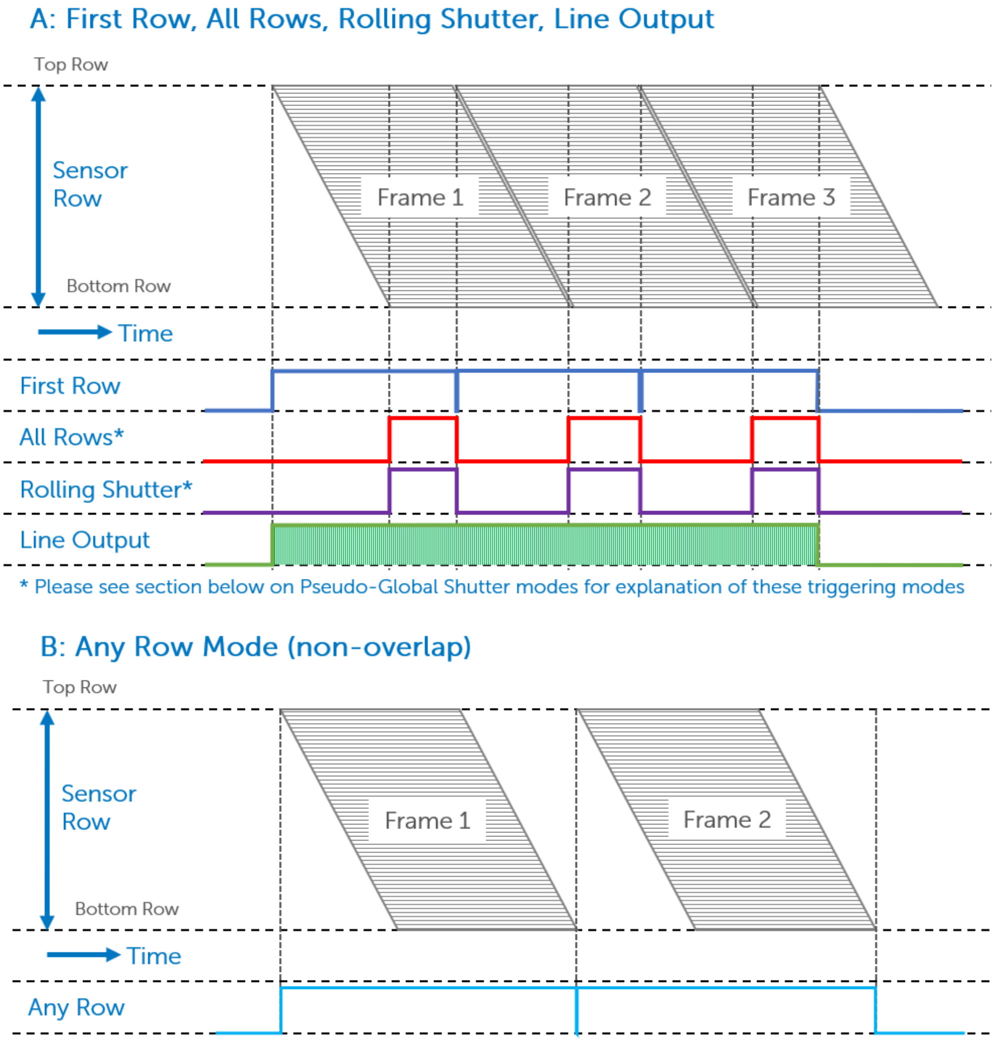


Figure 3: Expose Out Trigger Modes for CMOS cameras. A: These modes do not change the operating mode of the sensor, only the behavior of the output trigger. 'First Row' mode provides a high signal only while the top row of the camera is actively exposing. All Rows and Rolling Shutter modes both provide a high signal only when every row of the camera is actively exposing and the camera is in a 'global acquisition' state, so-called 'pseudo-global shutter' modes. Please see sections below. Line Output provides a high signal pulse for the start of acquisition of each line of the camera, for synchronization with galvo-scanning beam light sources. B: Any row mode provides a high signal while any row of the camera is actively exposing. In order to be effective for triggering hardware with hardware changes between frames, this mode forces the camera sensor out of overlap mode, meaning there will be no overlap in exposure between acquisition frames.

Expose Out Triggers: Pseudo-Global Shutter Modes

There are two key circumstances where the rolling shutter and 'overlap' of CMOS camera frames can be an issue. Firstly, for imaging multi-channels or multi X-Y or Z positions, any change between frames must wait for the frame to finish acquiring before a hardware change takes place. In for example multi-channel imaging, without use of triggering the overlap between frames of conventional rolling shutter acquisition could lead to some light from the following wavelength channel entering the current acquired frame.

Secondly, rolling shutter can be an issue for imaging high speed dynamic events where the rolling shutter can introduce artefacts relating to the different acquisition time for different lines. However, the delay between individual lines is so short that dynamics of high enough speed to introduce rolling shutter artefacts are rare.

Both these problems can be overcome with the use of hardware triggering of light sources and other hardware, putting the camera in 'Pseudo-global' operation, described in Figure 4. Due to the higher speed operation of rolling shutter sensors, these sensors will typically outperform 'true' global shutter sensors even when operating in a 'Pseudo-global' mode. Additionally rolling shutter operation is inherently lower noise than true global shutter operation, improving low-light sensitivity.

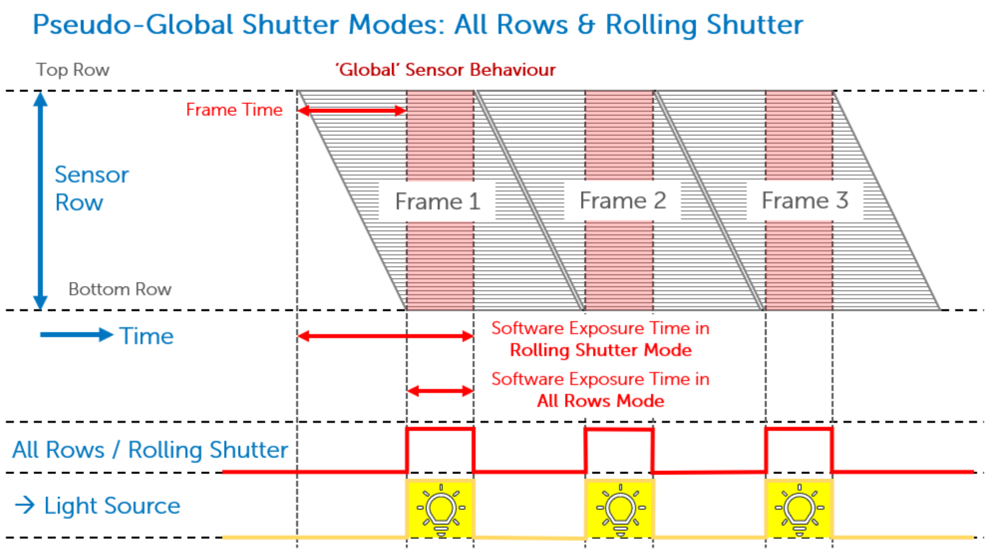


Figure 4: Pseudo-global shutter modes. In these modes, the camera begins acquiring a frame at the top of the sensor and the acquisition rolls down with the trigger to the light source deactivated, and no photons collected. Only when all of the rows of the camera are acquiring does the light source activate, acquiring global information, before then deactivating for the rolling readout process and the start of the next frame. Both 'All Rows' and 'Rolling Shutter' provide a pseudo-global behavior, the only difference is how the requested software exposure time is interpreted. See explanation in text.

The following two modes are not fundamentally different in the way they behave, as shown in Figure 4. However, they do change how the exposure time requested in software is interpreted, and should be chosen based on your imaging priorities.

'Rolling Shutter' Mode: Pseudo-global with defined framerate

In 'Rolling Shutter', software exposure time determines the **length of the total frame,** i.e. the inverse of the frame rate, to accurately set the frame rate of the camera for capturing dynamic events. The length of the trigger high signal is allowed to vary according to the number of lines in your region of interest, and is given by:

$$Trigger\ High\ Time = Software\ Exposure\ Time - Frame\ Time$$

Where once again the frame time is $Number\ of\ lines\ \times Line\ Time$ for the given camera setting. Example line times for different cameras are given in a table below.

Why use 'Rolling Shutter' mode? When you want to set the frame rate to capture dynamics of interest, but don't need an exact trigger high time.

'All Rows' Mode: Pseudo-global with defined trigger high time

In 'All Rows', software exposure time determines the **length of the trigger high time**, and the frame rate of the camera will be determined by this 'exposure time' plus the frame time. In this way, the camera frame rate will vary according to the number of rows in your region of interest.

Why use 'All Rows' mode? When you require a certain trigger high time for your light source to achieve enough light or to maintain constant imaging conditions, with framerate as a secondary concern.

Comparison to 'Global Reset' CMOS Cameras

Some CMOS cameras have an additional sensor mode that allows all rows to be reset simultaneously, beginning a global acquisition. However, aside from avoiding a small delay in the acquisition of the first frame of a sequence this leads to little or no practical advantage for streaming acquisition, as the delay between frames is the same. This is explored in Figure 5.

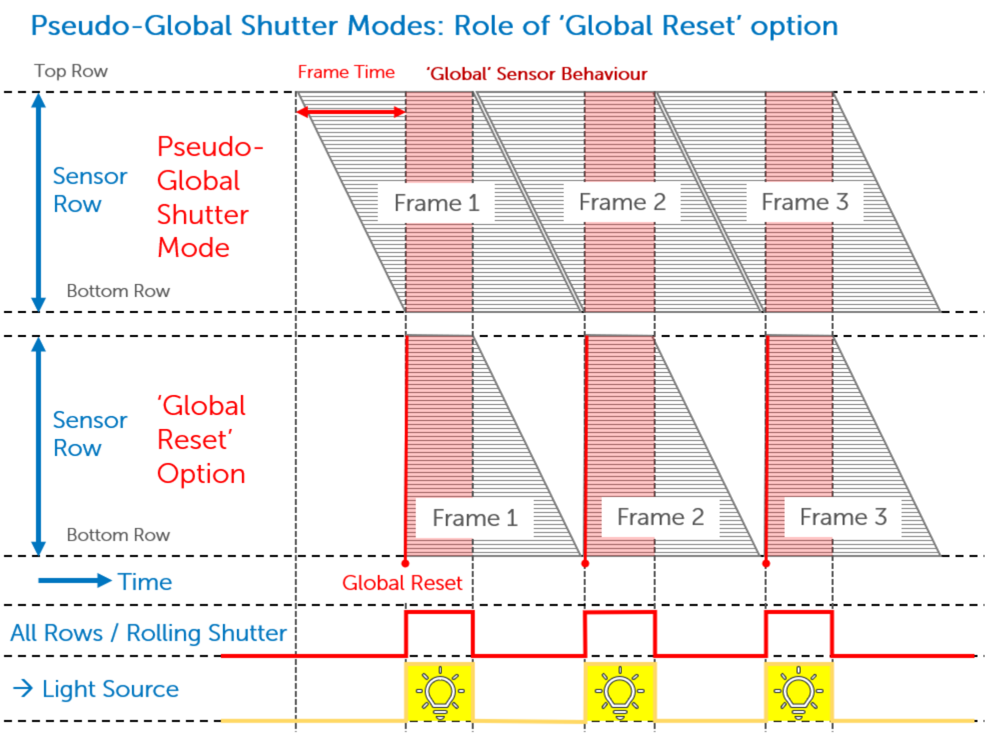


Figure 5: Role of the 'Global Reset' trigger option present on some CMOS sensors. For Pseudo-global acquisition, the only difference between the timing of operation for a camera with Global Reset versus without is the delay on the first frame of a stream acquisition. Otherwise, the readout time (given by the Frame Time) determines the delay between frames in both cases.

Additional Triggers

There are two additional triggers provided with many Teledyne Photometrics cameras. Their behavior is shown visually and described below.

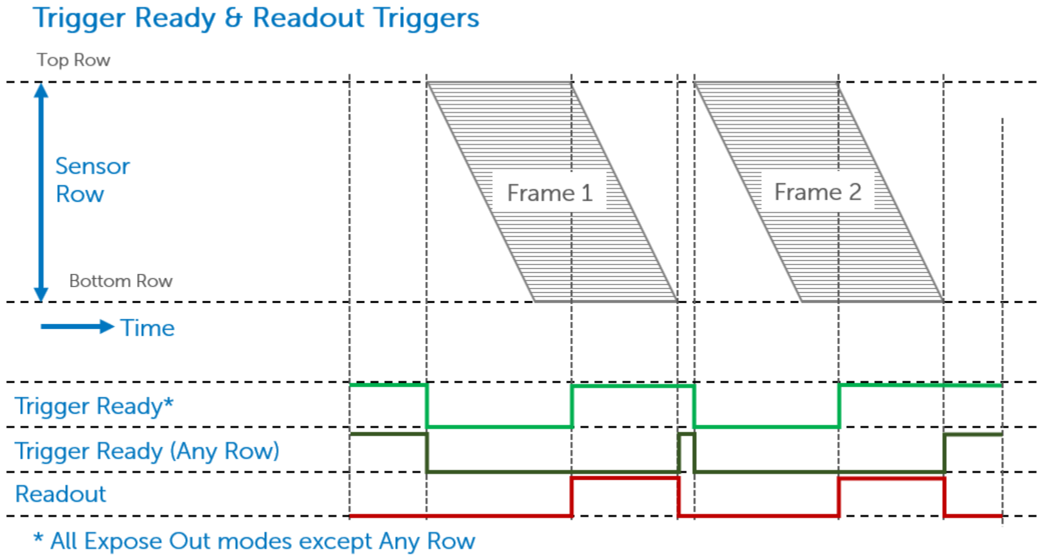


Figure 6: Additional output triggers

Trigger Ready

This additional output on the trigger cable provides a 'high' signal when the camera is ready to acquire an image. During acquisition or readout, if an instruction to the camera to acquire would be ignored, this trigger is set to 'low', or 0V.

For high speed acquisitions controlled by an external triggering controller, Trigger Ready is commonly used as an input signal to the controller to indicate when the next frame is ready to acquire. Due to the high speed of operation of hardware triggering, this approach allows the maximum speed of camera acquisition while allowing precise control over system hardware.

Note that as shown in Figure 6 above, the sensor and hence the 'Trigger Ready' signal have different behavior in 'Any Row' Expose Out mode, as in 'Any Row', the camera is not in overlap mode, so the acquisition of the following frame can only begin once the previous frame has entirely read out.

Read Out

This trigger is 'high' during the digitization of data from the camera.

Pseudo-Global Shutter Modes: Speed of Acquisition Tables

In this section, it is shown how to calculate frame rates and trigger-high times in Pseudo Global Shutter mode for CMOS cameras. Additionally, frame rates for specific example regions of interest and trigger high times are given for example cameras.

How to calculate framerate & trigger high time in pseudo-global shutter

In **'All Rows' mode**, the software exposure time determines the trigger high time of the camera, as shown in Figure 4. The equation for the camera frame rate is the following:

$$Pseudo\text{-}Global\ Frame\ Rate\ (All\ Rows) = \frac{1}{(Number\ of\ Lines\ \times Line\ Time + Software\ Exposure\ Time)}$$

In '**Rolling Shutter' mode**, the software exposure time determines the total length of a frame acquisition, and hence the frame rate. The trigger high time is then determined by:

$$Trigger\ High\ Time\ (Rolling\ Shutter) = Software\ Exposure\ Time - (Number\ of\ Lines\ \times Line\ Time)$$

Note that it is entirely possible for the frame acquisition time (given by $(Number\ of\ Lines\ \times Line\ Time)$) to be greater than the Software Exposure time! In this case, the trigger will never send a high signal and the light source will not be activated.

Kinetix Pseudo-Global Speed Table

Camera Line Times

Below are line times and maximum framerates for the Kinetix camera for the 3 imaging modes.

Mode	Framerate (fps)	Line Time (us)
Speed (8 bit)	500	0.625
Sensitivity (12 bit)	88.5	3.53
Dynamic Range (16 bit)	83.4	3.75

Speed (8-bit) Mode

Theoretical Pseudo-global shutter mode speeds for a Kinetix camera in Speed (8-bit) mode in 'All Rows' trigger mode, for 6 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.1 ms	0.2 ms	0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms
3200	2.00	476.2	454.5	400.0	333.3	250.0	142.9	83.3	45.5
2048	1.28	724.6	675.7	561.8	438.6	304.9	159.2	88.7	47.0
1024	0.64	1351.4	1190.5	877.2	609.8	378.8	177.3	94.0	48.4
512	0.32	2381.0	1923.1	1219.5	757.6	431.0	188.0	96.9	49.2
256	0.16	3846.2	2777.8	1515.2	862.1	463.0	193.8	98.4	49.6
128	0.08	5555.6	3571.4	1724.1	925.9	480.8	196.9	99.2	49.8

Sensitivity (12-bit) Mode

Theoretical Pseudo-global shutter mode speeds for a Kinetix camera in Sensitivity (12-bit) mode in 'All Rows' trigger mode, for 6 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms
3200	11.30	87.7	87.0	84.7	81.3	75.2	61.3	46.9	31.9
2048	7.23	136.4	134.6	129.3	121.5	108.3	81.8	58.0	36.7
1024	3.62	269.1	262.1	243.0	216.6	178.1	116.1	73.4	42.3
512	1.81	524.1	498.0	433.3	356.1	262.6	146.9	84.7	45.9
256	0.90	996.0	905.8	712.3	525.2	344.4	169.4	91.7	47.8
128	0.45	1811.6	1533.7	1050.4	688.7	407.8	183.4	95.7	48.9

High Dynamic Range (16-bit) Mode

Theoretical Pseudo-global shutter mode speeds for a Kinetix camera in HDY (16-bit) mode in 'All Rows' trigger mode, for 6 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms	0.1 ms
3200	12.05	82.3	81.6	79.7	76.6	71.2	58.7	45.4	31.2
2048	7.71	128.0	126.4	121.8	114.8	103.0	78.7	56.5	36.1
1024	3.86	252.8	246.6	229.6	206.0	170.8	112.9	72.2	41.9
512	1.93	493.2	470.0	411.9	341.6	254.6	144.3	83.8	45.6
256	0.96	940.0	859.2	683.1	509.2	337.4	167.7	91.2	47.7
128	0.48	1724.5	1470.9	1020.5	675.7	403.2	182.5	95.4	48.8

Prime 95B Pseudo-Global Speed Table

Camera Line Times

Below are line times and maximum framerates for the Prime 95B camera for the 2 imaging modes, shown for the 3 sensor size variants. Line times are identical for the 3 sensor sizes.

Sensor Size:	Prime 95B (1200x1200)	95B 22mm (1410x1410)	95B 25mm (1608x1608)	
Mode		Framerate (fps)		Line Time (us)
High Speed (12 bit)	80.1	68.2	60	10.4
High Dynamic Range (16 bit)	40.1	34.1	30	20.8

High Speed (12-bit) Mode

Theoretical Pseudo-global shutter mode speeds for the Prime 95B camera range in the high speed 12-bit mode in 'All Rows' trigger mode, for 6 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms
1608*	16.72	58.1	56.4	53.4	46.0	37.4	27.2	15.0	8.6
1410**	14.66	65.9	63.8	60.0	50.9	40.5	28.8	15.5	8.7
1200	12.48	77.0	74.2	69.1	57.2	44.5	30.8	16.0	8.9
512	5.32	171.7	158.1	136.5	96.9	65.3	39.5	18.1	9.5
256	2.66	316.2	273.0	214.5	130.5	79.0	44.1	19.0	9.7
128	1.33	546.1	429.0	300.2	157.9	88.3	46.9	19.5	9.9

* Region size provided by Prime 95B 25mm. ** Region size provided by Prime 95B 22mm and 25mm.

High Dynamic Range (16-bit) Mode

Theoretical Pseudo-global shutter mode speeds for the Prime 95B camera range in the high dynamic range 16-bit mode in 'All Rows' trigger mode, for 6 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms
1608*	33.45	29.5	29.0	28.2	26.0	23.0	18.7	12.0	7.5
1410**	29.33	33.5	33.0	31.9	29.1	25.4	20.3	12.6	7.7
1200	24.96	39.3	38.5	37.1	33.4	28.6	22.2	13.3	8.0
512	10.65	89.7	85.8	79.1	63.9	48.4	32.6	16.5	9.0
256	5.32	171.7	158.1	136.5	96.9	65.3	39.5	18.1	9.5
128	2.66	316.2	273.0	214.5	130.5	79.0	44.1	19.0	9.7

* Region size provided by Prime 95B 25mm. ** Region size provided by Prime 95B 22mm and 25mm.

Prime BSI & Prime BSI Express Pseudo-Global Speed Table

Camera Line Times

Below are line times and maximum framerates for the Prime BSI and Prime BSI Express cameras. These two cameras have identical line times in the High Dynamic Range (HDR, 16 bit) modes and the low-noise CMS mode (12 bit), but have different line times in the High Speed (11 bit) mode.

Camera & Mode	Framerate (fps)	Line Time (us)
Prime BSI - High Speed (11 bit)	63.1	7.74
Prime BSI Express – High Speed (11 bit)	94.6	5.16
CMS (12 bit) & Dynamic Range (16 bit)	43.6	11.20

Converting to Frame Times for 'Rolling Shutter' Triggering Mode

The Prime BSI and Prime BSI Express do not support 'All Rows' mode, instead 'Rolling Shutter' mode must be used for Pseudo-Global shuttering, meaning that the software exposure time is specified not by the 'High Trigger Time' in the table but according the frame rate. The exposure times that must be specified in software to achieve these frame rates are given by:

$$Software\ Exposure\ time = 1\ /\ Pseudo - Global\ Frame\ Rate$$

Prime BSI - High Speed (11bit) Mode

Theoretical Pseudo-global shutter mode speeds for the Prime BSI camera in the high speed 11-bit mode, for 4 example ROIs, based on line time and ROI size.

ROI	Frame	Pseudo-Global Frame Rate (fps): High Trigger Time (ms)							
(y height)	Time (ms)	0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms
2048	15.85	61.2	59.3	56.0	48.0	38.7	27.9	15.2	8.6
1024	7.93	118.7	112.0	100.7	77.4	55.8	35.8	17.3	9.3
512	3.96	224.1	201.5	167.7	111.6	71.6	41.7	18.5	9.6
128	0.99	670.8	502.3	334.4	166.9	91.0	47.6	19.6	9.9

Prime BSI Express - High Speed (11bit Mode)

Theoretical Pseudo-global shutter mode speeds for the Prime BSI Express camera in the high speed 11-bit mode, for 4 example ROIs, based on line time and ROI size. Note that this camera does not support 'All Rows' trigger mode, 'Rolling Shutter' mode must be used to achieve pseudo-global behavior.

ROI	Frame	Pseudo-Global Frame Rate (fps): High Trigger Time (ms)							
(y height)	Time (ms)	0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms
2048	10.57	90.4	86.4	79.6	64.2	48.6	32.7	16.5	9.0
1024	5.28	172.9	159.1	137.3	97.2	65.4	39.6	18.1	9.5
512	2.64	318.3	274.6	215.4	130.9	79.1	44.2	19.0	9.7
128	0.66	861.7	602.2	375.9	176.7	93.8	48.4	19.7	9.9

CMS (12 bit) & High Dynamic Range (16 bit)

Theoretical Pseudo-global shutter mode speeds for the Prime BSI and Prime BSI Express cameras in both the low-noise CMS (12-bit) mode and the high dynamic range (16-bit) mode, for 4 example ROIs, based on line time and ROI size.

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): High Trigger Time (ms)							
		0.5 ms	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms
2048	22.94	42.7	41.8	40.1	35.8	30.4	23.3	13.7	8.1
1024	11.47	83.6	80.2	74.2	60.7	46.6	31.8	16.3	9.0
512	5.73	160.4	148.5	129.3	93.2	63.6	38.9	17.9	9.5
128	1.43	517.2	410.9	291.2	155.4	87.5	46.7	19.4	9.9

Iris Pseudo-Global Speed Table

Camera Line Time (PCI-E)

For the Iris 15 and Iris 9, the line time and frames per second is provided below, which is equal for both cameras. This speed is achievable via the PCI-E interface only.

Mode	Framerate (fps)	Line Time (us)
Dynamic Range (16 bit)	30	11.25

Dynamic Range (16 bit)

ROI (y height)	Frame Time (ms)	Pseudo-Global Frame Rate (fps): Exposure Time (ms) (High Trigger Time)							
		0.5	1	2	5	10	20	50	100
2048	23.04	42.5	41.6	39.9	35.7	30.3	23.2	13.7	8.1
1024	11.52	83.2	79.9	74.0	60.5	46.5	31.7	16.3	9.0
512	5.76	159.7	147.9	128.9	92.9	63.5	38.8	17.9	9.5
128	1.44	515.5	409.8	290.7	155.3	87.4	46.6	19.4	9.9

Controlling Cameras from External Hardware

The camera can also be controlled by external hardware, independently from the trigger signals coming from the camera. The start of the acquisition of individual frames or of entire sequence acquisitions can be triggered to begin with the rising edge of a 0V to 5V TTL pulse.

Software & Triggering
To use these modes, an acquisition will still need to be started in control software – the camera will not acquire frames that the software has not requested.

Ensuring the camera is ready for triggers
If the rising edge of a trigger pulse occurs when the camera is not yet ready to acquire (i.e. the Trigger Ready signal is at 0V, as discussed above), it will be ignored. To avoid missing trigger signals, there are a number of options that still allow operation of the camera at high speeds:

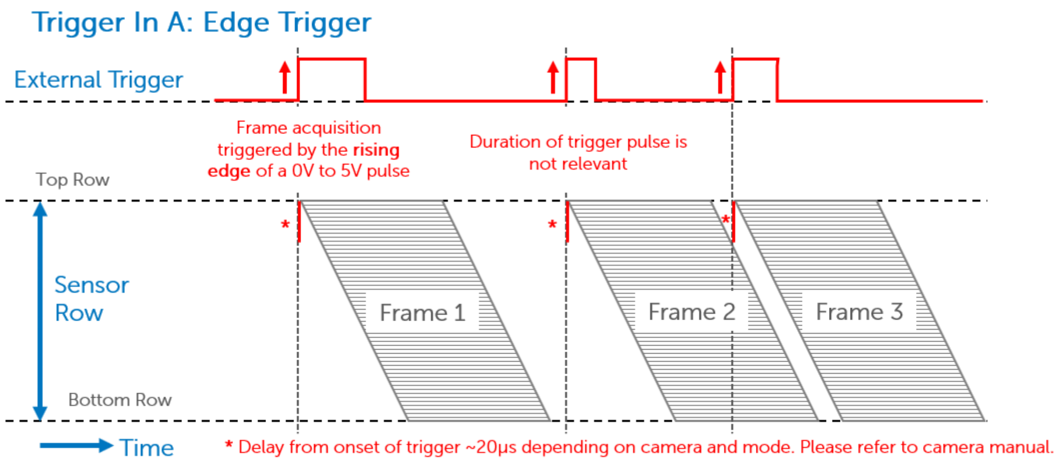
1. Monitor the 'Trigger Ready' output using an external triggering controller or real-time controller (RTC), and send the next frame trigger only once the 'Trigger Ready' signal goes to 5V. This method is well suited to high-speed imaging.

2. Use a pulse generator to send multiple short pulses instead of one pulse to begin frames. This allows high speed acquisition but less selectivity about timing.

3. Set the time between triggers to ~0.1ms longer than the total frame time to ensure adequate readout time, which is given by:
   First Row and Rolling Shutter Trigger Out mode: the software exposure time
   All Rows and Any Row Trigger Out mode: the software exposure time plus the frame time (given by Line Time x Number of Lines, with line times given in tables above)

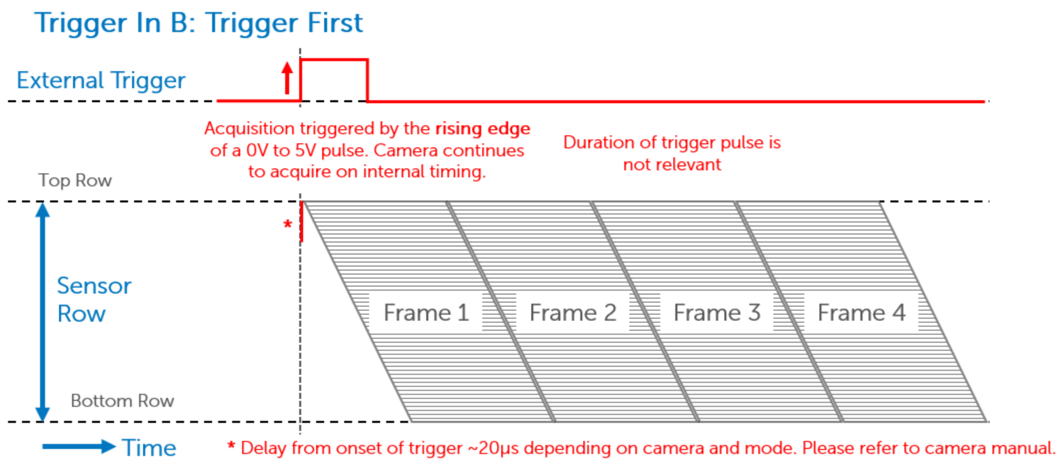
Below are shown the three options for controlling the camera from external hardware with trigger signals. Available options may vary between camera models.

Edge Trigger Mode



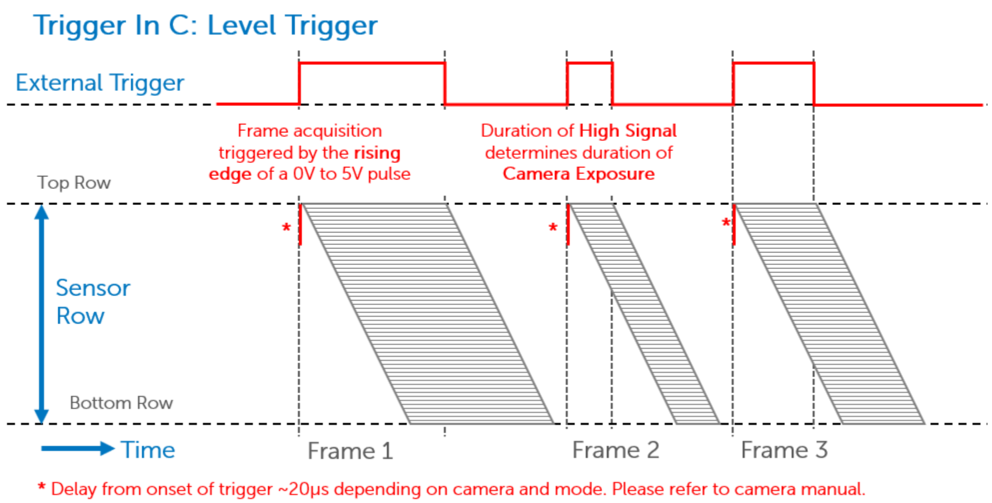
In Edge Trigger Mode, each frame of an acquisition is triggered by the rising edge of a 0V to 5V pulse.

Trigger First mode



In Trigger First mode, the camera will run on internal timing for an acquisition or sequence defined by software, but the start of that sequence will wait for the rising edge of a 0V to 5V pulse.

Level Trigger Mode



In Level Trigger mode, each frame is triggered independently as in Edge Trigger Mode, but the duration of the exposure time of the camera is determined by the length of the 0V to 5V pulse.

Simultaneous Acquisition with Multiple Cameras

When using multiple cameras for example for simultaneous multi-channel fluorescence acquisition, hardware triggering allows the best synchronization between the acquisition times for the cameras.

There are two common methods to manage multi-camera setups. Master-Slave configurations, where one 'Master' camera triggers the acquisition of other cameras, and controlling each camera via an external triggering controller or real-time controller (RTC).

Master-Slave Configurations

In Master-Slave operation, one camera is configured to be the Master, with other cameras' timing determined by this camera. The delay between the Master and Slave cameras should be negligible (~20 µs or less depending on camera and mode), yet the setup is considerably more simple than the use of an external triggering controller.

Configuration for the Master Camera

The following set-up should be used for the Master camera. It does not matter from a hardware perspective which camera you choose to be the Master camera, however if there is one camera that is used more frequently or primarily if multiple cameras are not always used, you should choose this camera for your master camera. However, even this is not strictly necessary as all cameras can run independently of each other when needed, according to software settings.

Exposure Times

Note: To ensure robustness of the setup, it is recommended that the **Master camera be given an exposure time ~50 µs longer (0.05ms) than the Slave cameras**, with the minimum recommended additional time being $2 \times Camera\ Line\ Time$. For the camera line times please see the tables above.

There is no requirement that the multiple cameras are given the same exposure time, though differences in exposure time should be kept in mind if analyzing high-speed dynamics. You also must then ensure that the following frame's trigger is only sent once the camera with the longest exposure time is ready to image. For this reason it can be advisable either to make the Master camera the camera with the longest exposure time typically required, or monitor the 'Trigger Ready' signal of the longest exposure time camera.

Setting up the Master Camera

1. Select 'Expose Out Mode' to be 'First Row'. Other triggering modes will change camera behavior or introduce delays between cameras. Note that in some software, a check box may be provided that explicitly marks one camera as 'Master Camera'. Check this if so.
2. For cameras with multiple 'Expose Out' cables, the green 'Expose Out 1' cable is your master trigger out. For cameras with only one 'Expose Out' cable, this is your master trigger out.
3. If using more than one Slave camera, using a splitter, separate the Master Trigger Out cable to the number required for the other cameras.
4. Connect the Master Trigger Out cable(s) to the 'Trigger In' cable of the slave camera(s). For cameras with a 'breakout' style triggering cable, the 'Trigger In' cable is red.
5. The Master camera can also be externally triggered by other hardware as discussed above.
6. When using the same exposure times for each camera, the Master camera should be given a slightly longer exposure time as discussed above. In software with a 'Master Camera' option, this is handled automatically.

Configuration for the Slave Camera(s) and Controlling Other Hardware

The Slave camera(s) will acquire frames when directed by the Master camera. They in turn can be used to control light sources and other hardware, including in Pseudo-Global operation as discussed above.

Setting up the Slave Camera(s)

1. Once physically connected as directed above, the 'Trigger In' setting of Slave camera(s) should be set to 'Edge Trigger' mode.
2. The 'Expose Out Mode' of the cameras can then be set according to your need for triggering from the camera. Note that this should not be set to 'Any Row' mode unless all cameras are set to this mode, as this affects camera timing.

Controlling Multiple Cameras via External Triggering (Real-Time Controllers)

When using real-time controllers, all cameras are 'Slaves', with the Real-Time Controller (RTC) managing the timing of the experiment. This has the advantage of flexibility in that for RTCs with multiple digital outputs, each camera can be individually triggered at certain times or at the same time. Or alternatively, one digital output can be split and sent to each camera for simultaneous acquisition.

The RTC can be used to control light sources and other hardware, or the cameras can be used to control other hardware as discussed above.

For RTCs with digital inputs and software that can manage them, connecting the 'Trigger Ready' output of the master camera or of all cameras to these digital inputs can provide an opportunity for full-speed triggered acquisition if the next 'Acquire' trigger is sent immediately after the 'Trigger Ready' signal goes to 5V. However, note that if cameras are using different exposure times, the 'Trigger Ready' of the longest exposure time camera will need to be monitored.

