

APPLICATION NOTE

Using ITR and IWR mode to maximize the framerate of Goldeye Cameras

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Introduction

This application note provides an in-depth explanation of the triggering implementation of Goldeye cameras, and explains how the camera reacts when overtriggering occurs. This behavior depends on the mode the camera is working in:

- ITR mode (Integrate Then Read), also called “triggering during the idle state”
- IWR mode (Integrate While Read), also called “triggering during the readout state”

The Goldeye’s firmware prevents that any ongoing exposure or readout is aborted by a new trigger event. For that reason, this application note is applicable only if firmware version 02.14.19002 or higher is installed.

Complete overview of the triggering concept

Figure 1 and Table 1 below provide a complete overview of the triggering concept as shown in the Goldeye technical manual.

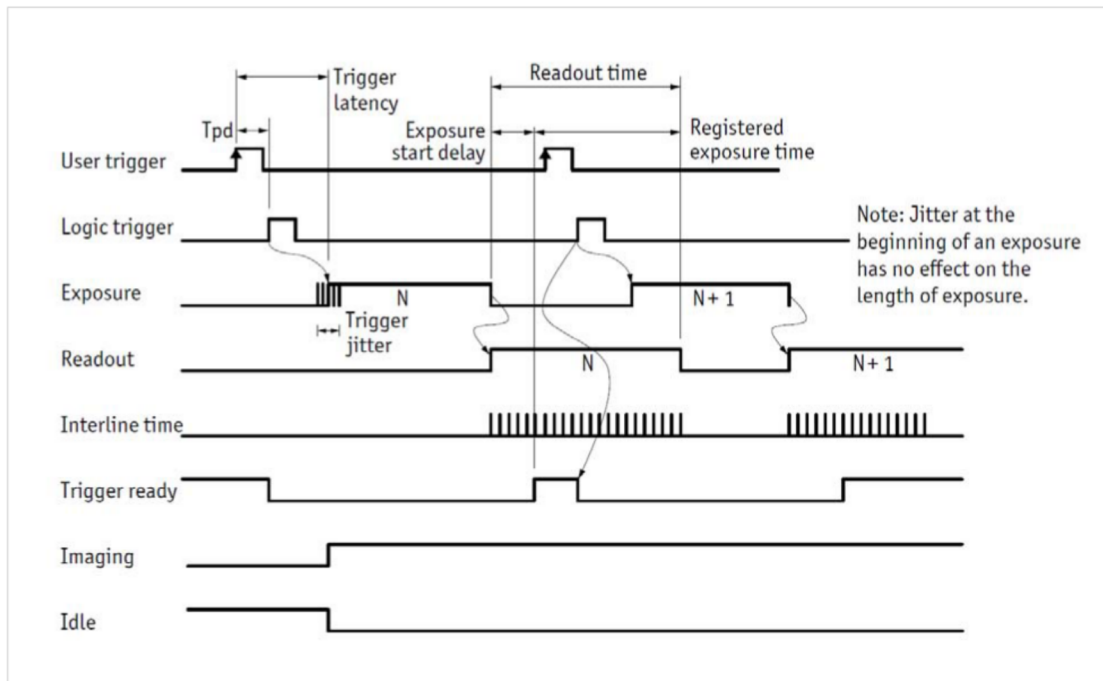


Figure 1: Trigger timing diagram

Term	Definition
User trigger	Trigger signal applied by the user (hardware trigger, software trigger).
Logic trigger	Trigger signal seen by the camera internal logic (not visible to the user).
T_{pd}	Propagation delay between the user trigger and the logic trigger.
Exposure	High when the camera image sensor is integrating light.
Readout	High when the camera image sensor is reading out data.
Trigger latency	Time delay between the user trigger and the start of exposure.
Trigger jitter	Error in the trigger latency time.
Trigger ready	Indicates to the user that the camera is ready to accept the next trigger.
Registered exposure time	Exposure time value currently stored in the camera memory.
Exposure start delay	Registered exposure time subtracted from the readout time. Exposure start delay indicates when the next exposure cycle can begin such that the exposure ends after the current readout.
Interline time	Time between sensor row readout cycles.
Imaging	High when the camera image sensor is either exposing and/or reading out data.
Idle	High if the camera image sensor is not exposing and/or reading out data.

Table 1: Trigger definitions

Trigger rules

- The exposure start must always correspond with the interline time if readout is true.
- Exposure start delay equals the readout time minus the registered exposure time.
- The exposure start depends on the trigger only, it is not based on requirements about exposure end. If the exposure of one frame ends before the readout of the previous frame ends, the exposure will be extended.
- The end of exposure will always trigger the next readout. This means that the readout follows directly upon the exposure.

Preconditions for this document

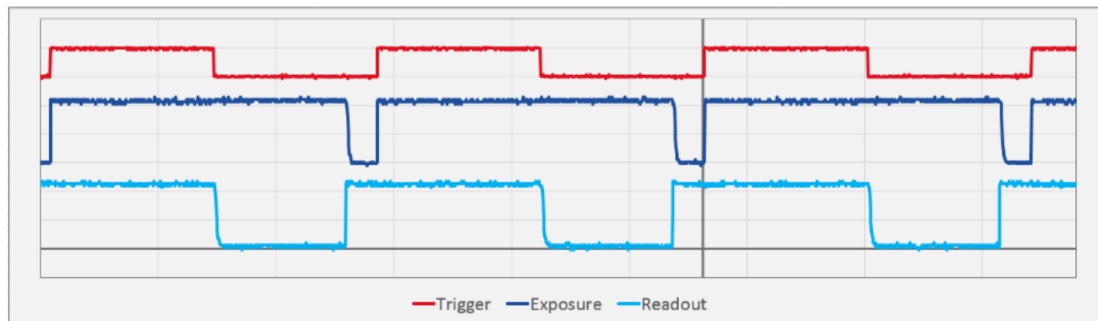


Figure 2: Trigger, exposure and readout timing taken from an oscilloscope - IWR mode

Table 1 displays a number of details on triggering. However, for reasons of simplification, some restrictions have been applied:

- The explanations concentrate on trigger, exposure time and readout time. The exposure time is influenced mainly by pixel mode and ROI, readout time is influenced mainly by the sensor's architecture.
- Considering the topic of this application note, the oscilloscope readout in Figure 2 shows that items like trigger jitter, trigger latency, exposure start delay, etc. are negligible and can be disregarded.
- This application note considers only the course of events running within the camera, data transfer between PC and camera is disregarded.

Details on triggering

If the trigger event occurs too early for the camera to properly react to the event, overtriggering occurs.

- In ITR mode, overtriggering occurs if the trigger event occurs before the readout is completed.
- In IWR mode, overtriggering occurs if the trigger event occurs before the exposure is completed.

This is explained in more detail below.

ITR mode: triggering during the idle state

ITR mode (Integrate Then Read) is used when the camera is triggered during the idle state.

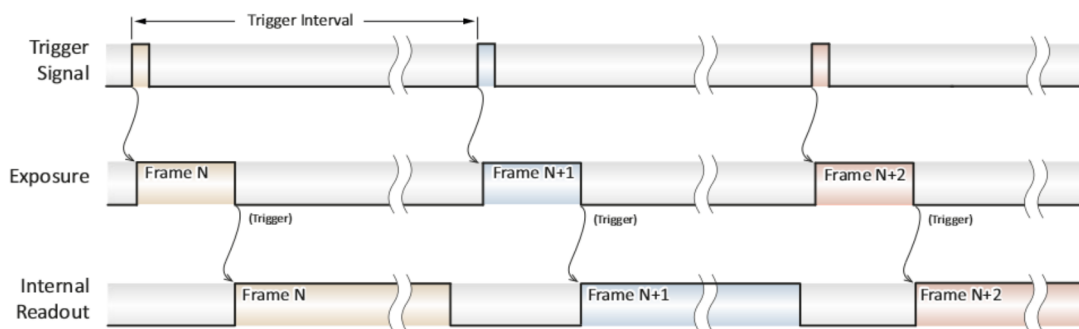


Figure 3: Trigger timing in ITR mode (rising edge trigger displayed)

ITR mode is selectable in Vimba Viewer under **AcquisitionControl > IntegrationMode**. If **IntegrationMode** is set to **IntegrateThenRead**, this forces the camera into ITR mode. In ITR mode, the start of a new exposure is triggered only after completion of readout. Readout is triggered by the completion of exposure. This means also that the trigger interval must be longer than the sum of exposure time and readout time.

IWR mode: triggering during the readout state

IWR mode (Integrate While Read) is used when triggering the camera during the readout state. In the Vimba Viewer under **AcquisitionControl > IntegrationMode**, different from ITR mode, IWR mode is not directly selectable.

If **IntegrationMode** is set to *IntegrateWhileRead*, the camera switches between ITR mode and IWR mode. This depends on various circumstances, as described further below.

In IWR mode, the start of a new exposure is triggered before the readout from the previous exposure is completed. This means the trigger interval is shorter than the sum of exposure time and readout time.

The readout is still ongoing while the new exposure already runs. However, the end of the exposure always triggers the next readout.

Therefore, it makes a difference whether the exposure time is longer or shorter than the readout time.

Exposure time shorter than readout time

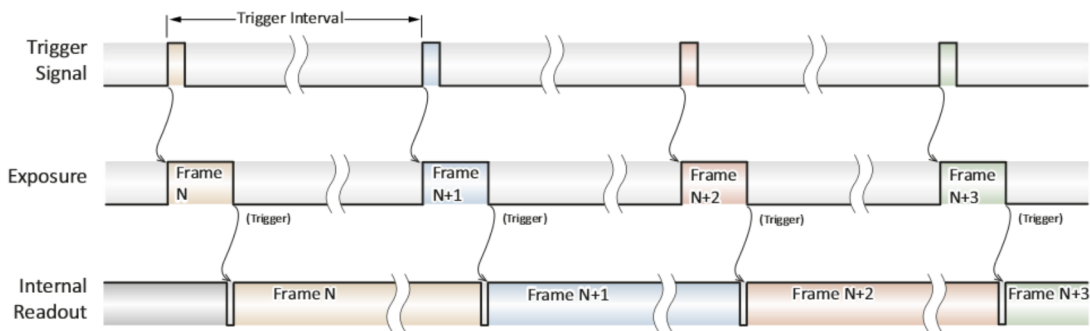


Figure 4: Trigger timing in IWR mode if exposure time is shorter than readout time (rising edge trigger)

When the exposure time is shorter than the readout time, the maximum possible framerate is determined almost entirely by the readout time. The example in Figure 4 shows shortened trigger intervals, that cause the exposure of any frame (for example, Frame N+1) to start while the readout for the previous frame (Frame N) is still ongoing. The interval between consecutive readouts is almost minimized. Shortening the readout time, for instance by reducing the ROI size, increases the possible framerate.

Exposure time longer than readout time

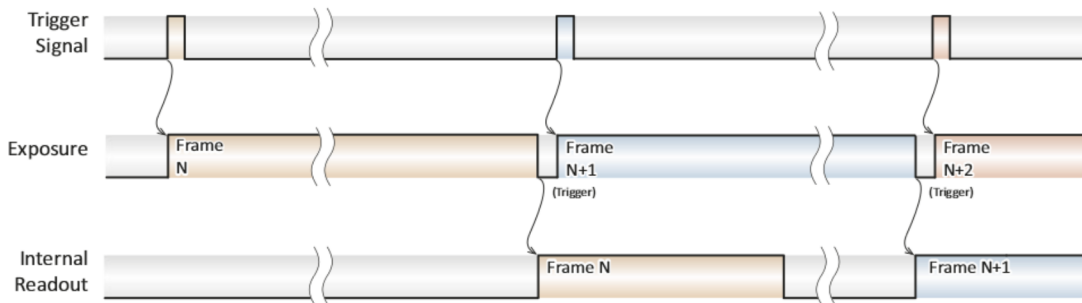


Figure 5: Trigger timing in IWR mode - exposure time is longer than readout time (rising edge trigger)

When the exposure time is longer than the readout time, the maximum framerate is determined almost entirely by the exposure time. As Figure 5 shows, since the exposure is longer than the readout, any

exposure will end only after the readout of the previous frame is completed. Shortening the exposure time increases the framerate.

Varying trigger intervals

If the camera is triggered by an external trigger, the trigger intervals may vary in length. Thus, the exposure of any frame may or may not start while the readout of the previous frame is still ongoing. The camera reacts to varying trigger intervals depending on the value that the **IntegrationMode** feature is set to.

Integrate While Read

When **IntegrationMode** is set to *IntegrateWhileRead*, the camera switches automatically between ITR mode and IWR mode.

If the trigger interval is longer than the sum of exposure time and readout time, the exposure of the next frame starts only if readout of the current frame is completed already. Thus the respective frame is acquired in ITR mode.

If the trigger interval is shorter than the sum of exposure time and readout time, the exposure of the next frame starts before readout of the current frame is completed. Thus the respective frame is acquired in IWR mode.

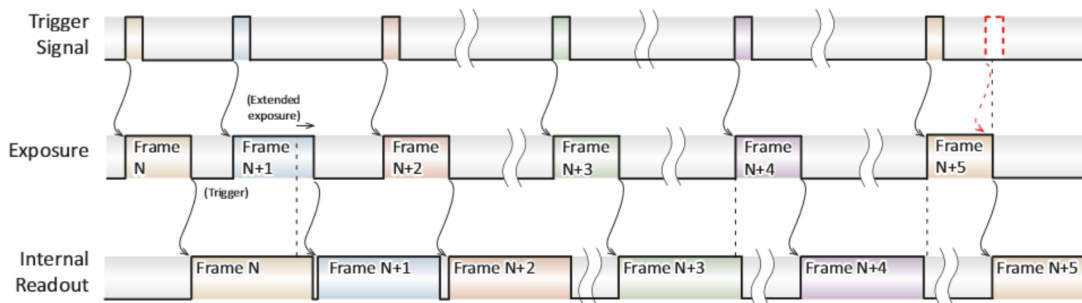


Figure 6: Trigger timing when *IntegrationMode* is set to *IntegrateWhileRead* - varying trigger intervals, the red dashed lines mark the overtriggering event

The scenarios described below are possible, as displayed in Figure 6.

- The exposure of a frame starts after the readout of the previous frame is completed. The frame is then acquired in ITR mode, since there is no ongoing readout during the exposure. See Frames N and N+5 as examples.
- If the exposure of a frame starts while the readout of the previous frame is still ongoing, the camera switches to IWR mode. Examples for this behaviour in Figure 6 are Frames N+2, N+3, and N+4.
- It is possible to further shorten the trigger interval, so that the exposure end of the current frame would occur before the readout of the previous frame ends. If that is the case, the exposure will be extended automatically to end only after the ongoing readout ends. Frame N+1 in Figure 5 displays this scenario, the dashed line marks the regular exposure end.

Exposures of different lengths will cause flicker since the longer exposed frames are brighter.

- If the trigger interval is even shorter, so that a trigger event occurs while an exposure is still ongoing, this means overtriggering the camera: the trigger event is ignored. This situation is shown in Figure 6,

after the trigger of frame N+5, in red. Only the first trigger event after exposure end starts the next exposure.

Integrate Then Read

When **IntegrationMode** is set to **IntegrateThenRead**, the camera is forced to stay in ITR mode. Every trigger event that occurs before the end of a readout is ignored. This is called overtriggering.

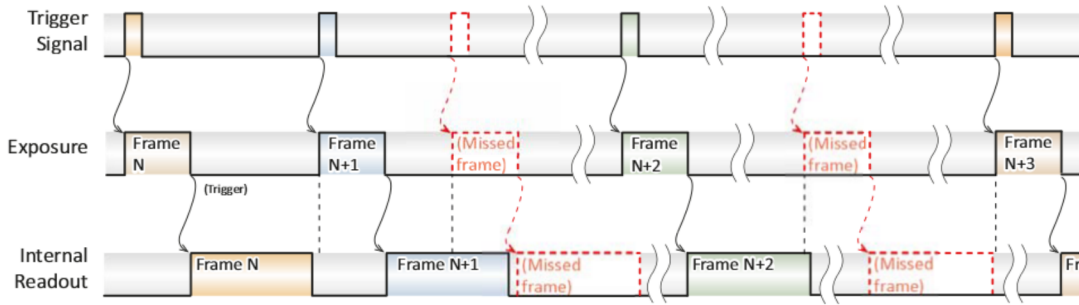


Figure 7: Trigger timing when *IntegrationMode* is set to *IntegrateThenRead* - the overtriggering events are marked in red

Figure 7 shows an example for overtriggering in ITR mode. The vertical dashed lines indicate the start of exposure.

- The trigger for the frame after N+1 is ignored, since the readout of Frame N+1 is still ongoing.
- The next frame thereafter is acquired, since the trigger event takes place after the readout of Frame N+1 is completed. Frame N+1 is the last frame that has been acquired before.
- The trigger event for the next frame is ignored again, because the readout of Frame N+2 is still ongoing.
- Exposure for Frame N+3 starts after completion of the previous readout, thus Frame N+3 is acquired.

The above examples show that even if the trigger interval is approximately equal, overtriggering may or may not occur. However, if overtriggering occurs, it cuts down the framerate up to almost 50%.

The examples also point to measures that help keeping the framerate as close as possible to the maximum.

Conclusion

Summary of conditions for using IWR mode or ITR mode

Conditions	IntegrationMode	
	= <i>IntegrateThenRead</i>	= <i>IntegrateWhileRead</i>
Trigger (N+1) occurs after readout of Frame (N)	ITR	ITR
Trigger (N+1) occurs before end of readout of Frame (N)	ITR	IWR

Table 2: Overview of usage of IWR mode and/or ITR mode

Table 2 summarizes when the camera uses ITR mode or IWR mode. Refer also to Figures 3 to 7.

Summary of overtriggering conditions

The table below summarizes the conditions when overtriggering occurs, or does not occur.

Conditions	IWR mode	ITR mode
Trigger (N+1) occurs after readout (N)	No	No
Trigger (N+1) occurs during readout (N)	No	Yes
Trigger (N+1) occurs during exposure (N)	Yes	Yes

Table 3: Overview of overtriggering conditions

Maximum achievable framerate combined

Based on the explanations above, and the formula provided in the technical manual, the maximum possible framerate can be calculated for any combination of readout time (depends on ROI size and pixel mode) and exposure time. The graph displayed in Figure 8 shows one possible result: the maximum framerate with increasing exposure time and a given readout time.

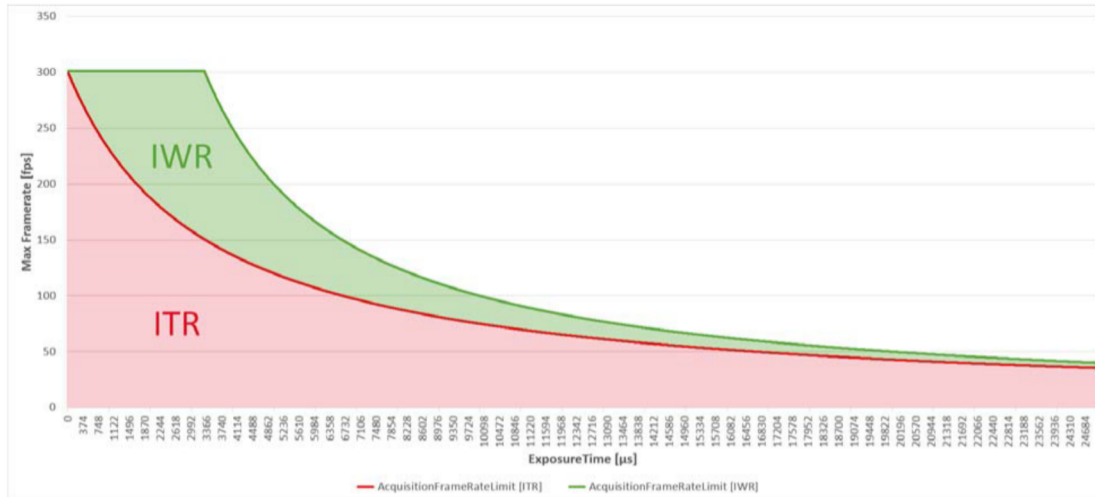


Figure 8: Maximum framerate ITR and IWR (Goldeye G-033, Mono mode: Mono8, ROI: 640x512).

If the framerate stays below the red line, for any given exposure time, then the camera operates in ITR mode. If the framerate stays above the red line, the camera operates in IWR mode.

The camera operates most efficiently in the range of framerate and exposure time that is marked in green. Within that range, close to the highest framerate, it is still possible to operate the camera with a reasonable exposure time. Both curves, are determinable for any resolution or ROI.

Calculating maximum framerate in ITR mode

The maximum possible framerate in ITR mode can be calculated from exposure time and readout time as shown in the formula below. Every shortening of the exposure time, and every decrease in readout time,

causes an increase of the maximum framerate. As Figure 3 shows, this mode creates a lot of idle time and is not the most efficient way to run a camera.

$$\text{FrameRate}_{\text{ITR,max}} = \frac{1}{\text{Exposure time} + \text{Readout time}}$$

The framerate achievable in ITR mode is represented by the red line in Figure 8. Framerate in ITR mode is always based on both the exposure time and readout time. Therefore, with increasing exposure time, the framerate decreases strongly right from the start. See also Figure 3 and Figure 7.

Calculating maximum framerate in IWR mode

For the formula to calculate the maximum frame rate in IWR mode, refer to the Resolution and ROI frame rates chapter in the Goldeye technical manual. Specific formulas are valid for each camera model.

The framerate achievable in IWR mode is represented by the green line in Figure 8. In IWR mode, the exposure is triggered and starts while at the same time a readout is still ongoing. Therefore the increase in exposure time will not cause any decrease in framerate, until the exposure time has reached the length of the readout time. This is indicated by the first horizontal part of the green line. See Figure 4, Figure 5, and Figure 6.

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