Kinetics Readout for Fast Temporal Studies

Introduction

"Kinetics" refers to a special readout mode in which a portion of the CCD is illuminated while rest of the active area is used to store a series of sub-frames. At the end of the exposure-shift sequence, the entire CCD is read-out to give a series of sub-frames (kinetic frames) separated in time. In order to support this special mode of operation, it is essential that camera architecture be made flexible with special access to underlying CCD control functions

Most of the Princeton Instruments/Acton cameras - including the new PIXIS CCD line and the PhotonMAX EMCCD line of cameras - support the kinetics operation. The feature is attractive to Bose-Einstein Condensate (BEC) community as well as researchers interested in capturing transient events at microsecond time scale. Aided by the back illumination technology for high QE and multiplication gain for sub-electron read noise, the kinetics mode in PhotonMAX provides the powerful combination of speed and sensitivity.

The technical note describes the kinetics mode operation in PhotonMAX: 512B EMCCD cameras as implemented in WinView and WinSpec software packages (ver. 2.5.19.4 or later). However, the concept can be applied, albeit as a simpler case, to other PI CCD cameras such as PIXIS.

Frame Transfer Readout

The CCD97 used in the PhotonMAX: 512B is a frame transfer CCD with an active area of 512 x 512 pixels and equivalent area of "frame transfer or masked" pixels.

In standard frame transfer mode, the sensor area is exposed for certain time, typically milliseconds to seconds. It is then transferred to frame transfer area and is read out via extended multiplication gain register or traditional serial register. In this mode of operation, full 512 x 512 sized frames can be captured as close as 33 µsec or at 30Hz as determined by the readout time. Even though, region of interest (ROI) and/or binning can improve the time resolution, it is limited to millisecond regime. For more information the exposure-readout of the CCD, please refer to the PhotonMAX operation manual.

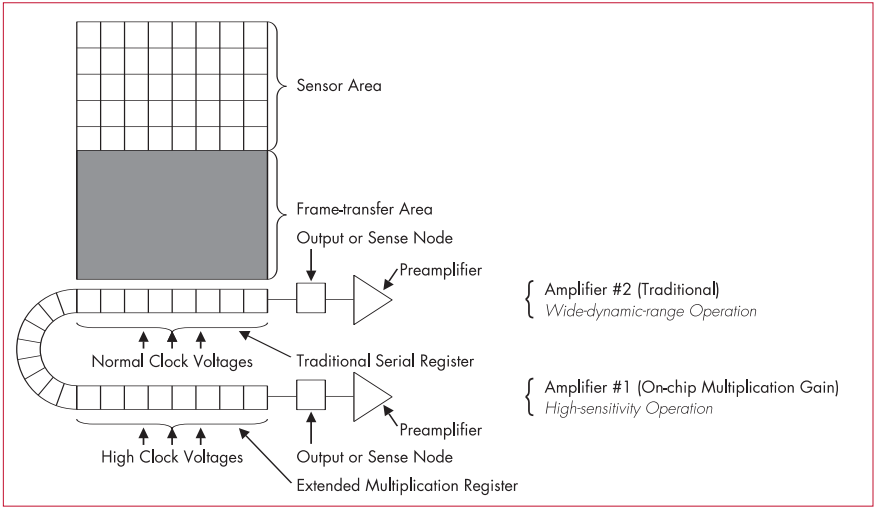


Figure 1. Architecture of the EMCCD used in PhotonMAX.

Kinetics Readout

Kinetics readout allows a burst of sub-frames be captured with µsec resolution. This is accomplished by shifting each sub-frame exposure under the mask before reading it out. Since there is no overhead of readout time between each exposure, faster time resolution is achieved. At the end of "exposure-shift" series, the entire frame can be read out at a slower read-out speed. The use of multiplication gain (EM Gain) in PhotonMAX further improves the SNR when the signal is below the read noise at faster speeds.

In kinetics mode, a portion of the CCD image is optically masked in order to minimize the cross-talk between sub-frames. Typically, in imaging applications, this is accomplished by placing a "knife edge" or optical mask in the collimated beam path. Whereas, in spectroscopy, this is best achieved by limiting the height of the entrance slit of the spectrograph. In most of the applications, ability to mask as few rows as possible sets the ultimate limit on the temporal resolution. The operation is illustrated in Figures 2-5 using an optical test target image.

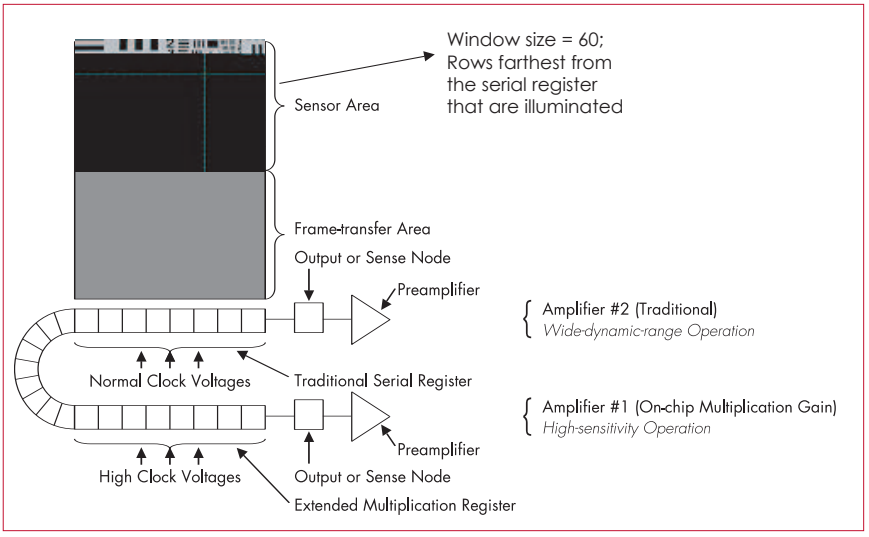


Figure 2. Partially illuminated image of a target is overlaid on the EMCCD diagram for illustration. Note that the illuminated area is the farthest from the serial register. In this experiment, the target is masked using a photographic "black" paper to prevent light from falling on the rest of the sensor area. Image acquired using frame transfer readout mode at 1MHz, Normal port operation. The window size is ~60 rows high.

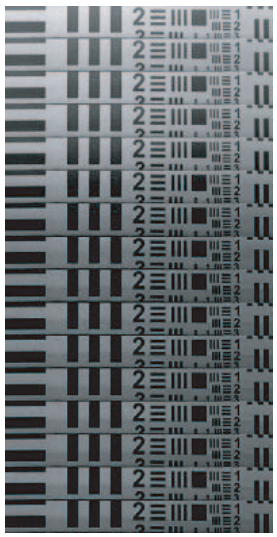
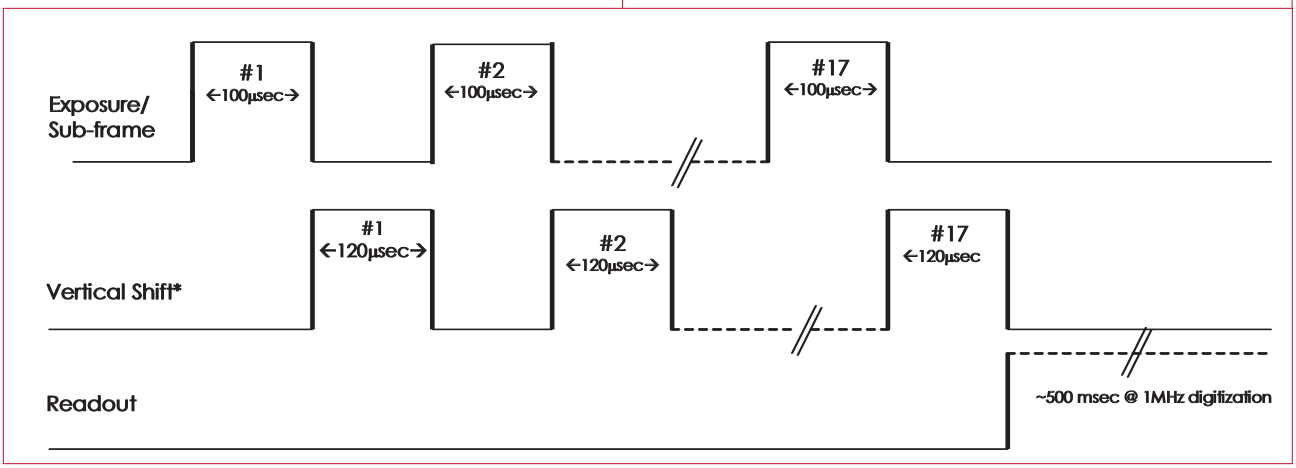


Figure 3. Data acquired using kinetics readout mode based on the masked image shown in Figure 2. The time resolution between each sub-frame is 220 µsec (= 60 rows* 2 µsec/row + 100 µsec exposure). The image is read out through the "Norma" port at 1MHz. Timing diagram for the setup. *Vertical shift time shown is theoretical (actual time may vary).



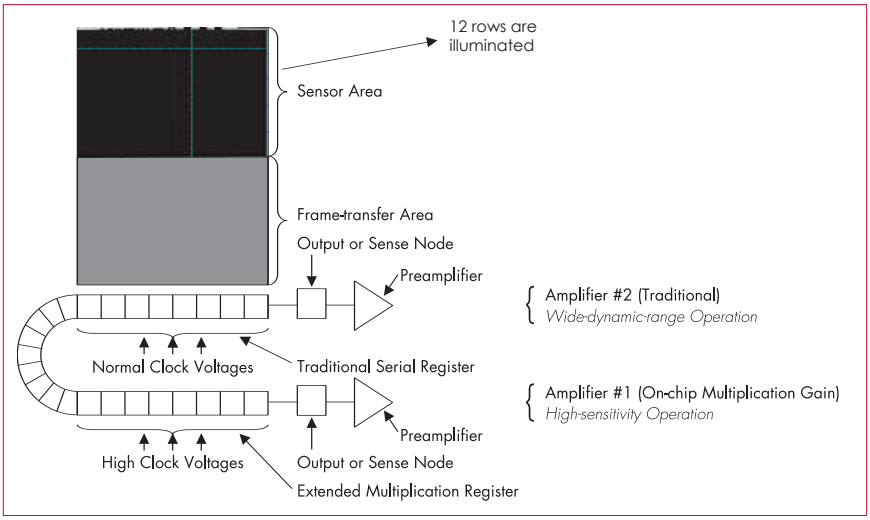


Figure 4: Masked image similar to the one shown in Figure 1, except it is readout using 10MHz, multiplication gain readout port. Reduced number of rows is illuminated to illustrate ways to achieve better time resolution between sub frames

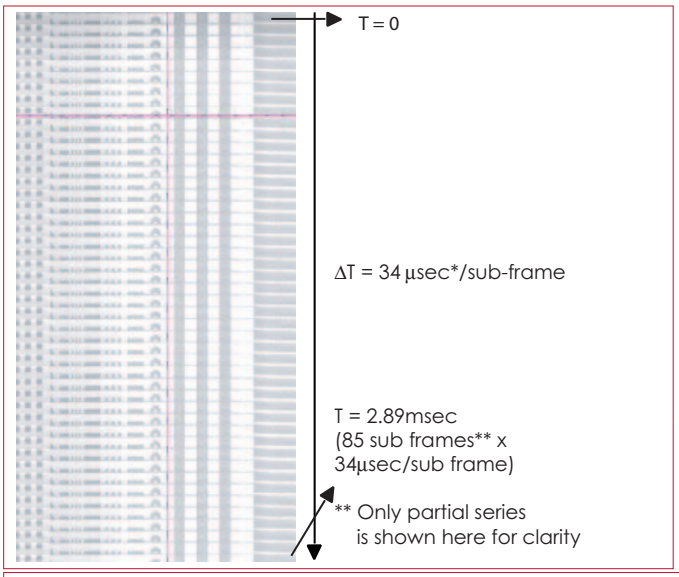
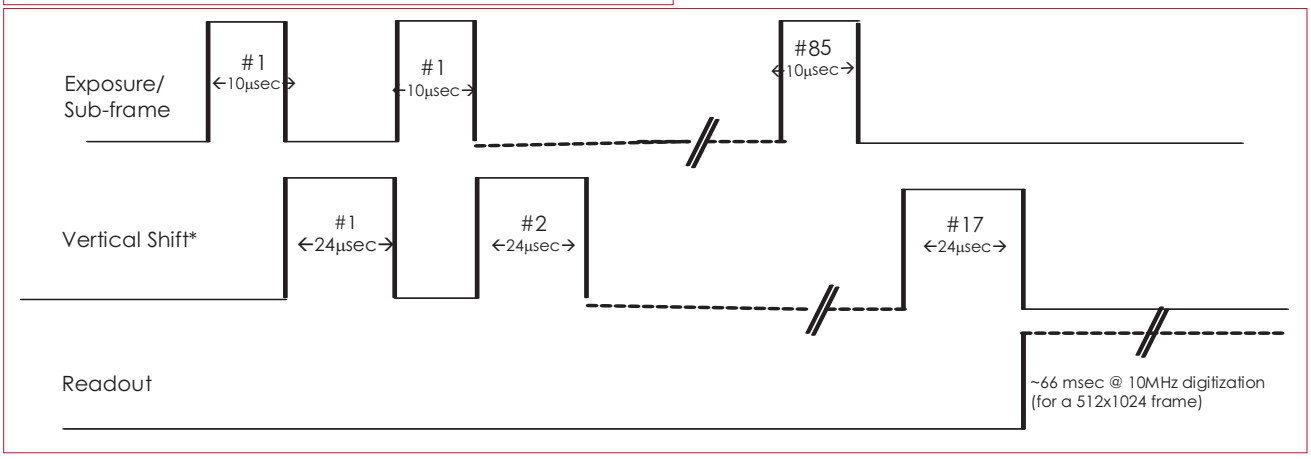


Figure 5: Data acquired using kinetics readout mode based on the masked image shown in Figure 4. The time resolution between each sub-frame is 34 µsec (=12 rows* 2 µsec/row + 10 µsec exposure). The image is readout through the "multiplication gain" port at 10MHz with a multiplication gain of 60x. The shading is due to the fact that the first image (T=0) is exposed for a shorter duration. Corresponding timing diagram is shown for the setup. *Vertical shift time shown is theoretical (actual time may vary).



Triggered Operation

PhotonMAX camera also supports a wide variety of triggered modes both in standard readout and kinetics readout mode operations. Free run mode is used for experiments that do not require any synchronization with the experiments. Two other trigger modes: single trigger and multiple trigger modes require external TTL pulses be applied to the camera. The camera can be triggered either on +ve or –ve edge of the incoming TTL pulse.

In single trigger mode, the camera requires only one trigger to initiate the entire "exposure-shift" sequence as shown in the timing diagram below. Here, the camera uses the exposure time as entered into the software.

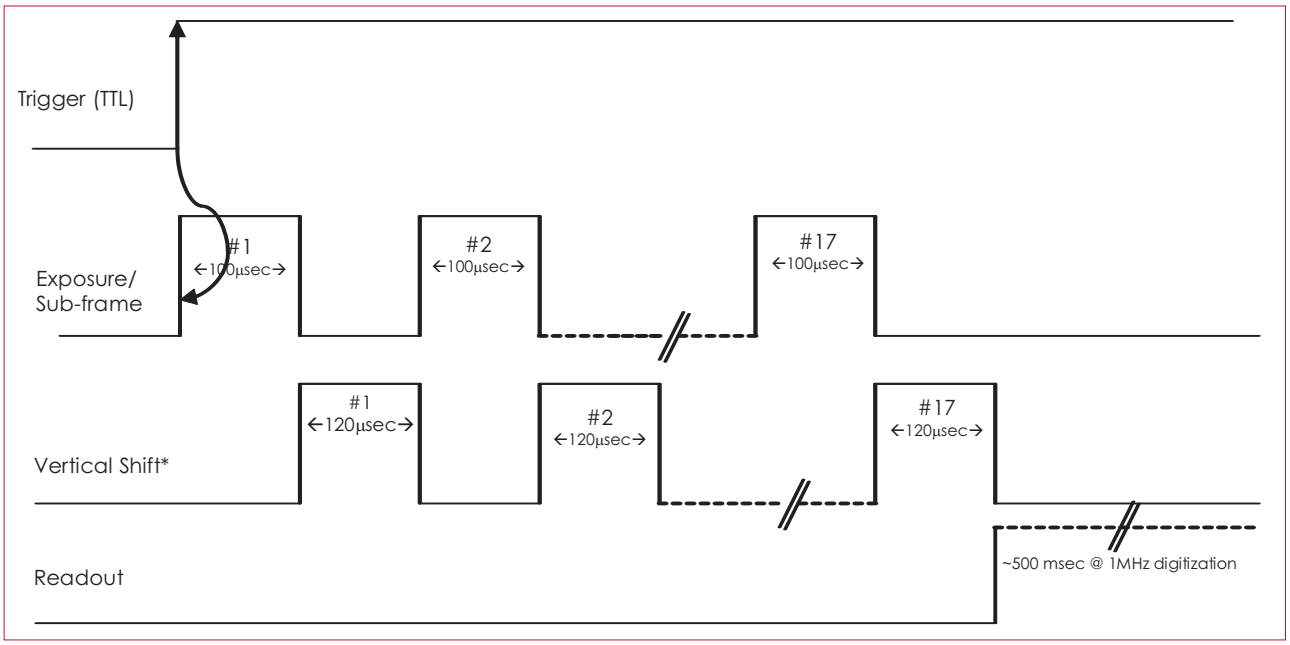


Figure 6: An example showing kinetics operation using "single trigger". Example uses the setup as shown in Figure 2. *Vertical shift time shown is theoretical (actual time may vary).

In multiple trigger mode, each sub-frame is triggered independently. In this mode, by varying the trigger arrival rate, it is possible to get different exposure times for each sub-frame.

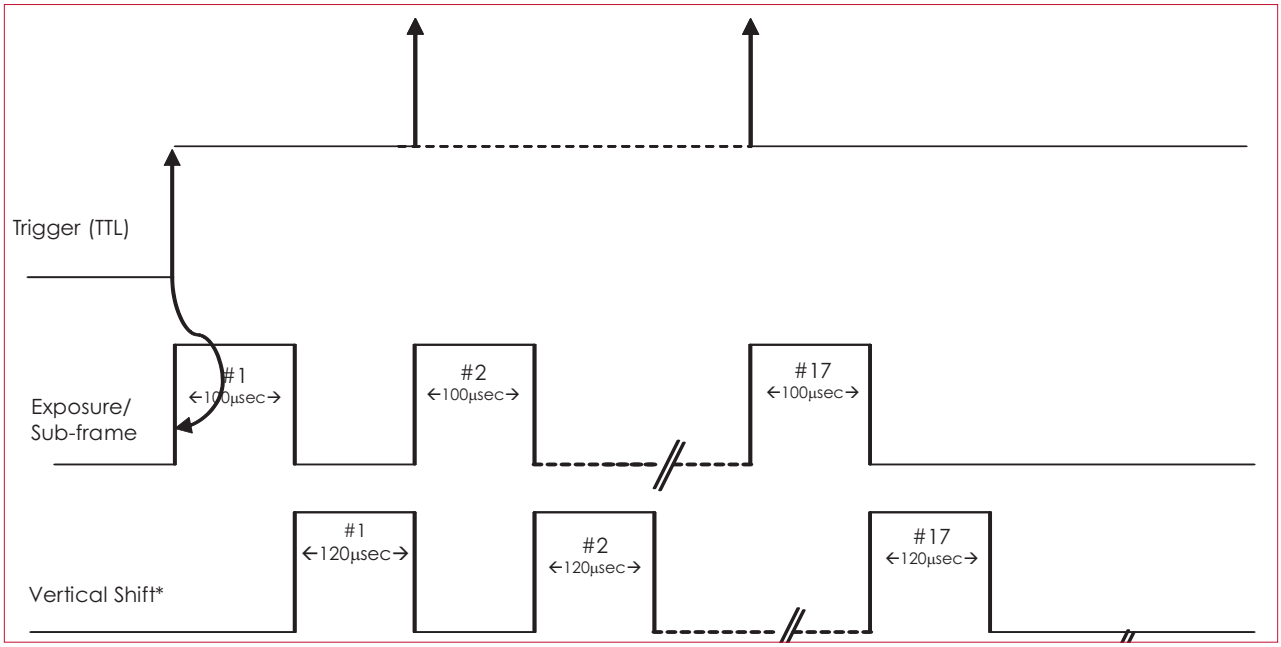


Figure 7: An example showing kinetics operation using "multiple trigger". In this mode, the effective exposure time for each sub-frame is determined by the trigger interval + exposure time set in the software. Example uses the setup as shown in Figure 2. *Vertical shift time shown is theoretical (actual time may vary).

Cleaning the CCD

Since the kinetics is most often used in asynchronous, single-shot experiments, it is important that CCD be cleared of accumulating background or dark charge while it is waiting for an external trigger. To take care of this, PhotonMAX automatically cleans the CCD "one row at a time" before the arrival of the trigger. This keeps the charge buildup on the CCD to a minimum at the same time minimizing the timing jitter (+/- 2 μsec). If desired, the number of cleans can be set to zero for the best jitter performance. However, the camera must be in dark environment to minimize the background.

Summary

The kinetics is a powerful feature that allows a burst of frames be captured with microsecond time resolution. However, careful attention must be paid to the optical and timing considerations, namely:

- The rows farthest from the serial register must be illuminated
- Rest of the active area need to be optically masked
- Feature is supported under WinView and WinSpec versions 2.5.19.4 or later
- Single trigger mode allows capture of the burst of frame with just one trigger
- In multiple trigger mode, camera requires a trigger for each "exposure-shift cycle"
- The highest time resolution between kinetic frames is determined by the window size
- Binning and ROI selections are supported as in the standard operation

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